The fundamentals of weaving and weaving machines

P. Tumajer, M. Bílek, J. Dvořák

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Authors: Ing. Petr Tumajer, Ph.D., doc. Ing. Martin Bílek, Ph.D., doc. Ing. Josef Dvořák, CSc.

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Dedication

The textbook is dedicated to persons who personify the field of weaving at the Technical University of Liberec (formerly the University of Mechanical and Textile Engineering of Liberec):

František Pompe

Jaroslav Simon

Oldřich Talavášek

Jaroslav Charvát

Vladimír Svatý

Stanislav Nosek

Vladimír Moravec

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1 Preface

You get into your hands this textbook, which describes the basic principles of the production of woven fabric and machinery (weaving machines) used in the production of such textile fabrics. Weaving is a dynamic technological process. As each process, it includes conflicts, the solution of which permanently increases performance and quality of the product (woven fabric). These changes have an adequate response in the construction of weaving machines. Individual mechanisms use a variety of technical means to ensure their functions. The textbook provide comprehensive information about the current state of weaving technology and trends. It is mainly focused on explaining the professional technological terms and principles.

1.1 For whom is the textbook intended

The textbook constitutes a comprehensive technical text applicable to the study by a wide range of students and experts with different levels of initial knowledge of the issue in question. Therefore, the textbook is suitable for beginners and laymen in the field as well as advanced experts and is drafted as a supplement to promote the teaching in the field of fabric engineering, weaving technology, construction of weaving machines and related fields.

The textbook does not contain a complete description of weaving technology. It does not include material preparation for weaving and also it does not include a detailed description of the weaving process in terms of mechanical and physical principles, which is part of the theory of weaving. Attention is given to the weaving machines for the production of standard woven fabrics, which were put into practice at the time of creation of the textbook. Therefore, the text does not provide information about the multi-sheds of weaving machines and other weaving technology represented as a minority.

1.2 Structure of the textbook and how to use it

A comprehensive description of the basic parameters of the product (woven fabric) and their relations to the production technology has been chosen as the means for achieving the above objectives with a subsequent description of the structural layout of the weaving machines, their mechanisms, and their trends.

The introductory part introduces the reader to the definition of the woven fabric and the basic principles of the production of this product. The chapter briefly explains the basic principles of weaving in connection with the long-term historical development, thus explaining these basic principles in a broader context also to beginners and laymen.

The textbook is further divided into two main chapters. Chapter “Design parameters of woven fabric” describes and precisely defines all the production parameters of woven fabric (number of warp threads per unit length, number of weft threads per unit length, textile weave, etc.) and explains their relation to production technology. Therefore, these parts are suitable for deeper study of the principles used in fabric engineering. Their understanding is a prerequisite for mastering the theme of subsequent Chapter “Weaving machines and their mechanisms”.

Chapter “Weaving machines and their mechanisms” provides information about the overall layout of weaving machines, construction and function of the various mechanisms in relation to the basic principles of weaving and design parameters of the woven fabric. This issue is described in terms of long-term trends with particular emphasis on the development of weaving machines from 1990 to the present.

he conclusion of the textbook is dedicated to performance and production parameters of weaving machines. After mastering the above theme, the reader is able to compare different weaving machines in terms of performance and plan the production of woven fabric based on the parameters of the weaving machine and the woven fabric produced. In the area of special weaving machines, attention is given to machines for the production of leno weave fabrics, which have undergone a rather interesting development at the turn of the millennium. At the end of the textbook, there is an up-to-date overview of current manufacturers of weaving machines with links to their company websites.

In the study, you are advised to use a summary of important findings listed at the end of each chapter. Mastering and understanding this information is an essential condition for the successful adoption of the lessons of this textbook.

1.3 In conclusion, word from the authors of the Preface

Our aim was to develop a clear and easy to understand textbook that will contribute to the understanding of the weaving process in a broader context. As mentioned above, this textbook is not a direct aid to support teaching of the theory of weaving. The main focus is to define technical terms and describe the weaving machines and their mechanisms. Simpler physical principles are mentioned occasionally in the text. For these reasons, it is necessary to emphasize that the principles of physics and mechanics are necessary to understand the weaving process in a broader context. It is therefore necessary to understand this textbook as a guide for mastering technical terms and further develop this knowledge in studying the theory of weaving as a field that describes and explains the method of applying physical and mechanical principles within the weaving process.

Weaving is an interactive process with two-way communication. Therefore, the successful mastering of this process despite the application of advanced monitoring elements and controllers in the mechanisms of weaving machines, is still very dependent on the empirical experience of the operator. This is mainly determined by the absence of a more sophisticated exact apparatus for describing the behaviour of textile materials (warp and weft threads) during the weaving process and is unlikely to change within the near time frame. Proper adjustment of the weaving machine, which ensures smooth production of quality woven fabric, requires some experience from the operator with the weaving machine and textile material in question. In practical terms, it is not possible to master weaving by simply studying the textbook but a wide range of specific knowledge and experience from normal operation under conditions of specific textile companies should be obtained. Here, at the start of a graduate of a vocational school is expected to have perfect knowledge of technical terms and a comprehensive overview of the technology in question. The textbook can help you in acquiring this knowledge.

We wish you much success in your studies.

2 Introduction

The introductory part is intended for understanding the essence of the term "woven fabric" and the basic principles of the production of such textile fabric. Chapter "What is woven fabric" contains definition of the term "woven fabric" and explains the most important terms that are associated with this definition. Chapter "A brief history of the production of woven fabrics" explains the basic principles of the production of woven fabric on the examples of development of the weaving process on a long-term basis.

2.1 What is woven fabric

Virtually every person has encountered the textile fabric called "woven fabric" in one's life. Woven fabrics are used as input material in the clothing sector (suiting fabrics, dress materials, ...), various technical fields (tarpaulins, geotextiles, screens, ...), household textile (drapes, upholstery and decorative fabrics, some types of carpets and curtains, ...), and other fields of human activity.

Figure 1: Examples of the use of different woven fabrics

But have you ever wondered what is the woven fabric? A precise definition is provided in standard ČSN 80 0021, which states: **woven fabric is any textile made of one or several sets of longitudinal threads and of one or several sets of lateral threads, interlaced with each other in the perpendicular direction**. The set of longitudinal threads is known as warp and the set of lateral threads is known as weft.

Multiple sets of warp or weft threads can only be seen in certain types of woven fabrics. For example, the so-called "multiple-warp and multiple-weft" technologies are used for room darkening drapes to ensure a consistent look of the face and back sides of fabric and increase the darkening effect. Several warps are also used for terry towels, where the so-called "interlacing warp" ensures fabric consistency and terry warp provides a massaging effect and absorbency when using the towel as well as its aesthetic appearance. A pile warp, ensuring the aesthetic appearance of the product, can also be seen in face-to-face and Wilton carpets with cut or loop pile.

Special types of woven fabrics also include the so-called "leno fabrics". In such fabrics, the warp threads are arranged in parallel, but their position changes, i.e. mutual interlacing occurs between the warp threads. Therefore, these fabrics can also be referred to as fabrics with interlaced warp. The warp of leno fabrics comprises two types of threads: rotating (leno) and stationary (ground). This method of interlacing provides a high consistency between the set of warp and weft threads and in some cases, is also used to ensure the aesthetic appearance of the product.

Figure 2: Examples of woven fabrics containing several sets of warp threads and leno weave fabrics

Most standard fabrics comprise one set of parallel warp threads and one set of parallel weft threads. These are the woven fabrics and the production machinery addressed in this textbook. For our purposes, we can therefore introduce somewhat simplistic definition of the term “woven fabric”: **woven fabric is any textile made by interlacing two sets of threads at right angle to one another (warp and weft)**.

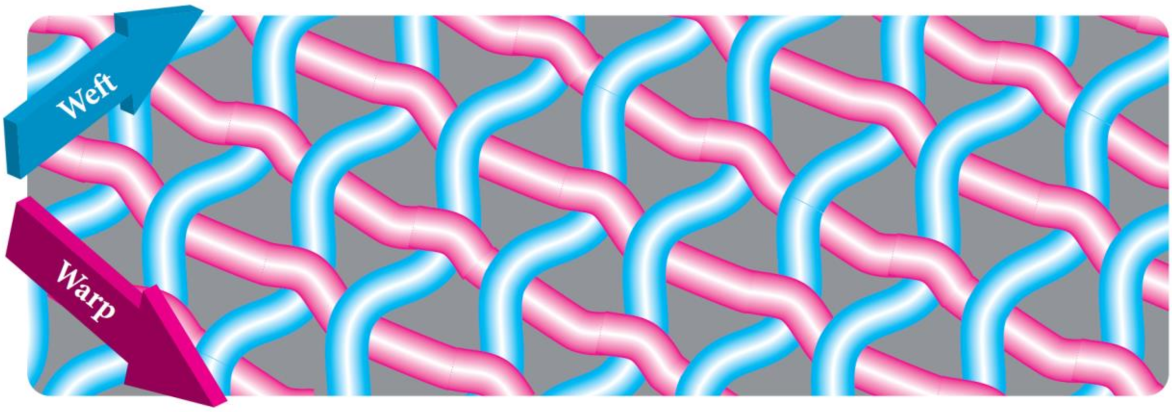


Figure 3: Scheme of standard plain weave fabric

The so-called “interlacing point” is formed at the point of inter-crossing of the warp and weft threads. In terms of the mutual position of the warp and weft threads, there are two types of interlacing points in the fabric: warp interlacing point (the warp is above the weft) and weft interlacing point (the weft is above the warp). Interaction of forces between the warp and the weft occurs in interlacing points, which ensures the consistency of the two sets and hence the consistency of the whole fabric. According to the law of action-reaction, the two forces, which form an inter-bonding between the warp and weft threads, are in equilibrium. The force applied by the warp on the weft is determined by the vector sum of the internal tensile forces in the warp thread and thus depends on the so-called “interlacing angle” of the warp thread. Similarly, we can express the force applied by the weft on the warp. This is also the vector sum of the internal tensile forces in the weft thread, which is dependent on the interlacing angle of the weft thread (see Figure 4).

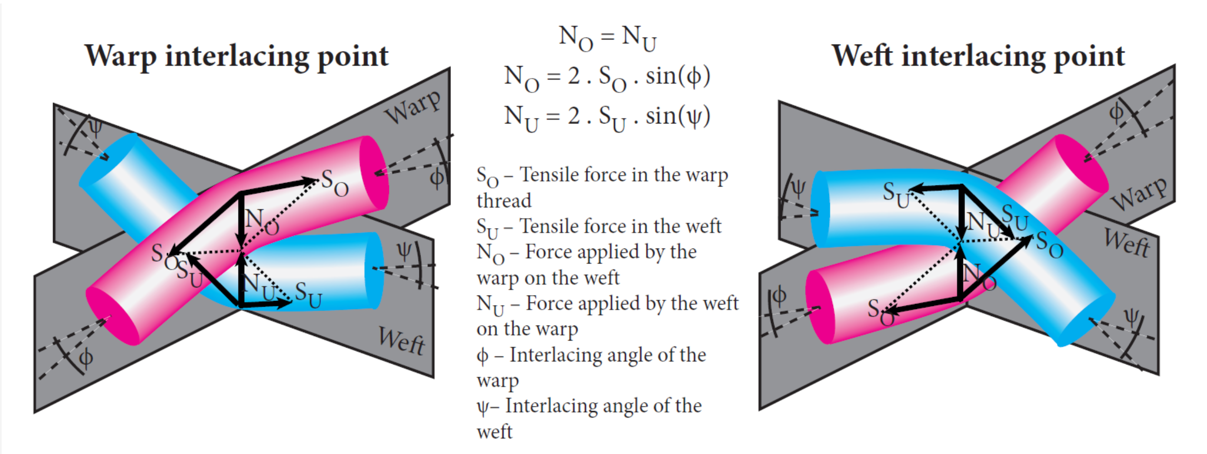


Figure 4: Warp and weft interlacing points, interaction of forces between the warp and the weft

The warp and weft system can be interlaced in the fabric in different ways. The method of interlacing the warp and weft threads is called the "textile weave" and this parameter affects the appearance and mechanical, physical, thermodynamic and functional characteristics of the product. The woven fabric illustrated in Figure 3 constitutes the so-called "plain weave" fabric. This is the weave with the densest interlacing, i.e. warp and weft interlacing points alternate on a regular basis. Plain weave is the most common textile weave and is one of the so-called "basic textile weaves". The basic textile weaves also include twill and satin weaves. This issue is addressed in more detail in Chapter 3.5.

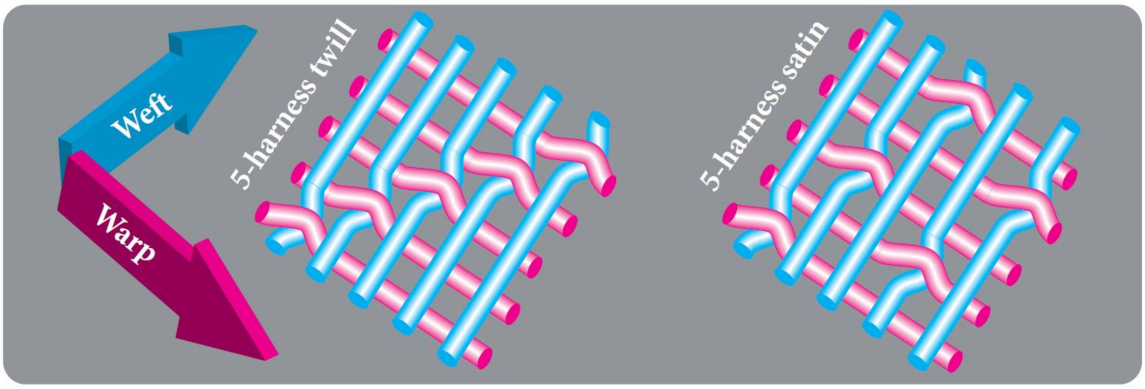


Figure 5: Scheme of twill and satin weave fabrics

Definition of the term "weaving" can be derived from the definition of the term "woven fabric". Weaving is an **interlacing of two sets of threads**. The following chapter briefly describes the basic principles of the weaving process and its development on a long-term basis.

Important findings of the chapter:

1) We know the precise or at least simplified definition of the term "woven fabric".
2) We know what is the warp and weft.
3) We understand the terms: warp and weft interlacing point, textile weave.
4) We know the way the warp and weft interlace with each other in the plain weave.
5) We know the types of basic textile weaves.
6) We know the simplified definition of the term "weaving".

2.2 Brief history of fabric production

The history of fabric production dates back to the distant past. How the fabrics were manufactured in the ancient times and in which direction has the development of weaving technology taken place? In the introduction, it should be stated that the development of weaving technology was in no case a smooth process. The basic principles of fabric production applied to the current machines have been known for thousands of years. However, the means for their implementation change in accordance with the technical knowledge obtained. Therefore, let's set out along the road towards clarification of the development of weaving technology in historical context.

2.2.1 Oldest fabrics

According to current knowledge in terms of archaeology, primitive production of fabrics can be assumed between 25,700 up to 27,660 BC. This is proven by the fragments of fired and unfired clay, which were found in the fifties and sixties of the twentieth century in the region of Pavlova. Some fragments contain imprints of woven designs. The appropriate fragments were subjected to more detailed analysis in the 70s of the twentieth century. Positive imprints were used to reconstruct the structure of textile designs and such designs are described in detail in [4].

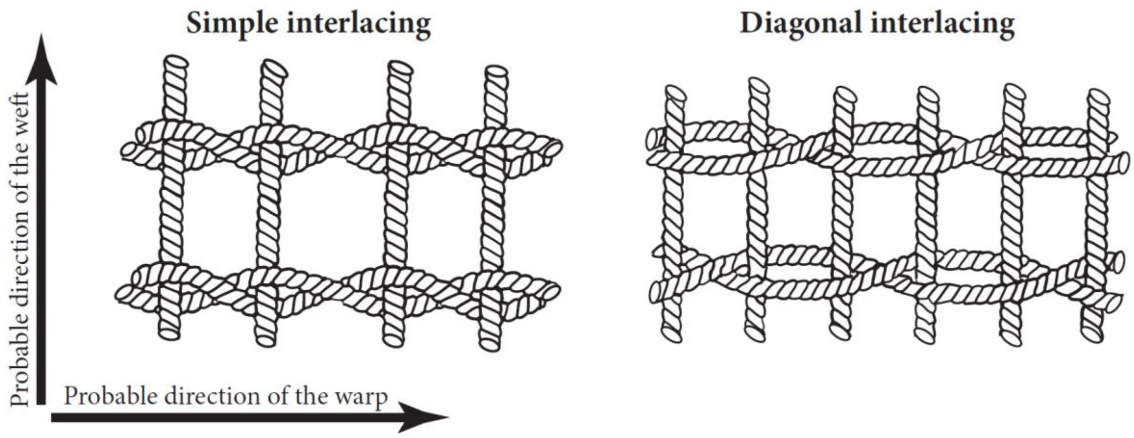


Figure 6: Scheme the oldest fabrics with the so-called "simple and diagonal interlacing"

Unfortunately, findings do not make it possible to obtain any knowledge about the production technology of these fabrics and therefore it is not possible to clearly determine the warp and weft system. According to the method of interlacing, it can be assumed that, in today's perspective, a vertical set of linear formations can be called the "warp" and a horizontal set is formed by wefts. Reconstruction of woven fabrics show that the wefts are not arranged in parallel but interlace with each other. Therefore, there is an analogy of the so-called "leno fabric", which is mentioned in the previous chapter (see Chapter 2.1 and Figure 2) and in which the warp threads interlace with each other. In terms of production technology of the oldest fabrics, the necessity of generating a certain tensile force in the warp may be expected and, therefore, it appears to be more likely to interlace weft threads when they are interlaced through the warp. The aforementioned methods of interlacing the warp and weft system are also interesting. Simple interlacing, where the warp and weft interlacing point alternates regularly on every weft and warp thread, is the predecessor of a plain weave. Diagonal interlacing, where two warp interlacing points and two weft interlacing points alternate on every weft, is the predecessor of textile weaves with a looser interlacing of the two systems (twill or satin weave).

2.2.2 Fabric production in the Neolithic Age

Based on the findings of stone weights from this period (see [5]), it can be assumed that the fabrics were produced on the so-called “vertical looms without shedding devices”.

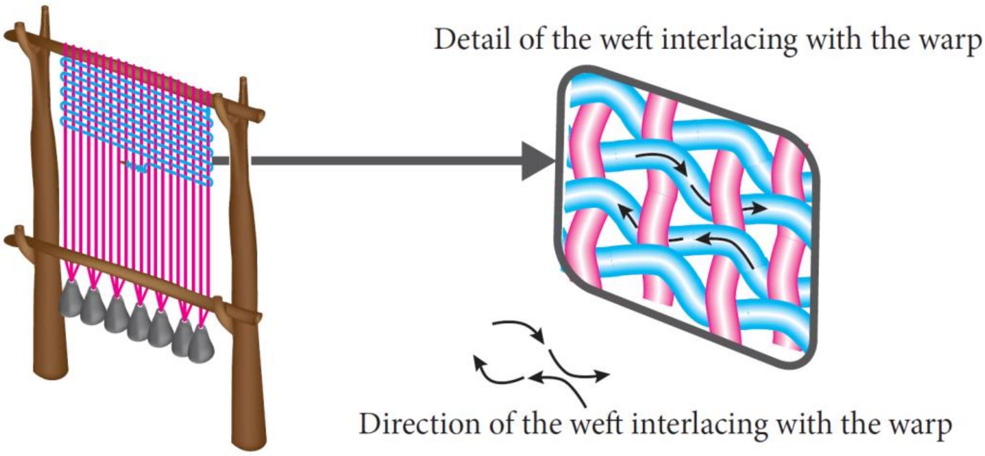


Figure 7: Probable method of fabric production in the Neolithic Age (vertical loom without a shedding device)

The warp threads are oriented vertically and the aforementioned weight generates the required tensile force therein. **The weft thread is interlaced by hand through the warp** in the plain weave. Linen is the material used (the oldest documented textile material). According to the archaeological findings of fabric imprints, plain weave [5] prevails and twill weave fabric occurs occasionally and, if appropriate, rib weave fabric, which is the derivative of plain weave fabric.

2.2.3 Fabric production in ancient Egypt

The oldest known representation of the loom comes from Egypt. It is the scene from the tomb of Pharaoh Khnumhotep (about 5,000 BC). Wall painting shows the horizontal loom (with the horizontally arranged warp) and its discovery enabled the reconstruction of the loom from this period.

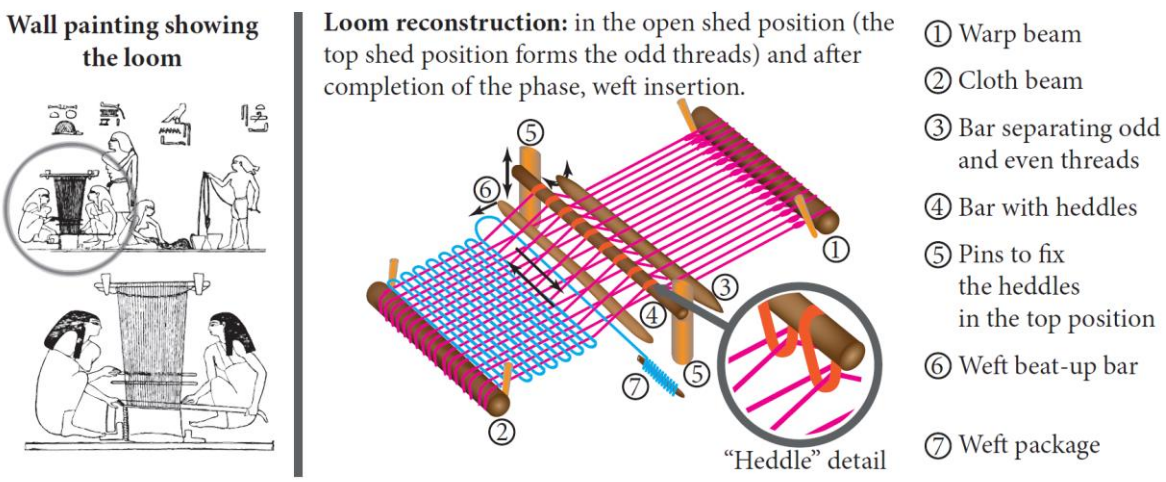


Figure 8: Scheme of Egyptian loom from the period of 5,000 BC

The loom frame is sunk into the ground, on which a bar with stretched warp (warp beam) and a bar with made fabric (cloth beam) are fastened by means of pins. The warp threads are threaded from the warp beam through a rectangular bar so that all even threads pass above the bar and all odd threads pass below the bar. Each odd thread then passes (is threaded) through an eye of the so-called "heddle", which is mounted on the second bar. The loom consists of the pins, which allow the second bar to be fixed in the top position. This separates the even and odd threads, which together **create** a wedge-shaped area, **the so-called "shed"** (the odd threads are in the top shed position and the even threads in the bottom shed position). Into this area, you can insert the weft thread (**weft insertion**). After passing the weft into the shed, it is necessary to push the thread toward the face of fabric (**weft beat-up**). Then, the pins supporting the second bar are removed, thus moving all warp threads (odd and even) into one plane, i.e. **the shed is closed** and the inserted weft is interlaced with the warp. In the following weaving cycle, the first bar is rotated by 90° so as to move all even threads into the top shed position and the even threads remain in the bottom position, i.e. forming the bottom shed position. It is then again possible to insert the weft into the shed and close the shed (interlace the weft with the warp) by rotating the first bar into the starting position. Thus, the device makes it possible to create the plain weave fabric. The following figure shows the individual phases of fabric production on the ancient Egyptian loom.

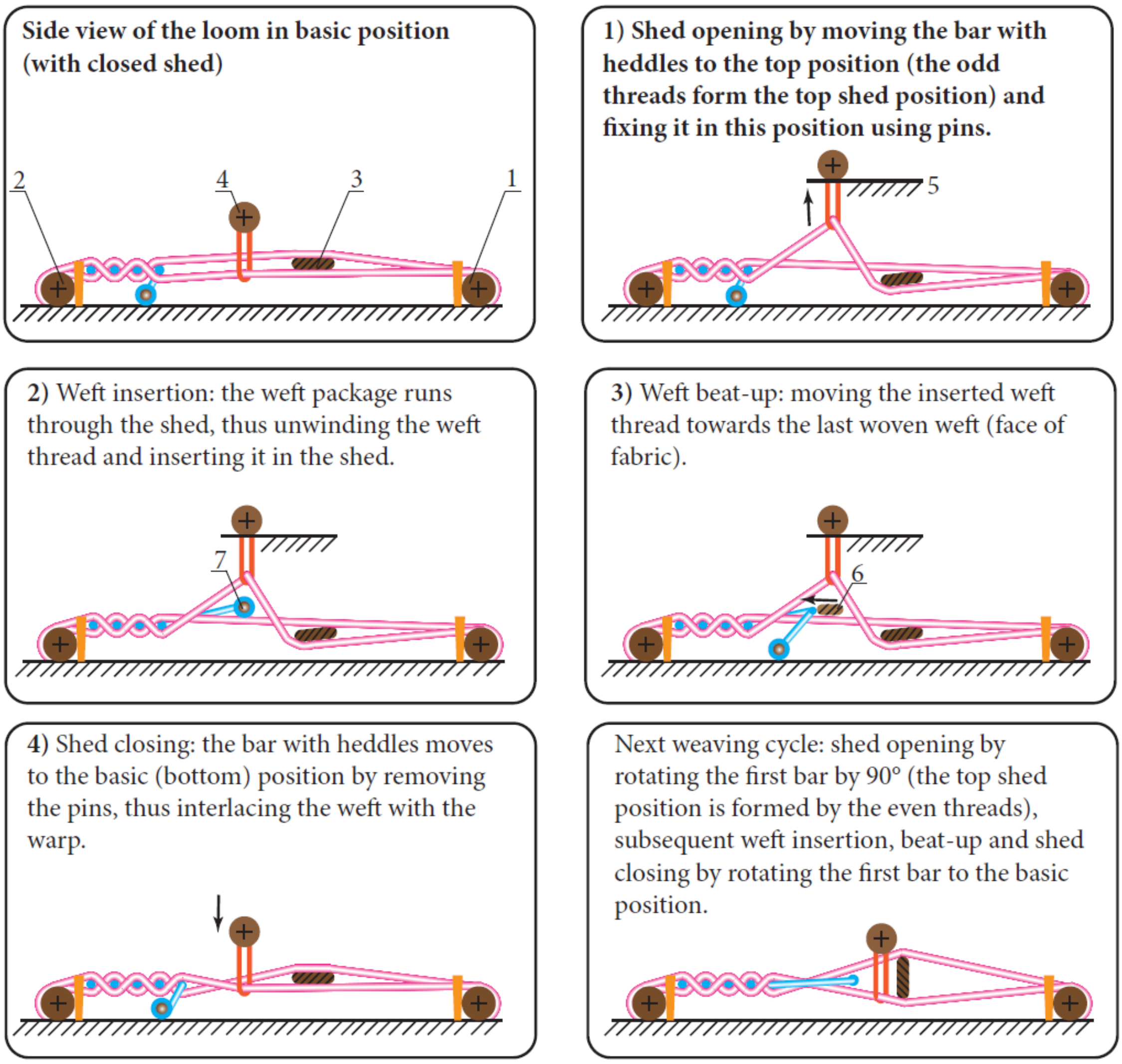


Figure 9: Phase of fabric production on the ancient Egyptian loom

It is important to realize that the above described principle of fabric production is also used on the current weaving machines. Therefore, it can be stated that the production of fabric has been implemented in the form of cyclic repetition of four basic phases of the weaving cycle for nearly 7,000 years.

1. Opening the shed
2. Weft insertion
3. Weft beat-up
4. Closing the shed

2.2.4 Chinese treadle loom and fabric production in the Middle Ages

There was a certain modification of the above described principle of fabric production in China in the 2nd century BC by introducing the so-called "treadle loom". In the 2nd century AD, this loom arrives in Europe and becomes the main means for fabric production in the Middle Ages.

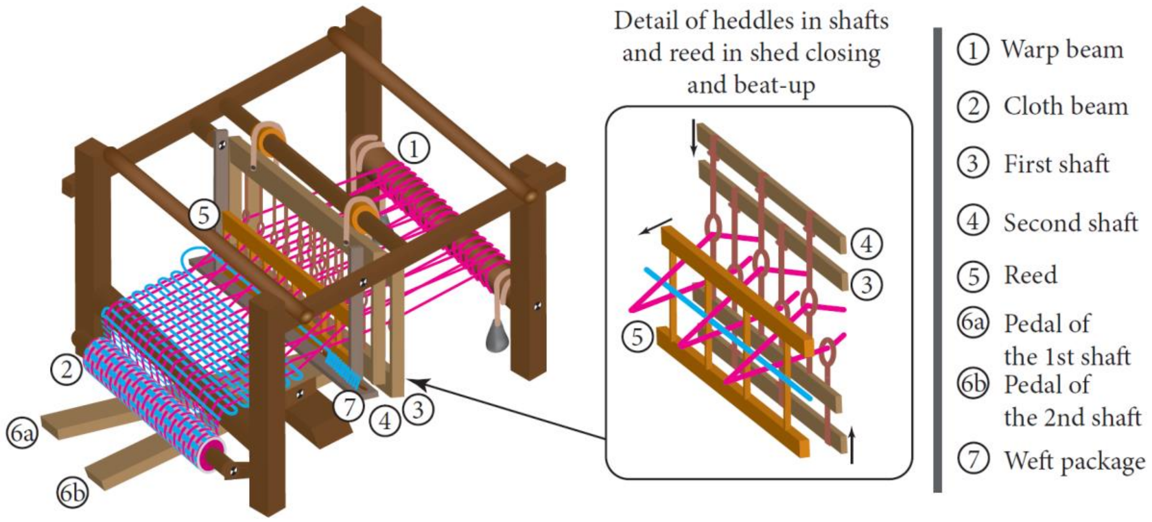


Figure 10: Scheme of hand loom from the Middle Ages

The frame of this device consists of a wooden structure, with the attached roller for supplying the warp threads (warp beam) and the roller for winding up the created fabric (cloth beam). Both bars of the ancient Egyptian loom are replaced by two shafts, which are the frames with heddles (strings with eyes for threading the threads). Another new feature is the so-called "reed" (comb) mounted on the single-arm hinged lever (batten). The even warp threads are threaded through the eyes of the heddles placed in one shaft and the odd threads are threaded through the heddles in the other shaft. All threads then pass through the dents of the reed. A treadle (pedal) is fastened to each shaft, which, when depressed, moves the shaft into the top position and the threads threaded through it create the top shed position. The threads threaded through the second shaft (with the treadle undepressed) remain in the bottom position and create the bottom shed position. The weaver creates the shed by stepping on a treadle (hence it derives the name "shed") and controls the batten with the reed by his/her hand. When the treadle is depressed, the reed is swung toward the shafts and the shed is therefore delimited by not only the warp threads in the top and bottom shed positions but also by the reed. The weft thread is inserted into this triangular area (shed). Then, the weaver releases the treadle and the shaft returns to the base plane. At the same time, the reed is swung toward the face of fabric, thus beating up the weft. **Therefore, the phase of closing the shed and beating up the weft takes place simultaneously.** The batten drives the cloth beam, which is rotated and winds up the produced segment of fabric. In the following weaving cycle, the weaver depresses the treadle of the second shaft and repeats the individual phases of fabric production. The loom with two shafts makes it possible to create the plain weave fabric. Looms with several shafts are available later, which are designed for creating textile weaves with a looser interlacing (twills, satins).

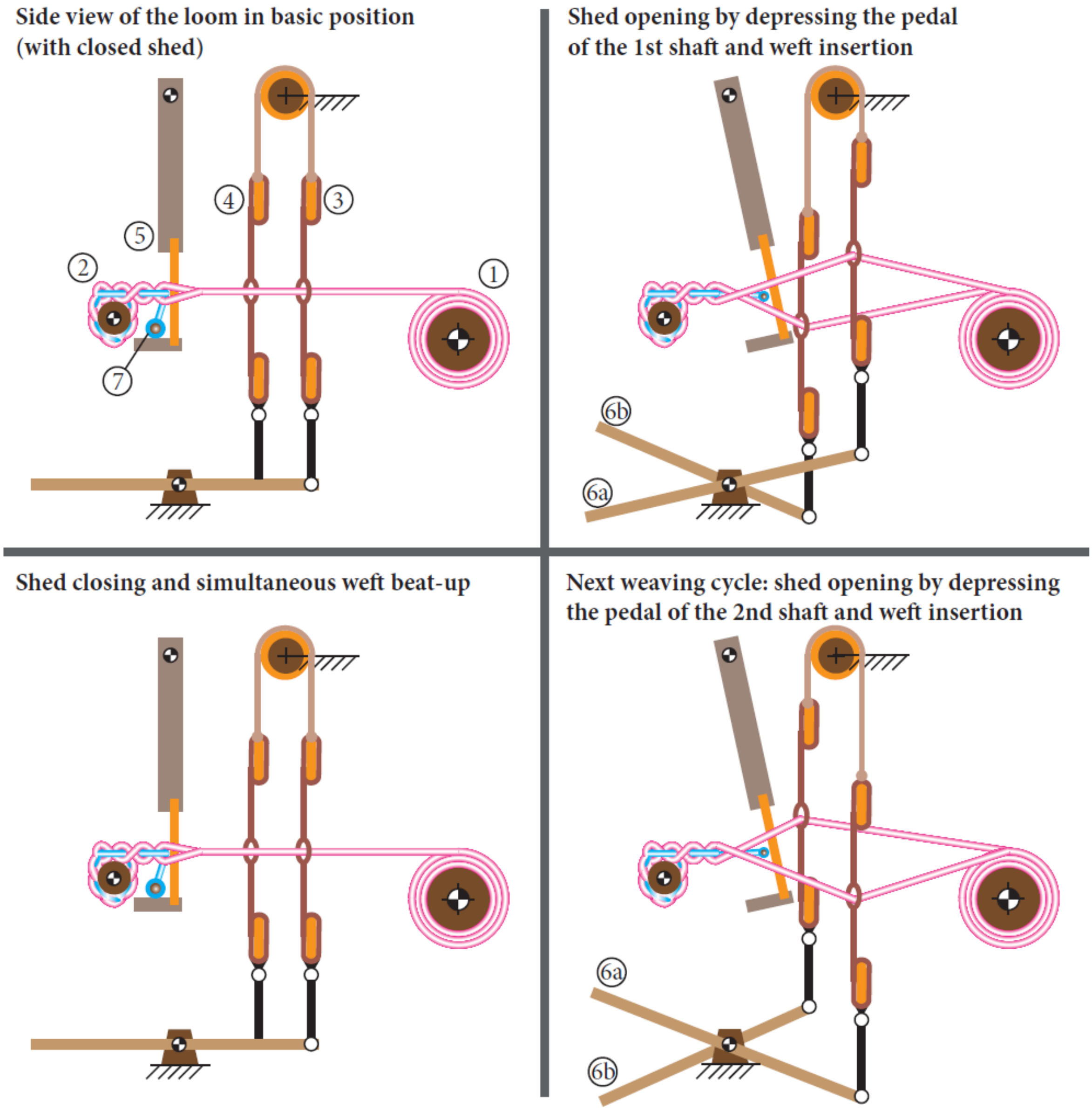


Figure 11: Phase of fabric production on the hand loom

Controlling the shafts with treadles on the medieval loom allows the simultaneous implementation of the phase of closing the shed and beating up the weft, which brings certain advantages in forming the fabric in comparison with the ancient Egyptian principle. The current weaving machines practically utilize the principle of fabric production of medieval treadle looms without substantial changes, i.e. the fabric on the weaving machine is produced in the following phases:

1. Opening the shed (first phase)
2. Inserting the weft (second phase)
3. Beating up the weft while closing the shed (third and fourth phases)

Warp feed and cloth winding-up are implemented on the current weaving machines continuously throughout the entire weaving cycle.

2.2.5 Other historical milestones

Historical evidence shows that the current principle of fabric production is known since the 2nd century BC and no substantial changes have been pushed through in the course of further development. This does not apply to devices that are used in implementing the individual phases of weaving cycle and in ensuring other functions necessary in terms of the weaving process. In this area, there are significant changes that reflect the current state of knowledge and the existence of new technical means available for implementing functions of the weaving machine. Development of specific mechanisms and assemblies of the weaving machine is addressed in more detail in individual chapters in the part “Weaving machines and their mechanisms”. Only a brief overview of the most important milestones in the development of weaving machines is provided here.

In 1733 (patent 1738), the so-called “flying shuttle” was invented, which substantially streamlined the insertion of weft on hand looms and created a precondition for the replacement of hand loom by mechanical loom, which does not use human power but the particular type of drive for driving the individual mechanisms. A working mechanical loom occurs in 1822. The following was gradually used to drive the loom: animal power (horse engine), steam engine, three-phase induction motor and, on current machines, synchronous electric motor with electronically adjustable speed.

As a result of increasing the number of shafts, which broadens bonding options of the looms, there is a quite interesting developments in the field of shedding mechanisms. In the twenties of the 19th century, a dobby loom significantly expands. It is the programmable control mechanism for shafts (shedding). In 1805, the Lyon weaver J.M. Jacquard constructed a Jacquard loom, which makes it possible to create rich figural patterns on fabrics. The heddles are not arranged in shafts but are individually suspended on the harness cords. The program of shedding mechanisms produces the so-called “cards” (punch cards) that are replaced with an electronic memory (the mechanism is controlled electronically) on the current shedding mechanisms.

In terms of the major milestones in the development of weaving machines, the field of weft insertion cannot be ignored. In the 50s of the 20th century, the so-called “shuttleless looms” begins to be largely applied in the industrial production of fabrics. This period is characterized by efforts to improve the performance of weaving machines and the shuttle looms (machines with the shuttle used for the insertion of weft) are not able to meet this requirement. Shuttleless looms with different systems are simultaneously developed: projectile, rapier and jet (water or air) looms. Shuttleless looms gradually displace shuttle looms in all areas of industrial production of fabrics. Rapier and air-jet weaving machines are currently the most widely used machines.

Important findings of the chapter:

1) We know when the first woven structures originated.
2) We can imagine a way of making fabrics in the Neolithic Age.
3) We know the phases of weaving cycle used on ancient Egyptian looms.
4) We know the way the phases of weaving cycle are implemented on the current machines.

3 Design parameters of fabrics

Fabric design parameters are a set of data that clearly define the fabric in terms of its production. In the production specification, it is necessary to specify the parameters of linear textiles (warp and weft), number of warp and weft threads per unit length, warped and picked patterns, textile weave, fabric length and reed width. Besides these basic design parameters, the woven fabric is characterized by other parameters that are affected by the design parameters given above. These are the so-called "warp and weft contraction", weight (weight of 1 m^2 of fabric) and the final width of fabric. This chapter deals with explanations and definitions of the above parameters.

3.1 Parameters of linear textiles

Linear textiles (threads) are the feed materials for fabric production. In this textbook, the generic name of the thread is used, which includes all kinds of linear textiles, i.e. yarn, multi-filament and mono-filament. Yarn is a linear textile consisting of the fibres of discrete length (the so-called "staple fibres") twisted together so that break of the yarn produces break of the individual fibres. Multi-filament is a linear textile consisting of multiple fibres of continuous length and mono-filament consists of a single fibre of continuous length. Silk is a typical representative of natural multi-filament.

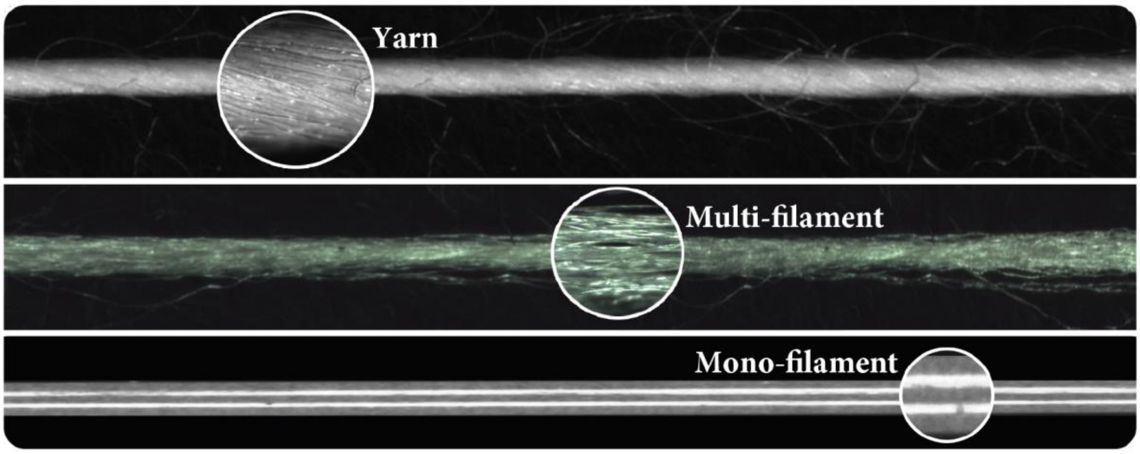


Figure 12: Examples of threads: yarn, multi-filament and mono-filament

The threads are characterized by a number of parameters [6]. **In terms of weaving, these are the most important parameters: fineness, twist and type of fibre**s.

3.1.1 Fineness

The standard ČSN 80 0050 defines the fineness as the ratio between the weight and the length of the thread. Therefore, the term "linear mass density" is also sometimes used. The unit of fineness is *tex*, which is defined as the **ratio of thread weigh in grams and its length in kilometres**. This definition can therefore be expressed as follows:

$$T(tex) = \frac{m(g)}{l(km)},$$

where *T* is the fineness in *tex*, *m* is the mass in grams and *l* is the length in kilometres.

Thread fineness in *tex* is the weight of one kilometre of thread in grams and determines basically the diameter of thread. With increasing fineness, thread diameter also increases, but this dependence is not linear. To help you better understand, it is possible to express the relationship between the so-called "major diameter of thread", its fineness and specific mass of fibres. The major diameter of thread is defined as the diameter of the homogeneous cylinder whose cross-section is completely filled with the material (fibres) [7]. The major diameter accurately expresses the diameter of mono-filaments of circular cross-section.

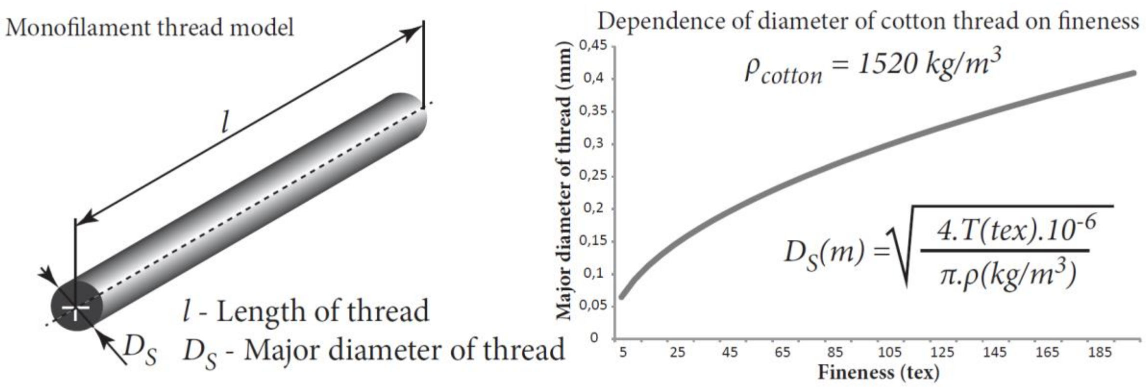


Figure 13: Model of thread (mono-filament), its major diameter and its fineness dependence

If the specific mass of fibres is given, we can express the mass of the thread model (homogeneous roller) by this relation:

$$m(kg) = \left(\pi.\frac{D_S^2}{4}\right).l.\rho,$$

where *m* is the mass of thread in kilograms, D_S is the major diameter of thread in metres, *l* is the length of thread in metres and *ρ* is the specific mass of fibres in kg/m^3.

Divide both sides of the above equation by the length of thread *l*, thus obtaining the following relation:

$$\frac{m(kg)}{l(m)} = \frac{\pi.D_S^2}{4}.\rho.$$

The definition of fineness shows that the ratio *m(kg)/l(m)* can be replaced by the symbol for fineness $T(tex).10^{-6}$, thus obtaining the following equation:

$$T(tex).10^{-6} = \frac{\pi.D_S^2}{4}.\rho,$$

which can be used to express the major diameter as a function of fineness and specific mass.

$$D_S(m) = \sqrt{\frac{4.T(tex).10^{-6}}{\pi.\rho(kg/m^3)}}.$$

As mentioned above, it is possible to use this method to accurately calculate the diameter of mono-filament. The real diameter of yarn or multi-filament will always be greater due to the air gaps between the individual fibres and in addition to the above parameters also depends on the fill factor of the yarn and fibre (see [7]).

In addition to *tex*, **derived units** are also used for designating threads. **Decitex** (*dtex*) is reserved for multi-filaments and mono-filaments and **kilotex** (*ktex*) is reserved for cables, tapes or other coarser linear formations. The following conversion relations apply between *tex* and derived units: *1 tex = 10 dtex and 1 tex = 0.001 ktex*.

The notation $T \times n$ is used for denoting plied threads (plied thread comprises two or more threads twisted together) where the symbol *T* represents the fineness of a single thread and the symbol *n* is the number of plied threads. Example: *25 tex* × *2* (double plied thread of the single threads with a fineness of 25 tex).

Other methods of designating thread fineness

For historical reasons, we may sometimes also encounter the method of designating thread fineness other than that recommended by the above standard ČSN 80 0050. These include, for example, the metric count referred to as *Čm* and is defined as the length of thread in kilometres per weight of one kilogram, i.e.:

$$Ćm = \frac{l(km)}{m(kg)},$$

where *l* is the length in kilometres and *m* is the mass in kilograms.

For denotation of plied threads, use the notation in the form *Čm / n*, where *Čm* is the metric count of single threads and *n* is the number of plied threads.

The definition of *tex* and metric count shows the conversion relation between these two ways of expressing fineness:

$$T(tex) = \frac{1000}{Čm}.$$

The fineness of mono-filaments and multi-filaments (mainly silk) was formerly expressed with the use of titre denier (denotation: *den*), which indicates the weight of nine kilometres of thread in grams, i.e. the definition can be expressed by the following formula:

$$Td(den) = \frac{9.m(g)}{l(km)}.$$

Plied threads are denoted in the same way as for the unit of *tex*, i.e. $Td \times n$, where *Td* is the fineness of single thread in the units of day and *n* is the number of plied threads.

The definitions show that the following conversion relation apply between the fineness expressed in *tex* and the fineness expressed in *den*:

$$T(tex) = \frac{Td}{9}.$$

In expressing the fineness of cotton yarns, we can see the so-called “English cotton count” (denotation: *Ne*). The English cotton count is defined by the number of hanks of 840 yards per pound, i.e. the definition is expressed by the formula:

$$Ne = \frac{l(yd)}{840.m(lb)}.$$

The following relation apply between the English cotton count and the fineness in the units of *tex* (see [6]):

$$T(tex) = \frac{590{,}541}{Ne}.$$

It should be noted that the only correct way of expressing the fineness of threads is the method defined by the standard, i.e. in principle, **it is necessary to use the unit of tex or its derived units**: dtex (for multi-filaments and mono-filaments) or ktex (for cables and tapes). However, in practice, the above mentioned older forms of expression of fineness can be seen.

3.1.2 Twist

Thread twist greatly affects processing properties of threads during weaving. Furthermore, this parameter can also affect the functional and appearance properties of the resultant fabric. Thread designation includes **a numerical value** that **indicates the number of twists per one metre of the length of thread and this numerical value is followed by a capital letter "Z" or "S", which determines the direction of twist**. In case of plied threads, such data determine the so-called "ply twist" (twist applied in putting single threads together).

3.1.3 Types of fibres

Also, the type of fibres of which thread is composed significantly affects its processing properties and functional and aesthetic properties of the final product (fabric). For thread designation, **it is recommended to indicate the full names of the type of fibres** (wool, cotton, polyester, viscose, etc.) and the percentage in the case of mixed materials (for example: 45/55 wool/polyester).

3.1.4 Examples of thread designation

29.5 tex, 850 S, cotton	Single thread with a fineness of 29.5 tex with the number of twists of 850 per metre, S-direction, made of cotton fibres.
29.5 tex × 2, 400 Z, cotton	Plied thread composed of two single threads with a fineness of 29.5 tex with the number of ply twists of 400 per metre, Z-direction, made of cotton fibres.
25 tex, 470 Z, 45/55 wool/polyester	Single thread with a fineness of 25 tex with the number of twists of 470 per metre, Z-direction, made of a blend of wool and polyester fibres in a proportion of 45% of wool and 55% of polyester.
100 dtex f 80, 50 Z, polyamide	Single thread with a fineness of 100 dtex, composed of 80 fibrils (continuous filaments) with 50 twists per metre, Z-direction, made of polyamide continuous filaments.

Important findings of the chapter:

1) We know the definition of the unit of tex, its derived units and we know where to use them.
2) We have an idea how thread fineness relates to thread diameter.
3) We know how plied threads are designated.
4) We know the way of designating the twists of threads and the types of fibres of which they are made.
5) We can correctly interpret and explain the various details that are part of thread designation.

3.2 Number of warp and weft threads per unit length

The number of warp threads per unit length is defined as the number of warp threads per centimetre of the width of fabric *do (threads/1 cm)* or ten centimetres of the width of fabric *Do (threads/10 cm)*. Therefore, the number of warp threads per unit length defines the spacing of warp threads in fabric *A (cm) = 1 / do*.

The number of weft threads per unit length is defined as the number of weft threads per centimetre of the length of fabric *du (threads/1 cm)* or ten centimetres of the length of fabric *Du (threads/10 cm)*. Therefore, the number of weft threads per unit length defines the spacing of weft threads in fabric *B = 1 / du*.

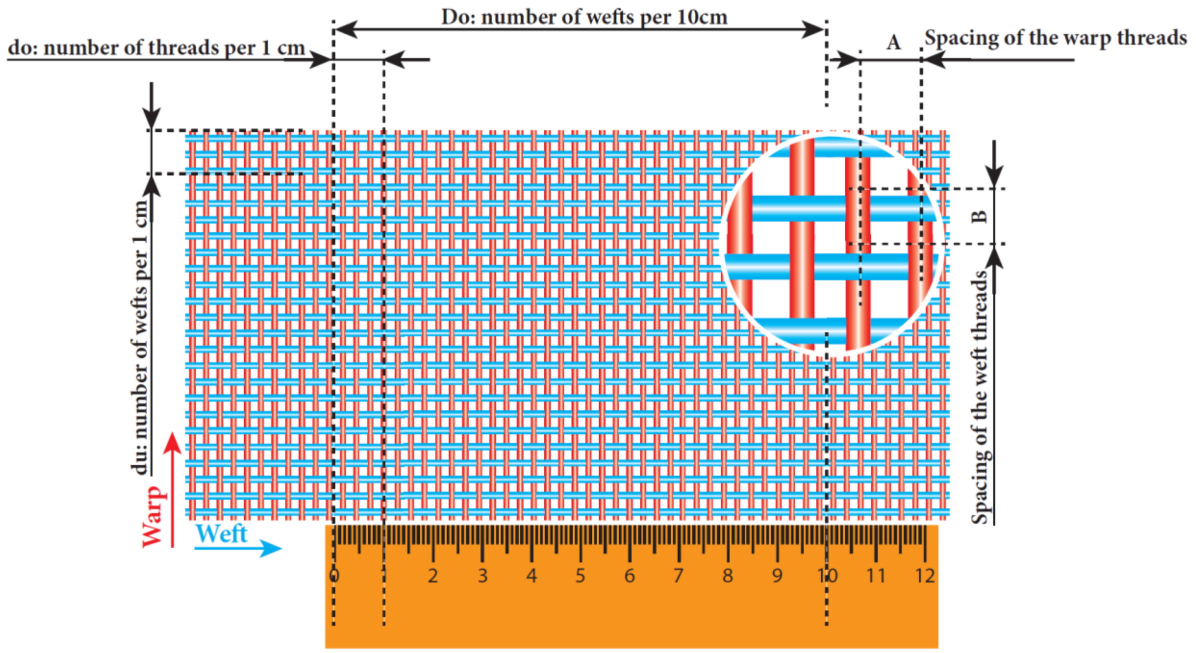


Figure 14: Number of warp and weft threads per unit length

3.3 Warped pattern

Warped pattern shows the sequence of colour threads in the warp system and creates longitudinal (in the direction of warp threads) colour stripes on the fabric. In most cases, a group of colour stripes repeats regularly in the direction of the width of fabric (in the direction of weft threads). Warp threads that comprise this repeating group are called the pattern repeat of warped pattern.

In most cases, pattern repeat for the warped pattern is provided in the form of a table, which contains all the colours used in the warp in the single rows and the appropriate cells contain the numbers of threads that constitute the individual colour stripes in the order in which they are arranged in the pattern repeat for the warped pattern.

For specific warp, the warped pattern is uniquely determined by the breakdown of warped pattern [8] and during its creation, it is necessary to ensure a symmetrical appearance of fabric, i.e. the fabric must begin and end with the same stripe. The procedure for ensuring the symmetry is described in detail in [8].

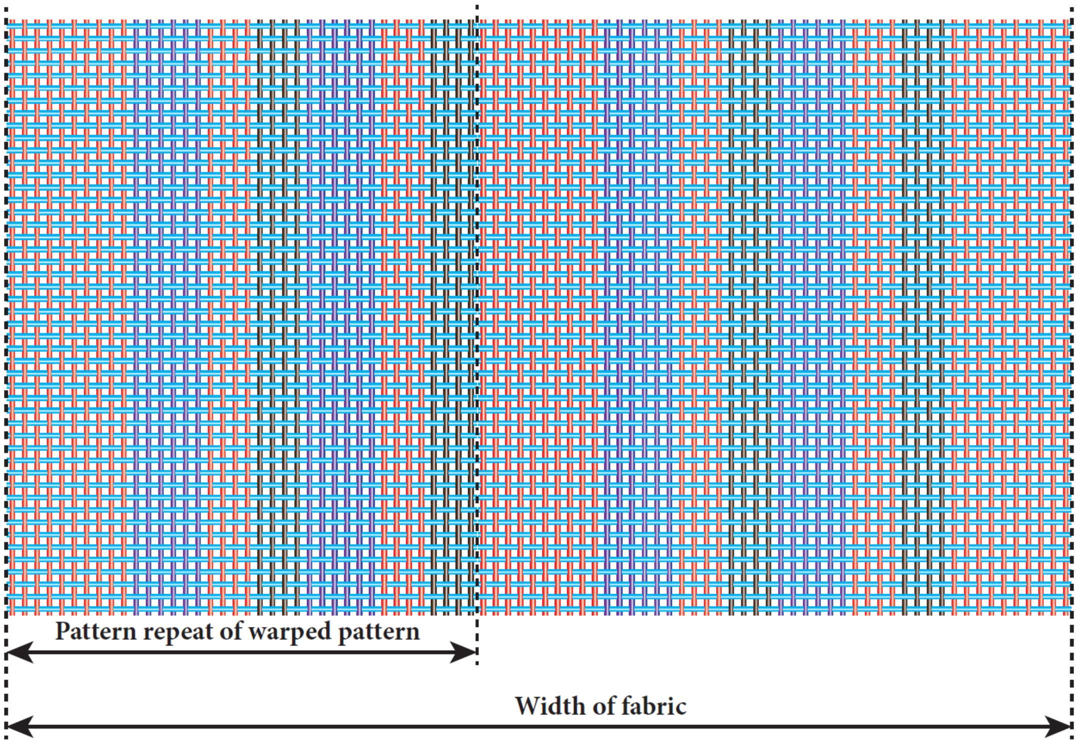


Figure 15: Scheme of fabric with warped pattern

Example of the entry of the pattern repeat of warped pattern for the above scheme of fabric:								Total
red	10		4			4		18
purple		6			6			12
grey				4			4	8
Total number of threads in the pattern repeat of warped pattern								38

Breakdown of warped pattern for the above scheme of fabric with the number of 20 warp threads per 1 cm and the width of fabric of 4.3 cm (e.g. ribbon)

10 threads red
6 threads purple
4 threads red
4 threads grey
6 threads purple
4 threads red
4 threads grey
} 2 × pattern repeat

10 threads red - end

Breakdown of warped pattern for fabric with the standard width of 190 cm and the number of 20 warp threads per 1 cm

5 threads red
6 threads purple
4 threads red
4 threads grey
6 threads purple
4 threads red
4 threads grey
5 threads red
} 100 × pattern repeat

Figure 16: Example of the details of warped pattern

3.4 Picked pattern

Picked pattern shows the sequence of colour threads in the weft system and creates lateral (in the direction of weft threads) colour stripes on the fabric. A group of colour stripes repeats regularly in the direction of the length of fabric (in the direction of warp threads). Therefore, it is possible (as with the warped pattern) to determine the pattern repeat for picked pattern. The pattern repeat for picked pattern is written in the same way as the pattern repeat for warped pattern. By combining the warped and picked patterns, it is possible to create the so-called "checked fabric". This fabric is characterized by a rectangular pattern and is typical for shirt fabrics.

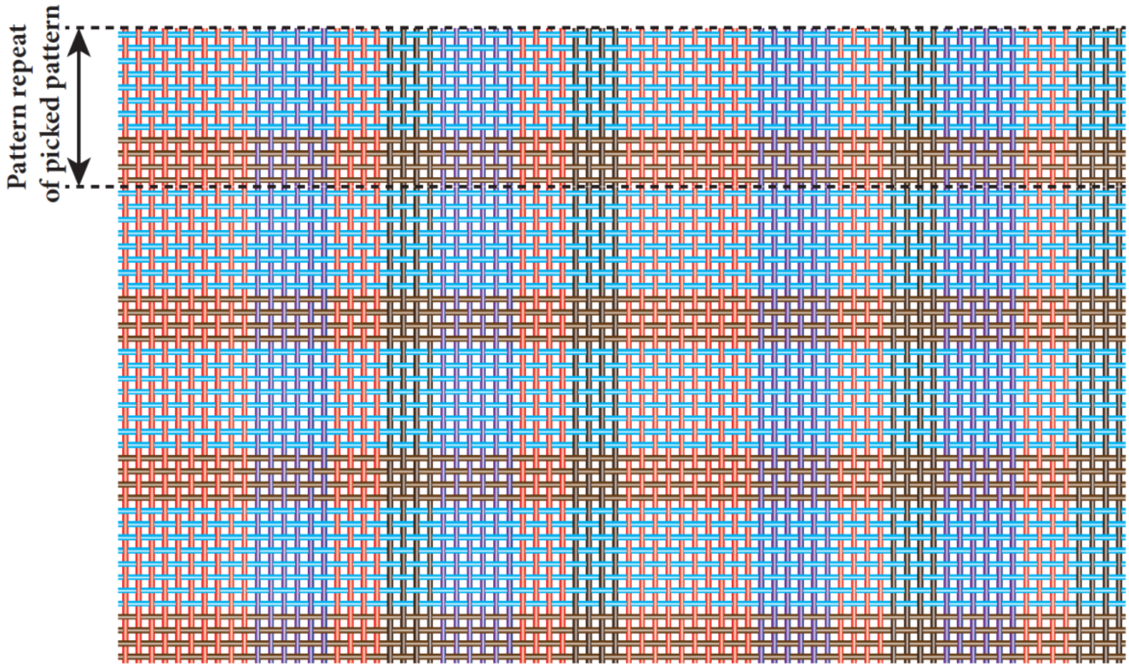


Figure 17: Scheme of checked fabric

Example of pattern repeat notation for picked pattern for the above scheme of fabric:			Total
purple	8		8
brown		4	4
Total number of threads in the pattern repeat of picked pattern			12

Important findings of the chapters:

1) We know the definition of terms "number of warp threads per unit length" and "number of weft threads per unit length".
2) We know the definitions of terms "warped pattern" and "picked pattern".

3.5 Textile weave

The method of interlacing warp and weft threads (weave) significantly influences the properties of the resultant fabric. Therefore, this design parameter is very important and, in technological practice, it is used to provide the required mechanical-physical, functional and decorative properties of the product. This chapter describes the way of drawing the textile weaves for technological purposes, provides an overview of basic weaves and designs of Jacquard weaves.

3.5.1 Drawing textile weaves

As mentioned in Chapter 2.1, different methods of interlacing the warp and weft threads are employed in the production of fabrics. For technological reasons, it is necessary to graphically represent the textile weave in the form of the so-called "pattern" (point paper design).

Weave pattern is drawn on the so-called "pattern chart paper", which is the grid showing a plan view of fabric. Vertical spaces represent the warp threads and horizontal spaces represent the weft threads. Every square or rectangle thus represents an interlacing point. In most cases, pattern chart paper with a division of 8:8 is used for drawing basic and derived textile weaves, which means that one section (square or rectangle defined by the thickest lines) contains eight warp threads and eight weft threads. In the case of Jacquard weaves, it is necessary to use the division, which corresponds to the ratio of the number of threads per unit length in the warp and weft (see Chapter 3. 5. 4).

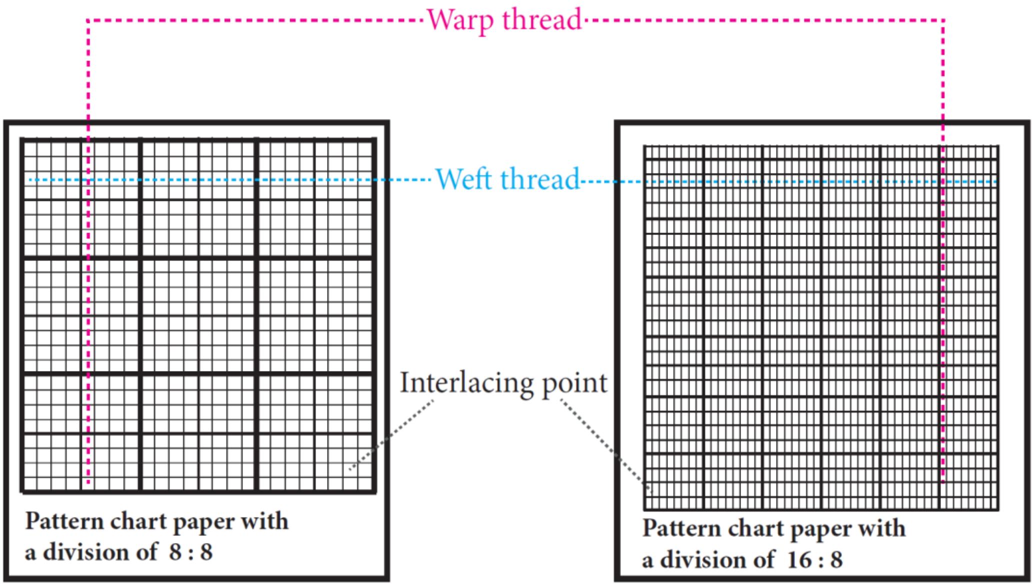


Figure 18: Example of pattern chart papers with different divisions

Another important term in the field of weaves drawing is **weave repeat in warp and weft**. Pattern repeat in the warp is a group of warp threads, whose way of interlacing repeats regularly in the direction of the width of fabric (in the weft direction). Pattern repeat in the weft represents a group of weft threads, whose way of interlacing is repeated regularly along the length of fabric (in the direction of the warp threads). If the number of warp and weft threads in the pattern repeat is identical, the pattern repeat is regarded as a square pattern repeat. For example, a plain weave has a square pattern repeat consisting of two warp threads and two weft threads.

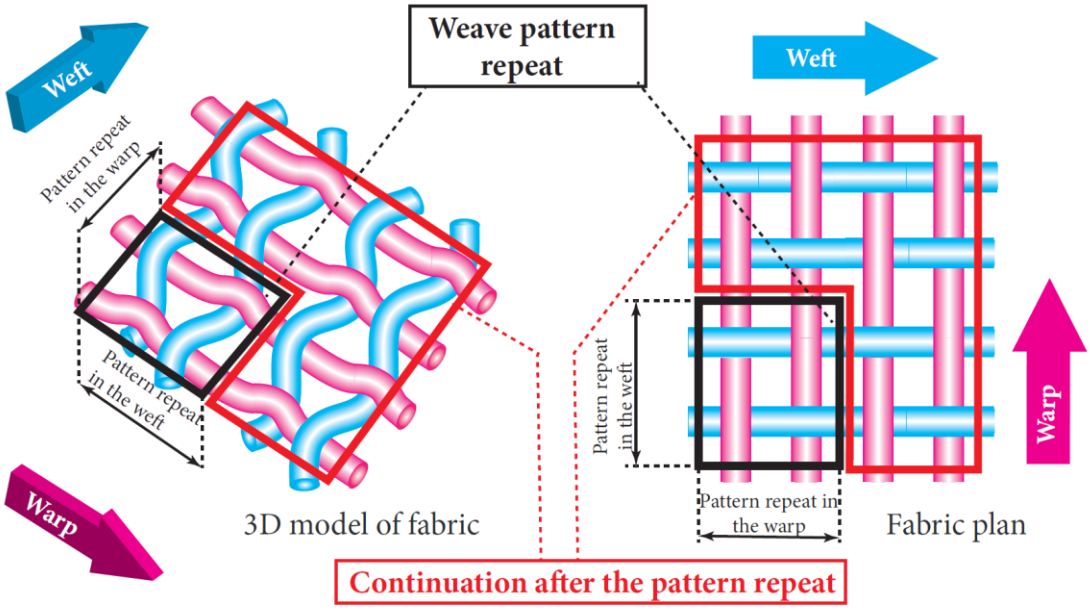


Figure 19: Pattern repeat and continuation after pattern repeat for plain weave

When drawing textile weaves on the pattern chart paper, **indicate warp interlacing points by filling the square** and blank squares represent weft interlacing points. When drawing a pattern repeat, use black colour and red colour to indicate the warp interlacing points and the continuation of textile weave after pattern repeat, respectively.

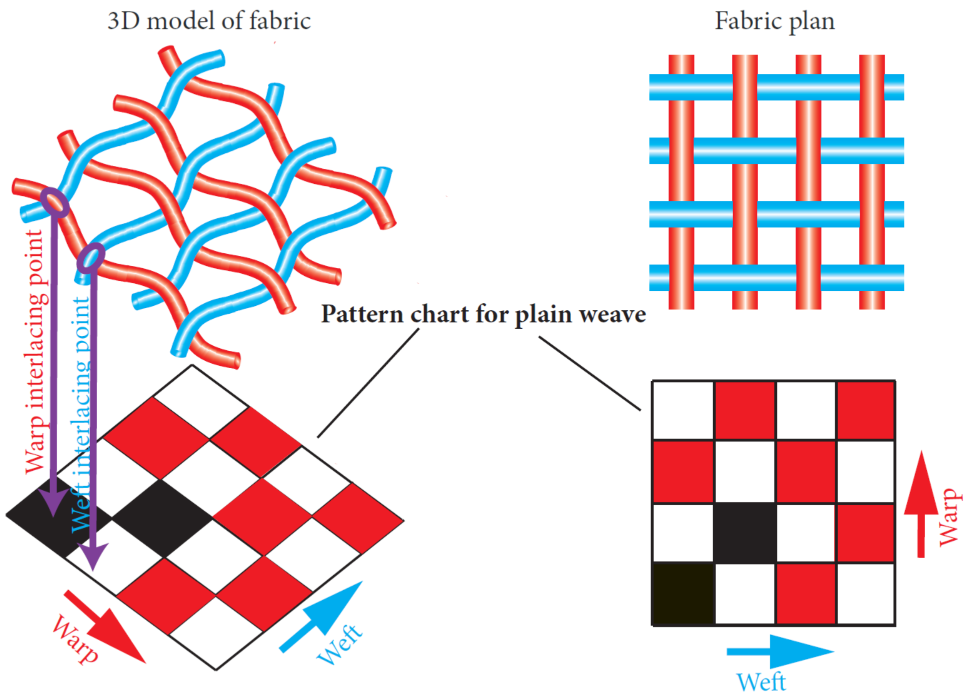


Figure 20: Method of indicating warp and weft interlacing points on the pattern chart paper (for plain weave)

In principle, it is always necessary to colour the pattern repeat in black, thus determine uniquely the textile weave. You can then continue by tracing in red the pattern repeat in different directions so as to highlight better the weave in the pattern chart.

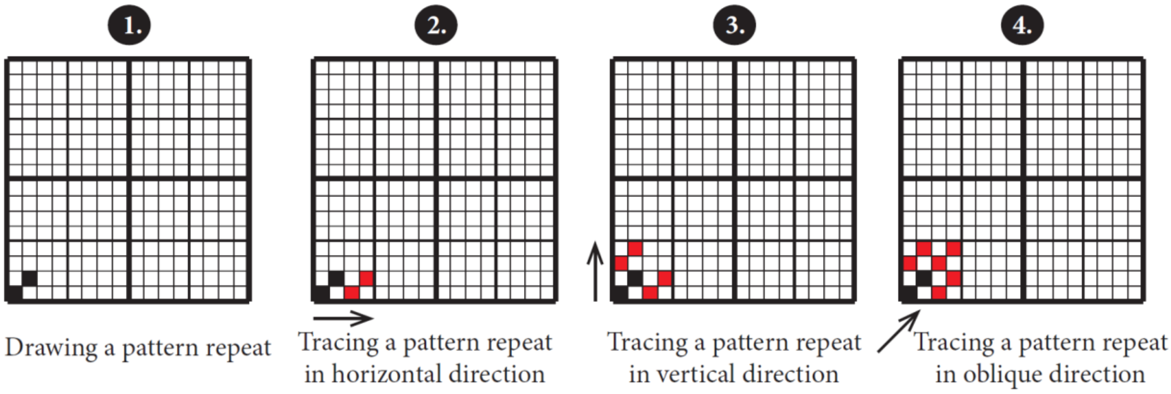


Figure 21: Procedure for showing in detail the continuation of textile weave after pattern repeat (for plain weave)

This makes it possible to relatively easily graphically represent any form of interlacing the warp and weft threads (see example of the so-called "5-harness twill weave" shown in Figure 22).

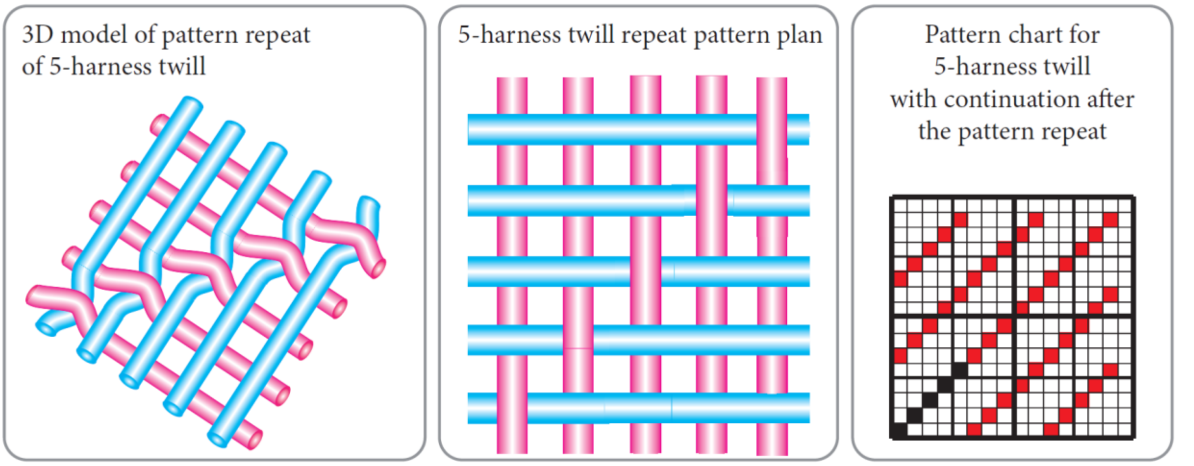


Figure 22: Example of 5-harness twill pattern chart

In some cases, it is advisable to draw a lateral or longitudinal section through the fabric to illustrate the method of interlacing the particular weft or warp thread. **Cross section** is a section which is taken along a selected fabric weft, i.e. at right angle to warp threads. Therefore, the warp threads are drawn with circles in this section that represent the section through individual warp threads and the weft in question is drawn with a line (curve) that represents the method of interlacing through the warp. The cross section is drawn beneath the pattern chart so that the face of fabric is at the top.

Longitudinal section is a section which is taken along a selected fabric warp thread, i.e. at right angle to weft threads. Therefore, the weft threads are drawn with circles in this section that represent the section through individual wefts and the warp thread in question is drawn with a line (curve) that represents the method of interlacing that warp thread between the wefts. The longitudinal section is drawn to the left of the weave pattern so that the face of fabric is on the left hand side.

The warp threads (vertical spaces) and the weft threads (horizontal spaces) are usually numbered in the pattern chart from left to right and from bottom to top, respectively.

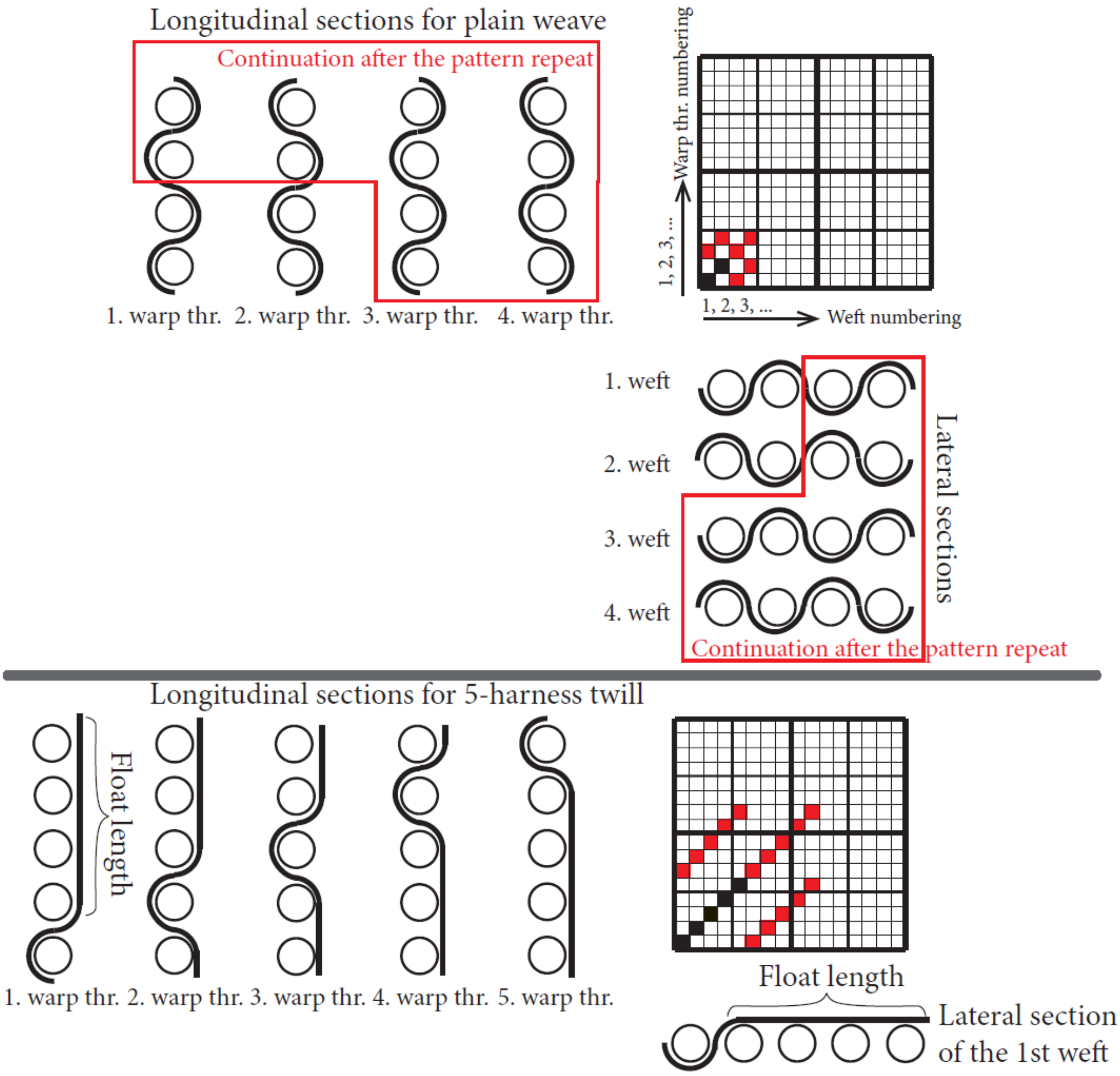


Figure 23: Representation of the lateral and longitudinal section through plain and twill weave

Note: **Float length** - this term refers to a segment of warp or weft thread, which does not interlace and passes along a straight line on the back or face side of fabric. For example, each weft thread in the above mentioned 5-harness twill weave (twill with the pattern repeat of 5 threads in the warp and 5 threads in the weft) floats over 4 warp threads and each warp thread floats over 4 wefts.

Important findings of the chapter:

1) We know what is the pattern chart paper and what are the vertical and horizontal spaces in that grid. We know what are the individual squares or rectangles in the pattern chart paper.
2) We understand the terms of weave pattern repeat in the warp and weft. We can highlight warp interlacing points in the weave pattern repeat and also in the continuation after the pattern repeat.
3) We can draw the different ways of interlacing the warp and weft threads on pattern chart paper, i.e. we can draw the weave patterns.
4) We can draw the lateral and longitudinal sections through fabric and we know what is the term “float length”.

3.5.2 Basic weaves

An overview of basic weaves was already provided in Chapter 2.1. Why different ways of interlacing the warp and weft threads are used in fabric production? As stated above, the weave influences a wide range of the end-use properties of fabric. These include mechanical, thermodynamic (thermal insulation properties, liquid and vapour permeability, abrasion, heat conduction, etc.), comfort (touch, shrinkage, etc.) and decorative properties. Different ways of interlacing the warp and weft threads, represented by basic weaves (plain, twill, satin weaves), are able to support some of the properties to the detriment of others. Therefore, the description of the different types of weaves mentions not only their designs but also their influence on the properties of the resultant fabric.

The interlacing point is an essential element of fabric and is actually the most important means, the arrangement of which can reflect the requirements associated with achieving specific properties. However, the possibilities of rearranging the interlacing point are limited. The densest interlacing is represented by a plain weave. Furthermore, we can only reduce the density of interlacing and create weaves with looser interlacing, in which the threads float (see twill, satin weaves). The interaction of forces occurs only in interlacing points with interlacing warp and weft. In case of interlacing points with floating threads, force interaction equals to zero.

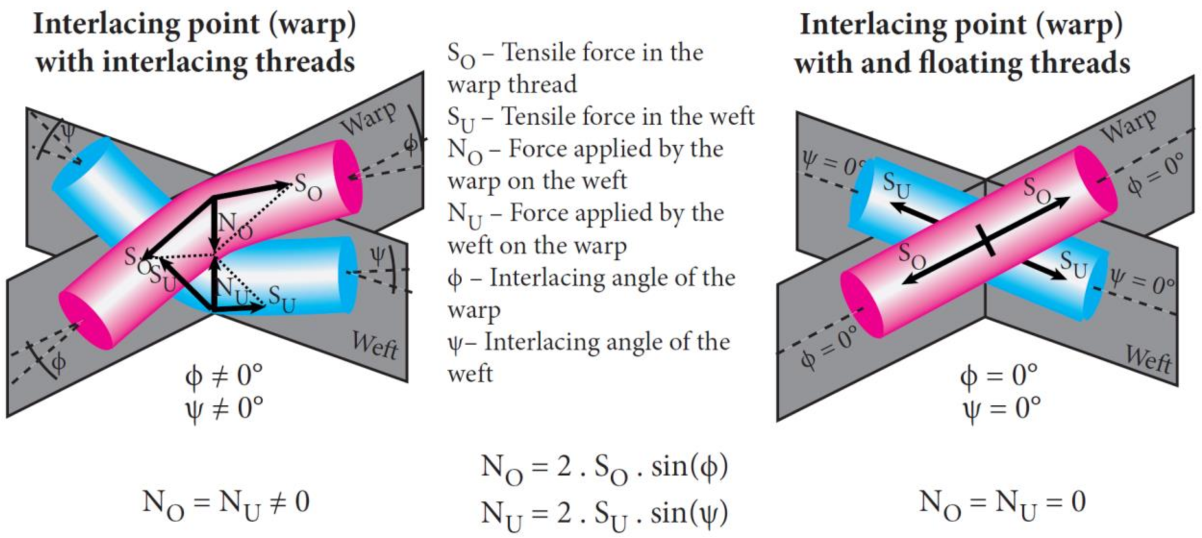


Figure 24: Action of forces between the warp and the weft in the interlacing point (warp) with interlacing and floating thread

It is therefore obvious that with the increased number of interlacing points in which threads float, mutual consistency (the force required to shift the threads in fabric) between the warp and weft systems decreases. Plain weave is able to ensure the maximum consistency of warp and weft threads in fabric.

Plain weave

In plain weave, warp and weft interlacing points alternate regularly on each warp and weft thread. Therefore, there are no floating segments of threads. This produces the densest possible interlacing and with the given number of threads per unit length, fineness, twist and fibre type in the warp and weft, the maximum consistency between the two sets of threads and high fabric filling are ensured. Plain weave fabrics are used in various technical fields, clothing sector, household textiles, etc.

In the pattern repeat for a plain weave, there is the same number of warp (2) and weft (2) interlacing points. Therefore, it is the so-called “double weave”, i.e. the back or face side of fabric with this weave cannot be recognized.

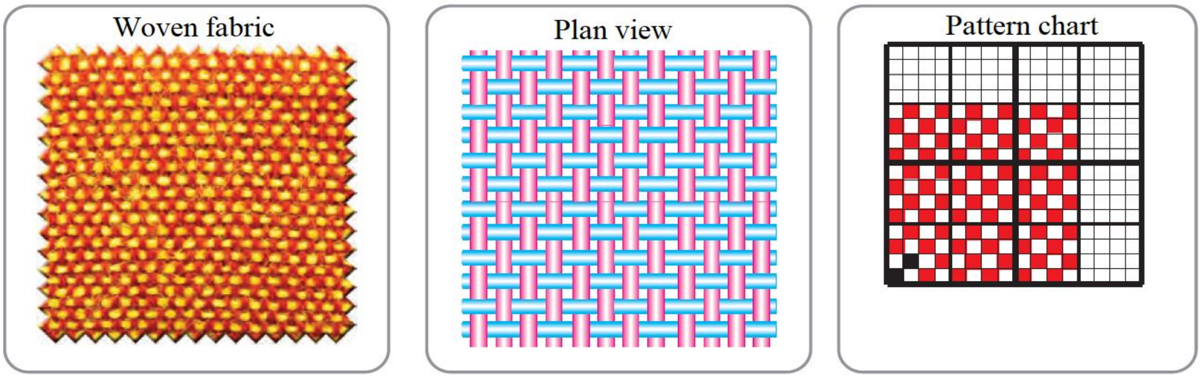


Figure 25: Plain weave

Some physical properties (liquid and vapour permeability) and decorative properties of a plain weave are rather average properties. Therefore, other textile weaves with a looser way of interlacing (twill, satin weaves) are used.

Twills

With regard to plain weave, the density of interlacing of ground twill weaves decreases and there are floating thread segments in fabric. This (with regard to plain weave) reduces the consistency of warp and weft threads but, on the other hand, improves some of the physical parameters (e.g. liquid and vapour permeability). Derivatives of twill weave can be used to create a variety of decorative effects on fabric.

The interlacing points, in which the warp and the weft are interlaced, follow each other diagonally, which produces characteristic oblique ribs on the fabric. **The ground twill with the minimum pattern repeat has three warp threads and three weft threads in weave pattern repeat. However, the maximum pattern repeat of ground twills is not theoretically limited.** Therefore, we can create a wide variety of ground twills. The ground twills always have a square pattern repeat and are called 3-harness, 4-harness, 5-harness, etc., twills by the number of threads in the pattern repeat. In practice, the maximum pattern repeat is, of course, limited in that long segments of the floating threads should not significantly disrupt the consistency of the warp and weft.

According to the prevailing interlacing points on the face of fabric, it is possible to distinguish twills between warp (warp interlacing points prevail on the face) and weft (weft interlacing points prevail on the face) twills. For technological reasons, twills are mostly produced on the loom as the weft weaves (from the perspective of a weaver, weft interlacing points prevail on the fabric). Therefore, this textbook contains examples of basic twill weave patterns as weaves of weft character.

Since it is possible to produce a large number of different ground twill weaves, the standard ČSN 80 0020 introduces the **designation of twill weaves using the formula**:

$$K\frac{No\qquad}{\qquad Nu}\ Z\ nebo\ \nearrow\ ,$$

$$K\frac{\qquad No}{Nu\qquad}\ S\ nebo\ \nwarrow\ ,$$

where letter *K* denotes twill, *No* in the numerator is the number of warp interlacing points on the first weft (always 1 for ground weft twills), *Nu* in the denominator is the number of weft interlacing points on the first weft yarn and letter *Z* or *S* (or arrows) indicates the direction in which it is necessary to move the warp interlacing point in the next weft (the warp interlacing point moves in the indicated direction always by one warp thread). Typical use of fabrics in twill weaves covers jeans (denim) or work clothing (overalls).

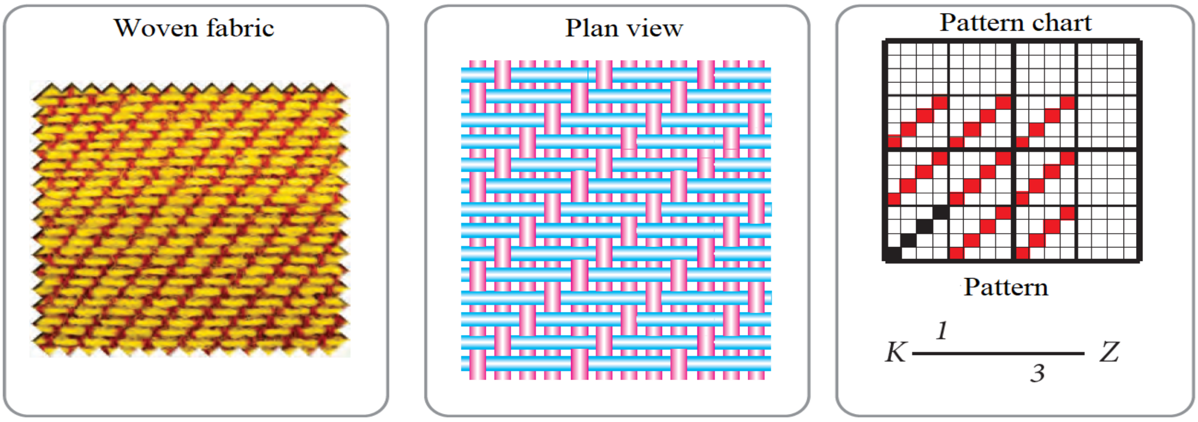


Figure 26: 4-harness twill weave

Note to the way of drawing twill weave patterns: The sum of the numbers in the denominator and the numerator always determines the pattern repeat for twill weave, i.e. the area of pattern chart paper, which should be reserved for pattern repeat. By fraction, draw the first weft and draw other wefts while moving the warp interlacing point by one warp thread in the direction indicated.

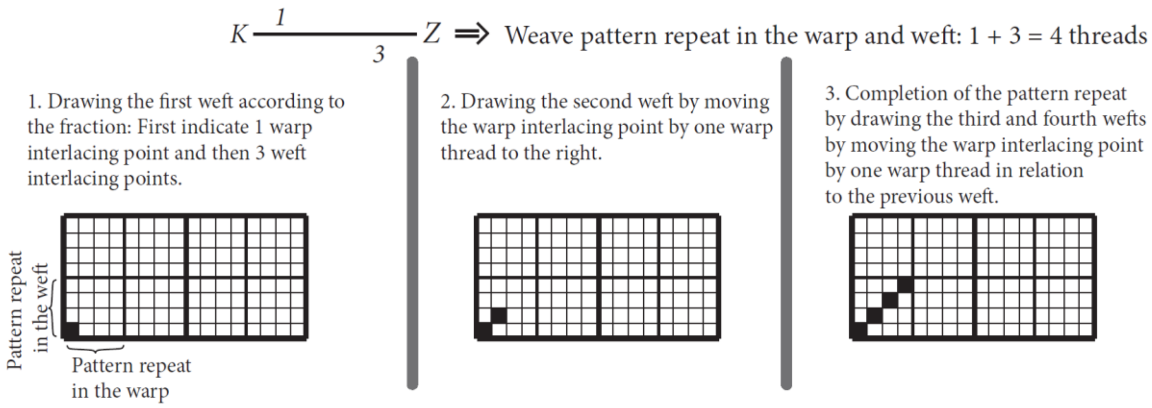


Figure 27: Procedure for drawing 4-harness twill as indicated (according to the pattern)

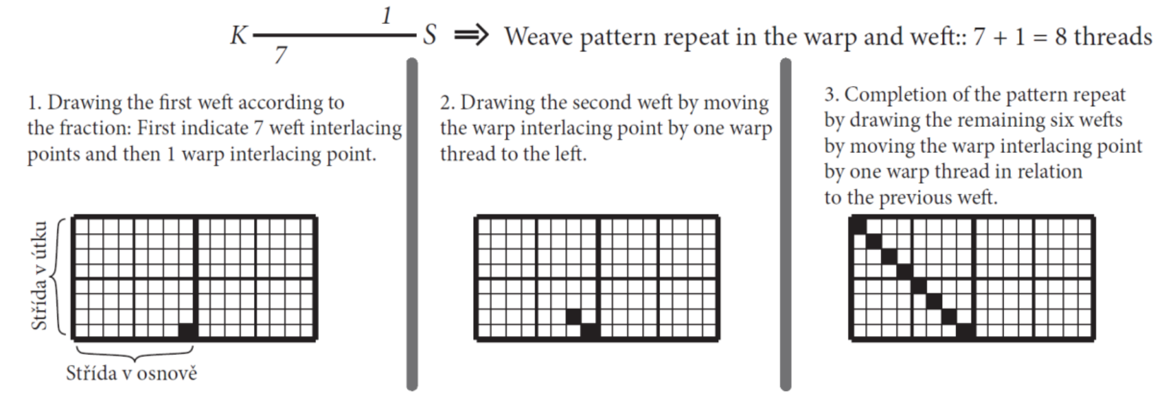


Figure 28: Procedure for writing the pattern according to the given weave (6-harness twill in the Z direction)

Satins

For satin weaves, the density of interlacing further reduces and to the detriment of the consistency between the two sets of threads, the physical and functional properties up to the physiological comfort improve significantly.

The interlacing points, in which the warp and weft interlace, have no mutual contact and the length of floating thread segments increases. **The ground satin with the minimum pattern repeat has five warp threads and five weft threads in weave pattern repeat. As in twills, the maximum pattern repeat is not theoretically limited.** The ground satins always have a square pattern repeat and are called 5-harness, 7-harness, 8-harness, etc., satins by the number of threads in the pattern repeat. Even here it is possible to distinguish between the satins of warp and weft characters, but for the reasons set out above, the textbook presents only examples of weft satins.

Also, the method of **designating satin weaves with a pattern** is defined by the standard ČSN 80 0020:

$$A\frac{No}{Nu}\ (P\check{C})\ ,$$

where letter *A* denotes satin, *No* in the numerator is the number of warp interlacing points on the first weft (always 1 for ground weft satins), *Nu* in the denominator is the number of weft interlacing points on the first weft and *(PČ)* is the move number that indicates the number of warp threads by which the warp interlacing point is moved in the next weft.

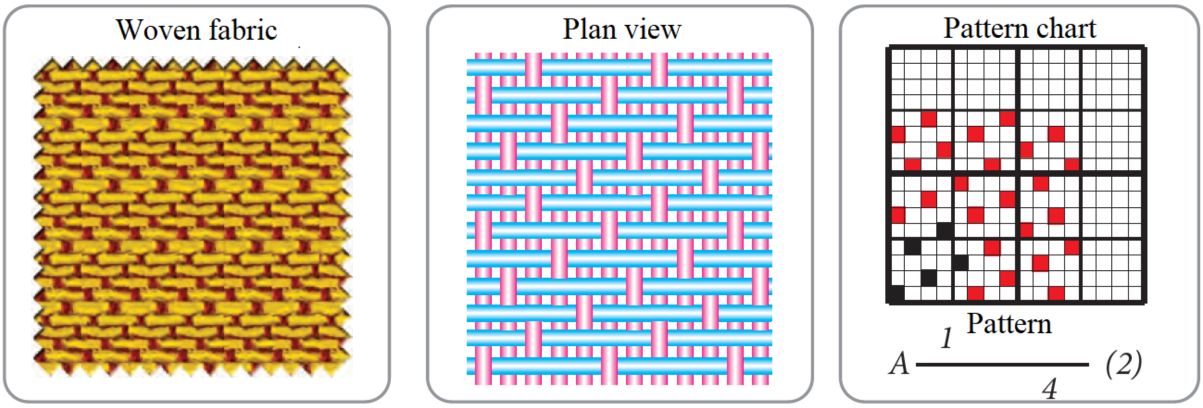


Figure 29: 5-harness satin weave with move number 2

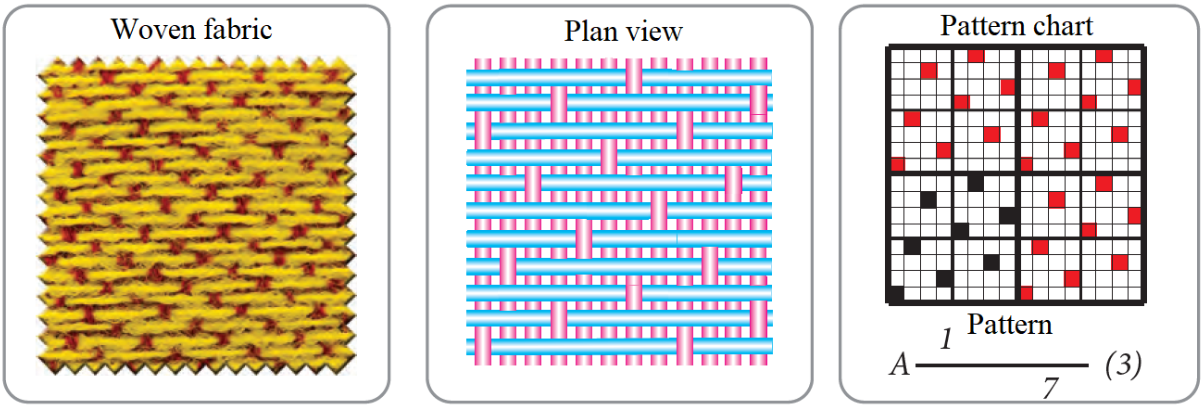


Figure 30: 8-harness satin weave with move number 3

Note to the way of drawing satin weave patterns: Even here it is possible to determine the dimensions of weave pattern repeat by summing up the numbers in the numerator and denominator. Then draw the first weft by the fraction. The move number indicates the number of threads by which the warp interlacing point is moved in the next weft. Therefore, count such a number of vertical spaces on the first weft, which is indicated by the move number and mark the warp interlacing point in the appropriate point on the second weft. Then again count the same number of vertical spaces on the second weft and mark the warp interlacing point on the third weft. Continue until the entire pattern repeat is drawn.

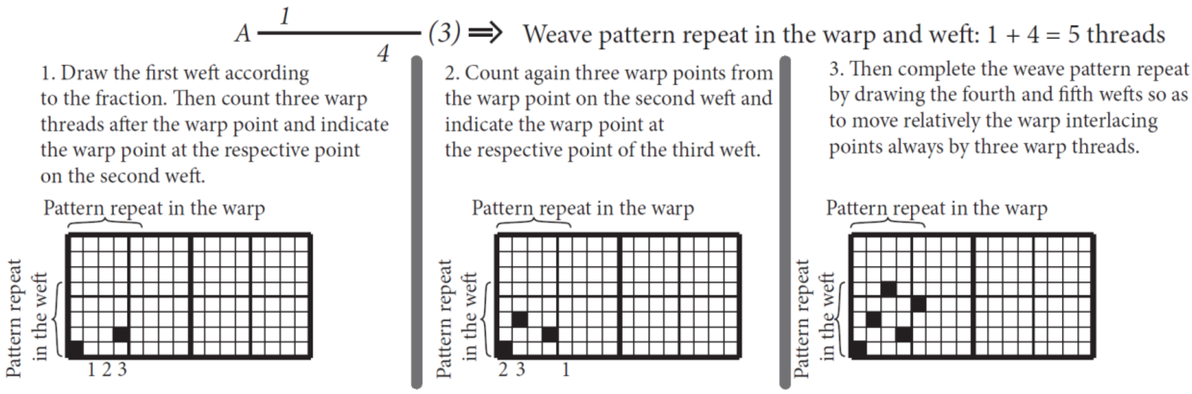


Figure 31: Drawing procedure for 5-harness satin weave with move numbers 3

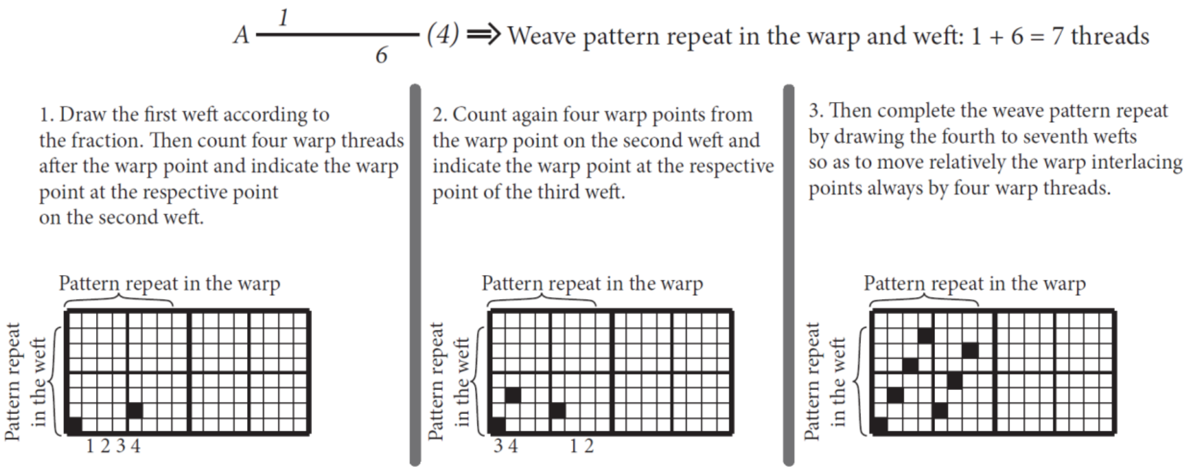


Figure 32: Drawing procedure for 7-harness satin weave with move numbers 4

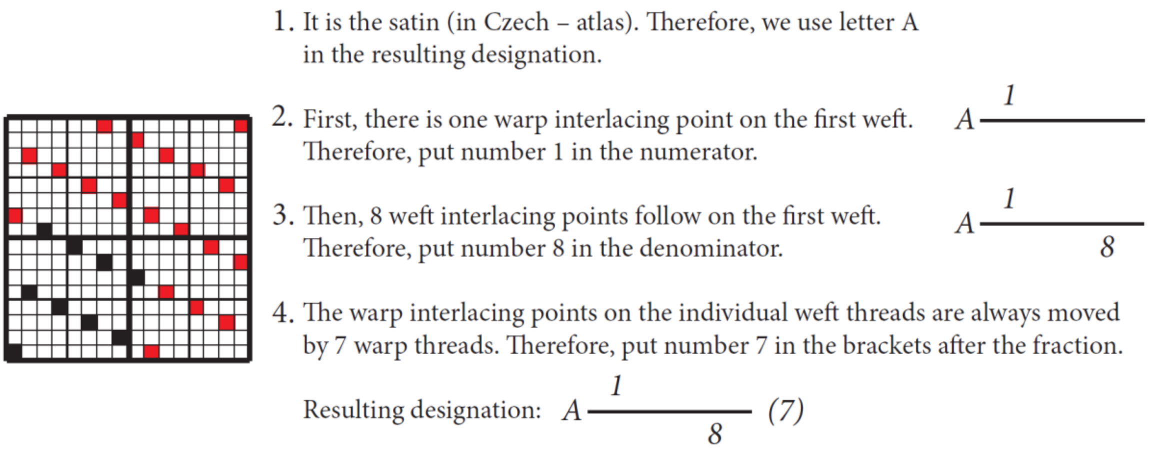


Figure 33: Procedure for writing the pattern according to the given weave (9-harness satin with move number 7)

Note to the way of determining the move number for satin: The warp interlacing points of ground weft satins should not touch each other and must be evenly distributed in the pattern repeat, which is ensured by using the correct move number. Determine the move number on the basis of the size of the pattern repeat (basically pick the numbers from one for the pattern repeat) and the following rules:

1. The move number is smaller than the pattern repeat, i.e. always remove number equal to the pattern repeat.
2. The move number is greater than 1, i.e. always remove number 1 (in the case of using number 1, the warp points touch each other and twill is produced instead of satin).
3. Always remove number one less than the pattern repeat (in the case of using it, the warp interlacing points again touch each other).
4. Remove all numbers which have a common integer divisor (they are commensurable) with the pattern repeat (in the case of using them, some of the threads will not interlace in the fabric).

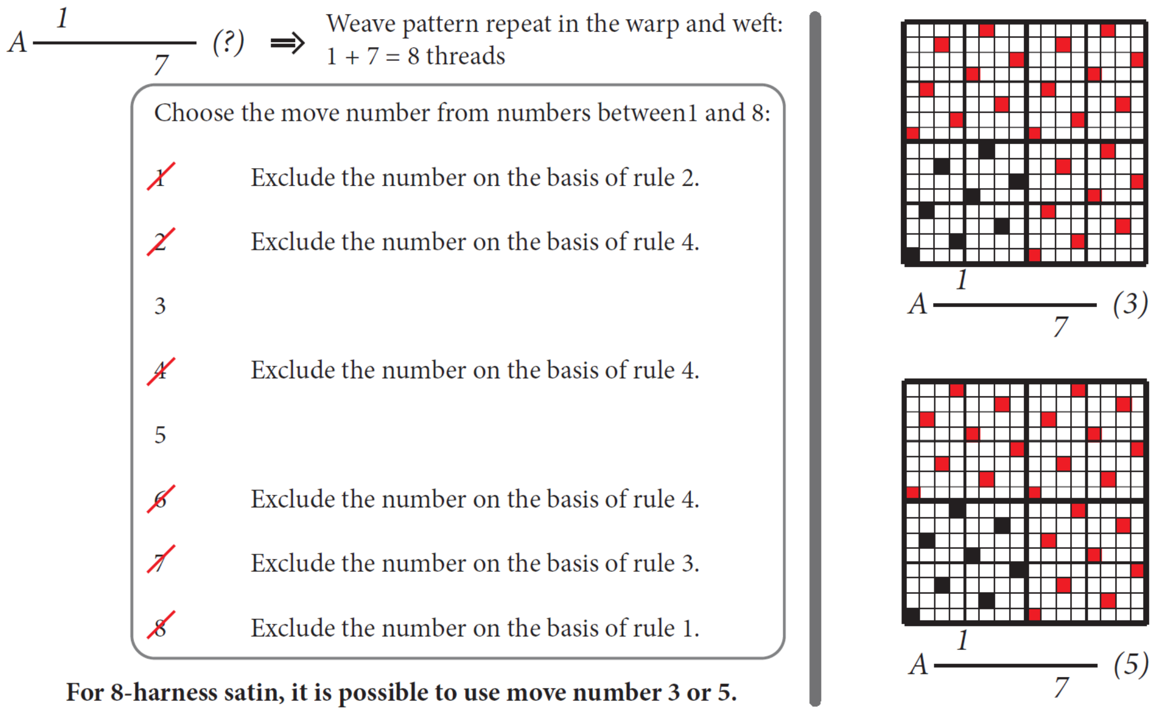


Figure 34: Procedure for determining the move number for 8-harness satin

Important findings of the chapter:

1) We know the overview of basic weaves and we know why different ways of interlacing the weft and warp threads are used.
2) We can draw the pattern chart for plain weave.
3) We can draw the pattern charts for basic twill weaves using the patterns.
4) We can write the patterns according to the pattern charts for basic twill weaves.
5) We can draw the pattern charts for basic satin weaves using the patterns.
6) We can write the patterns according to the pattern charts for basic satin weaves.
7) We can determine the correct move numbers for satins.

3.5.3 Design of Jacquard pattern fabrics

The term "Jacquard pattern fabric" refers to a fabric with the so-called "figural patterning", i.e. patterns created by interlacing (geometric patterns, floral motifs, ornaments, figures, etc.). The name of Jacquard pattern fabrics is derived from the name of shedding mechanism (Jacquard shedding device), which is able to create this type of fabric.

The principle of function of the Jacquard shedding mechanism is described in detail in the appropriate Chapter (4.4.3) in part "Weaving machines and their mechanisms". This chapter explains the design of Jacquard pattern fabric on the example of the preparation of the so-called "technical drawing". The **technical drawing** and the appropriate section uniquely determine the method of interlacing the warp and weft threads in Jacquard pattern fabric. The general description of the preparation of technical drawings is provided, for example, in [10], exceeds the capacity of this textbook. Therefore, we focus only on the description of the preparation of a particular technical drawing of the so-called "single (with only one set of warp and weft threads) Jacquard fabric with a plain ground.

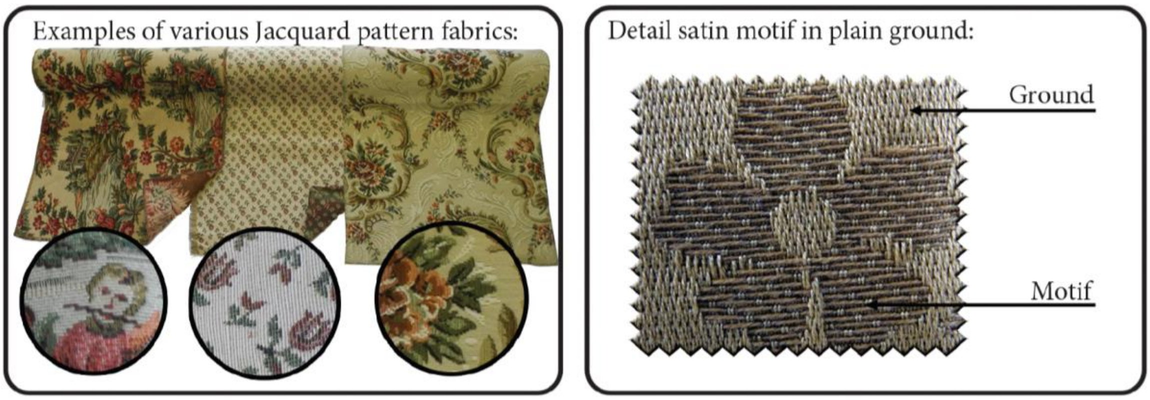


Figure 35: Examples of various Jacquard pattern fabrics and detail of fabric with a satin pattern and a plain ground

Procedure for preparing technical drawing:

1. First, draw the motif (preferably in real size) or scan then existing motif into an electronic format when using software for designing Jacquard pattern fabrics.
2. Furthermore, transfer the motif on the pattern chart paper (grid) with the appropriate division (see Chapter 3.5.1). The pattern chart paper with a division of 8:8 can therefore be used for fabrics with a ratio of the number of threads per unit length in the warp and weft of 1:1.

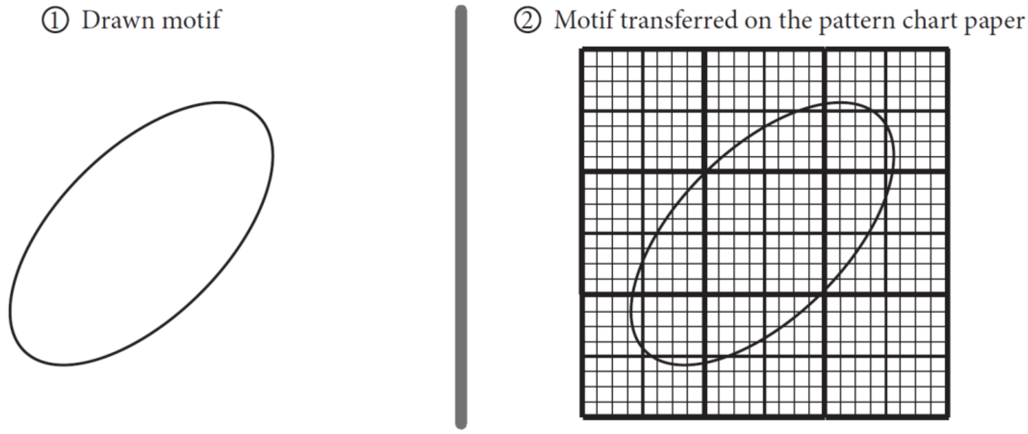


Figure 36: Motif and its transfer on the pattern chart paper

3. The so-called “designing of motif contours” follows. The curves, which form the contour of the motif, must be converted to grid as close as possible. In designing, red colour is mostly used to fill the squares. After designing, the area of the motif is coloured in red.

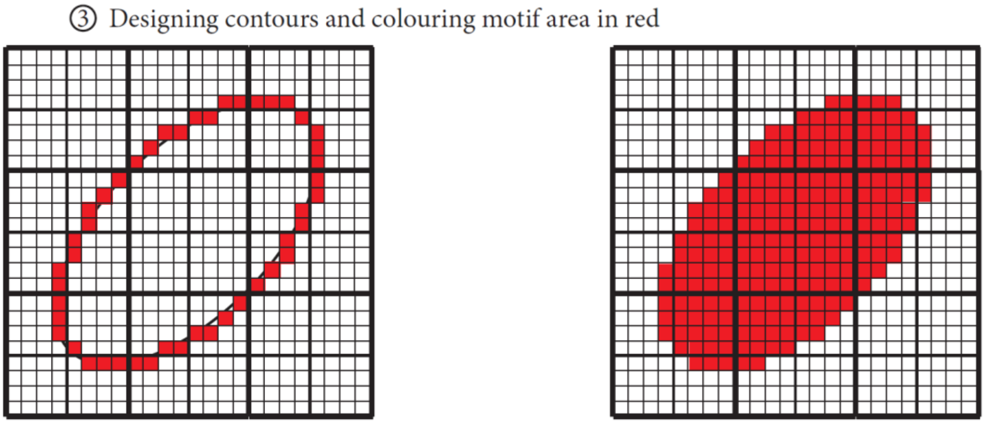


Figure 37: Designing motif contours and colouring motif area in red

4. The specific weaves are then assigned to the ground and motif. In our case, assign the plain weave to the ground (draw the plain weave in the ground in red) and assign the satin weave to the motif (in the red area of the motif, draw a 5-harness satin with move number 3 in black).

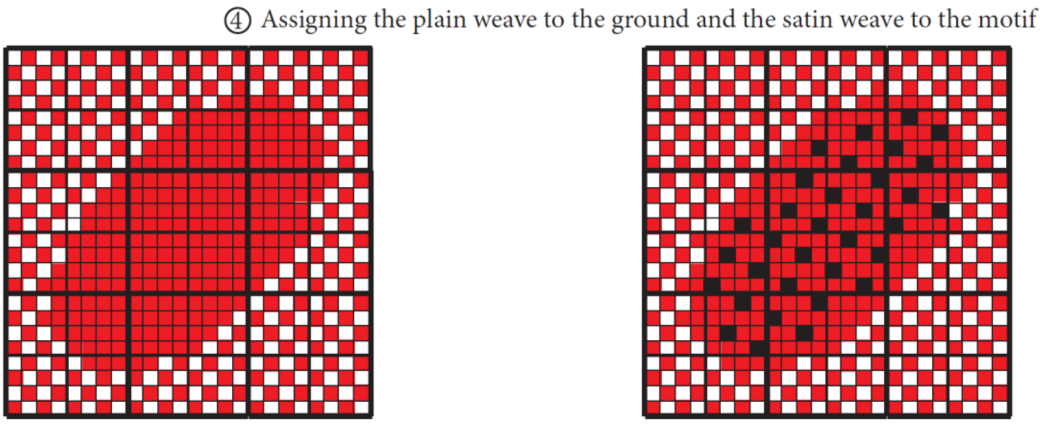


Figure 38: Assigning the plain weave to the ground and the satin weave to the motif

5. For actual determination of the importance of individual colours in a technical drawing, it is necessary to complement a cross section for the selected weft space that includes all the colours used.

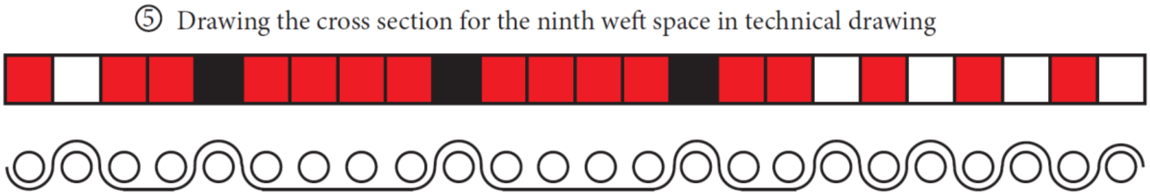


Figure 39: Cross section for the selected space from technical drawing

From the above section it is clear that the white points in the ground and black points in the motif represent the weft interlacing points and the red points represent the warp interlacing points. Therefore, the motive in this case is formed by warp.

In Jacquard pattern fabrics, the motifs, which form the fabric pattern, are arranged in different ways. The possibilities of arrangements of motifs are given by the shedding mechanism, specifically by the so-called “tying of harness cords” (see Chapter 4.4). For some fabrics, the pattern is formed only by warp or weft, and some have the pattern formed by both warp and weft. In this case, it is necessary to use another colour in technical drawing to distinguish the pattern formed by warp and the pattern formed by weft. Technical drawing with the appropriate section allows the production of the so-called “cards” (punch cards) for mechanically controlled Jacquard shedding mechanisms (see in [10]).

The preparation of technical drawing is currently somewhat automated and facilitated by using software for designing Jacquard pattern fabrics. In addition to the preparation of technical drawing, the relevant software is able to directly generate a program for an electronically controlled Jacquard shedding device or visualize different products of Jacquard pattern fabrics, which brings undisputed technological advantages. Examples include CAD systems *DesignScope* of the EAT company, *Penelope* of the Informàtica Tèxtil company or *Design Jacquard* of the Textronics company (see websites of the above companies: [11], [12] and [13]).

It is evident that **in comparison with the fabrics in the basic or derived weaves, Jacquard pattern fabrics comprise a large number of different interlacing warp threads**, which is obtained by assigning different weaves to the motifs or portions thereof. For these reasons, the production of Jacquard pattern fabrics is rather specific and different in technological terms and with regard to used machinery from the production of fabrics in basic or derived weaves.

For Jacquard pattern fabrics, the most important are their decorative properties. We can encounter them in the field of clothing (dress materials, ties, etc.) and particularly household textile (drapes, upholstery fabrics, etc.).

Important findings of the chapter:

1) We know what is the Jacquard pattern fabric and what makes it different from fabrics in basic weaves.
2) We understand the terms “technical drawing”, “ground”, “motif” or “pattern” and we know the procedure in the preparation of technical drawing.
3) We know the importance of technical drawing and the appropriate section in technological practice when using mechanical or electronically controlled Jacquard shedding mechanisms.

3.6 Length

Fabric length L_{TK} is defined as its dimension in the direction of warp threads and represents the most common method for indicating the amount of fabric. The unit used is the so-called “linear metre” (*lm*), which is the length of fabric with the given width in metres.

Note: The direction of warp and thus the length of fabric can be clearly determined from a sample of fabric only if the sample contains the edge of fabric. The edge obviously runs parallel to the warp and its appearance is dependent on the type of weaving machine, or the method of weft insertion. On shuttle looms, a selvedge is created automatically and its appearance is shown in Figure 89. In shuttleless looms, the edge must be reinforced using a certain type of special mechanism (see Chapter 4.5.3) and leno weave is currently most often used to reinforce the edges (see Figure 89).

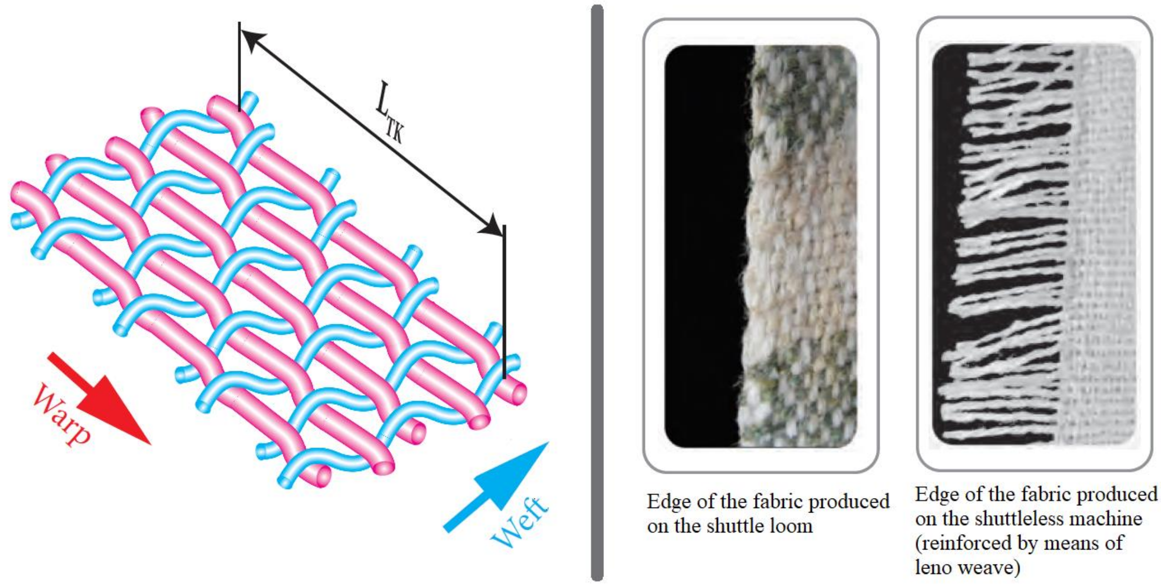


Figure 40: Fabric length and edge of fabric produced on shuttle loom and shuttleless machine

If the sample of fabric does not contain the edge (e.g. it is cut from the middle of fabric), the direction of warp and weft cannot be unambiguously determined. But for the most common fabrics, we can use the following auxiliary features as a guide:

1. The number of warp threads per unit length is usually greater than number of weft threads per unit length.
2. Warp contraction (see Chapter 3.8) is usually less than weft contraction.
3. Where there are colour stripes on the fabric, they are usually formed by a warped pattern, i.e. stripes run parallel to the warp.
4. If plied threads are applied only in one set, it is usually the warp system.

3.7 Width

Fabric width $Š_{TK}$ is defined as its dimension in the direction of weft threads and is indicated in metres or centimetres. The design parameter of fabric is its **reed width** $Š_P$, i.e. the width of fabric or warp pass in reed on a weaving machine. Fabric width on the cloth beam $Š_{TK}$ is always somewhat smaller than the reed width $Š_P$ and its value cannot be accurately predicted before fabric production.

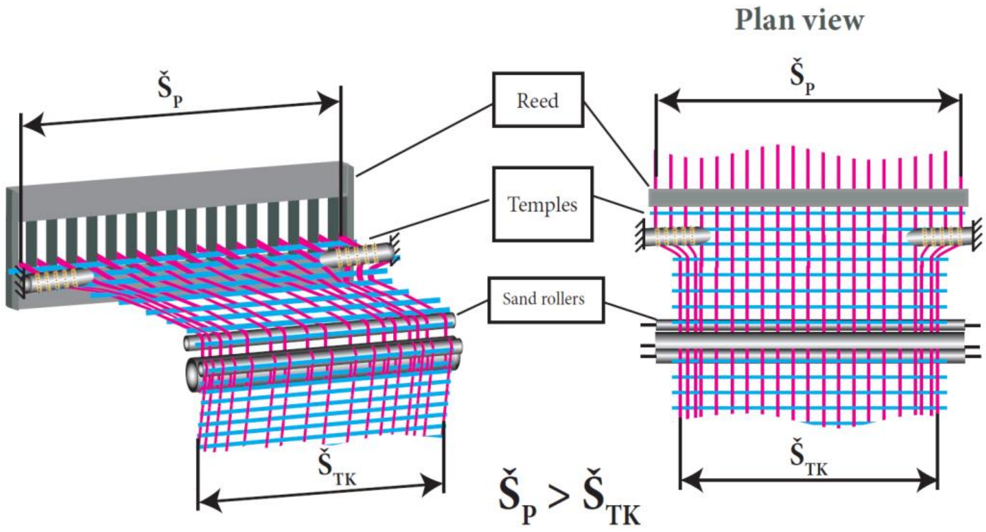


Figure 41: Reed width of fabric and fabric width on the cloth beam

The difference between the reed width and the fabric width on the cloth beam occurs due to internal tensile forces which arise in the weft after interlacing it. The weft is inserted into the open shed parallel to the face of fabric (see Figure 91) and therefore, on the pitch of the warp threads A , the length of weft lu is brought, which is just equal to the pitch A or smaller length (if weft is braked while being inserted into the shed).

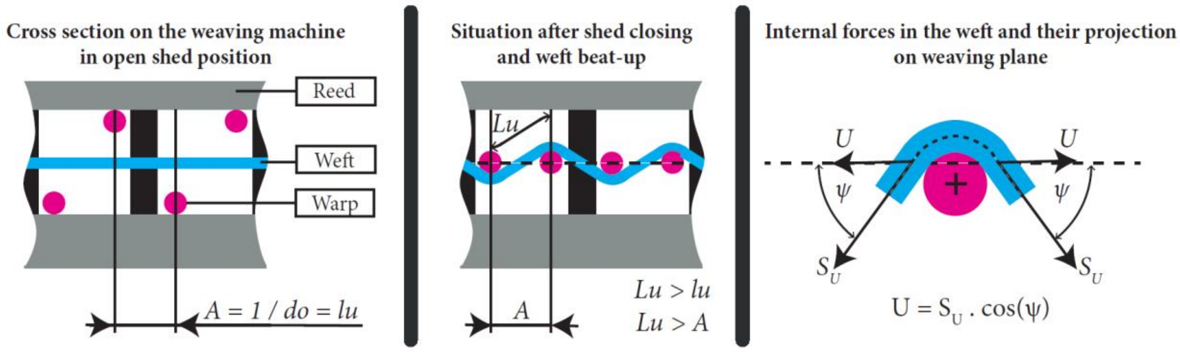


Figure 42: Situation after inserting weft in the shed and after interlacing it

Interlacing of the weft (after closing the shed and beat-up) results in elongation of the element of weft thread Lu. Due to elongation, tensile forces S_U are generated in the weft, whose projection on weaving plane U causes contraction of fabric. In the space behind the reed, the so-called “temples” (see Chapter 4.1) are placed on the weaving machine, which generate a reaction against the tensile forces U and maintain fabric in the reed width. However, no reaction against the forces U is generated behind the temples and the width of fabric is therefore reduced. Changing the width of fabric is dependent on the parameters of the weft and warp threads, their deformation properties, the number of threads per unit length in the warp and weft, and the weave. Therefore, it is usually impossible to pinpoint exactly this change before fabric production and the resultant width of fabric $Š_{TK}$ on the cloth beam is therefore not included among the design parameters.

Important findings of the chapters:

1) We know the definitions of terms “fabric length” and “fabric width”.
2) We know what is the reed width of fabric.
3) We know why the width of fabric on the cloth beam is smaller than the reed width.

Note to the design parameters of fabrics

Now we have described all design parameters that clearly define the fabric in terms of its production. Therefore, these include the following parameters:

1. Parameters of linear textiles, i.e. warp and weft threads (see Chapter 3.1).
2. Number of warp and weft threads per unit length (see Chapter 3.2).
3. Warped pattern (see Chapter 3.3).
4. Picked pattern (see Chapter 3.4).
5. Textile weave (see Chapter 3.5).
6. Length (see Chapter 3.6).
7. Reed width (see Chapter 3.7).

Fabric is also characterised by other important parameters that can be usually determined after its production. We have already mentioned the resultant width of fabric on the cloth beam. Other important parameters of this type include warp contraction, weft contraction and fabric weight.

3.8 Warp and weft contraction

Warp contraction s_O is defined as the difference between the length of ripped warp thread L_O and the length of fabric sample L_{TK} expressed in percentage of fabric length.

Weft contraction s_U is defined as the difference between the length of ripped weft thread L_U and the width of fabric sample $Š_{TK}$ expressed in percentage of fabric width.

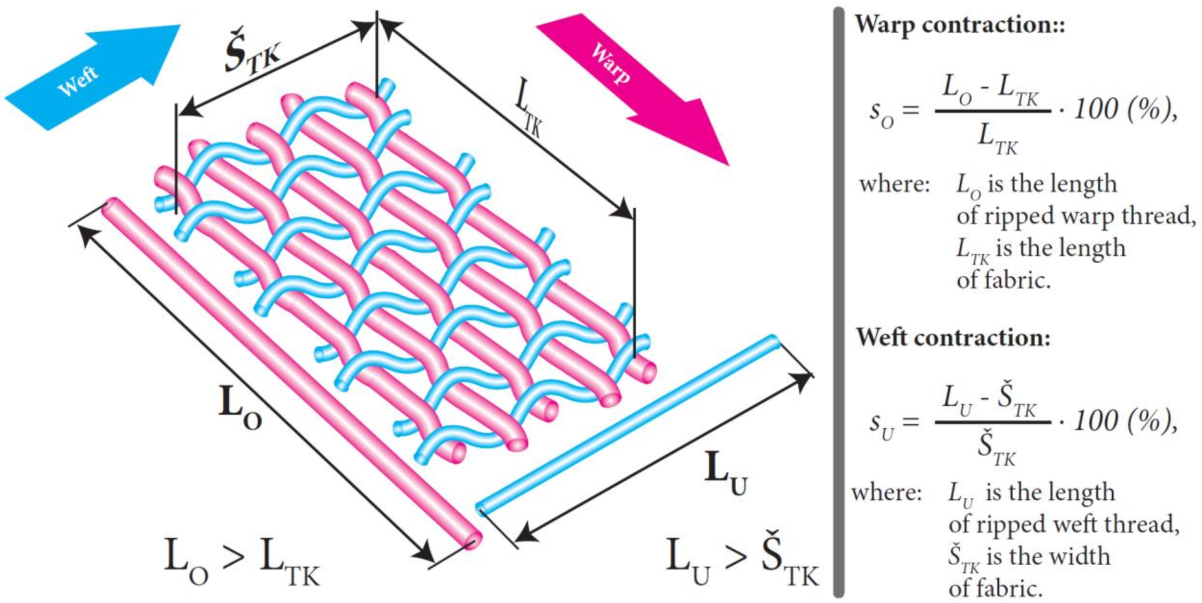


Figure 43: Warp and weft contraction

The value of warp contraction is useful, from practical point of view, for example when determining the required length of warp to produce the required length of fabric, i.e.:

$$L_O = L_{TK}.\left(1 + \frac{s_O}{100}\right),$$

where L_O is the required length of warp in metres, L_{TK} is the required length of fabric in metres and s_O is the contraction of warp in percentage.

In technical practice, the consumption of material is normally scheduled in kilograms. Based on the definition of fineness (see Chapter 3. 1. 1) and the number of warp threads per unit length (see Chapter 3.2), we can easily convert the warp length L_O into the appropriate mass:

$$M_O(kg) = \underbrace{L_O(m).T_O(tex).10^{-6}}_{\text{Mass of one warp thread in kg}}.\underbrace{d_O(1/cm).100.\check{S}_{TK}(m)}_{\text{Total number of threads in the warp}},$$

where M_O is the mass of warp in kilograms, L_O is the length of warp in metres, T_O is the fineness of warp threads in the units of tex, d_O is the number of warp threads per unit length with a dimension of the number of threads per 1 cm and $\check{S}_{TK}$ is the width of fabric in metres.

On the basis of weft contraction, it is also possible to express the length of weft needed to produce the required length of fabric:

$$L_U = \underbrace{\check{S}_{TK}.\left(1 + \frac{s_U}{100}\right)}_{\text{Length of one weft thread in metres}}.\underbrace{d_U.100.L_{TK}}_{\text{Number of wefts in the required length of fabric}},$$

where L_U is the required length of weft in metres, $\check{S}_{TK}$ is the width of fabric in metres, s_U is the contraction of weft in percentage, d_U is the number of weft threads per unit length with a dimension of the number of threads per 1 cm and L_{TK} is the required length of fabric in metres.

and convert this length into the appropriate mass:

$$M_U(kg) = L_U(m).T_U(tex).10^{-6},$$

where M_U is the mass of weft in kilograms, L_U is the length of weft in metres and T_U is the fineness of weft in the units of tex.

3.9 Fabric weight

Fabric weight (surface density) **is defined as the weight of one square metre of fabric.** Of course this parameter can be determined by directly weighing a sample of fabric.

Where laboratory scales are not available, **weight can be determined by calculation** based on the following parameters: fineness of warp threads T_O*(tex)* and fineness of weft threads T_U*(tex)*, number of warp threads per unit length d_O *(1/cm)* and number of weft threads per unit length d_U *(1/cm)*, warp contraction s_O*(%)* and weft contraction s_U*(%)*.

The fabric is made up of warp and weft threads. Therefore, the weight of one square metre of fabric is determined by the sum of the weights of the warp and weft threads contained in one square metre, i.e. fabric sample with a length of 1 m and a width of 1 metre.

Based on the definition of fineness, number of threads per unit length and contraction, we can express the mass of the warp threads contained in one square metre of fabric by the following relation:

$$m_O(g)=\underbrace{d_O(1/cm).100.\left(1+\frac{s_O(\%)}{100}\right)}_{\substack{\text{Length of the warp threads contained}\\ \text{in 1 } m^2 \text{ of fabric in metres}}}.T_O(tex).10^{-3}$$

and the mass of the weft threads contained in one square metre of fabric by the following relation:

$$m_U(g)=\underbrace{d_U(1/cm).100.\left(1+\frac{s_U(\%)}{100}\right)}_{\substack{\text{Length of the weft threads contained}\\ \text{in 1 } m^2 \text{ of fabric in metres}}}.T_U(tex).10^{-3}$$

We can then express the fabric weight by summing up the mass of warp threads m_O and the mass of weft threads m_U:

$$M_S(g)=m_O(g)+m_U(g)=\frac{d_O(1/cm).\left(1+\frac{s_O(\%)}{100}\right).T_O(tex)+d_U(1/cm).\left(1+\frac{s_U(\%)}{100}\right).T_U(tex)}{10}$$

Fabric weight is the important characteristic of fabrics used not only in technological (as part of production specifications) but also commercial practice.

Important findings of the chapters:

1) We know the definition of terms "warp contraction" and "weft contraction".
2) We can calculate the required length or mass of the warp for the required length of fabric.
3) We can calculate the required length or mass of the weft for the required length of fabric.
4) We know the definition of term "fabric weight" and we can determine this parameter by calculation.

4 Weaving machines and their mechanisms

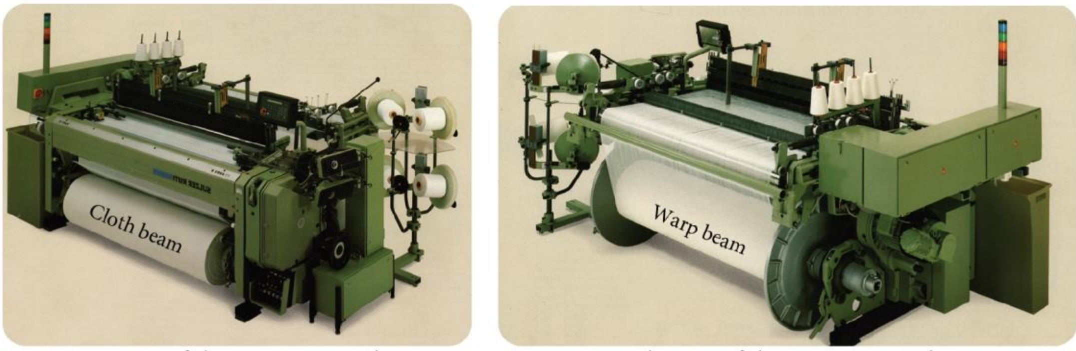
Each chapter of this part of the textbook informs the reader about the general layout of the weaving machines, the method of their driving, warp feed and cloth take-up mechanisms, shedding mechanisms, methods of weft insertion and beat-up mechanisms. Last but not least, attention is paid to the methods of controlling the operation of weaving machines, automation elements and operator comfort. In addition to the design layout and principle of operation of the mechanisms, their properties are described in terms of current technological operation and the method of ensuring the required design parameters of the product (fabric). The developments of weaving technology are briefly described on a long-term basis and the main attention is paid to the development from 1990 to the present. Thus, this part of the textbook directly follows the previous publication (see [1], [2] and [3]).

4.1 Layout of weaving machines and weaving cycle

In terms of position of the weaving plane, various methods of layout of the weaving machines can be traced in the distant past. In the Neolithic Age, fabrics were produced by interlacing the weft into the vertically oriented warp threads by hand (see Chapter 2.2.2). The oldest Egyptian looms had their weaving planes oriented horizontally (see Chapter 2.2.3) and the looms with a vertical weaving plane appear later. The looms with a vertical plane are also characteristic for the Age of Antiquity (Ancient Greece, Rome). The looms with a horizontally oriented weaving plane (see Chapter 2.2.4) appear again at the beginning of our era.

In the 1970s, the weaving machines with an inclined weaving plane appear, having both the warp beam and the cloth beam on one side of the machine. A typical representative of weaving machines with this method of layout are the air-jet machines of Czechoslovak production, PZ and PN type series, or the water-jet machines of the type H (see [1] and [3]). An inclined weaving plane to a certain extent increases operator comfort in repairing breaks of the warp threads and reduces the floor dimensions of the weaving machine. Placing the warp and cloth beams on the same side of the machine minimizes handling areas but also complicates handling of the warp beam when it is being replaced (the warp beam is positioned above the cloth beam). Therefore, we no longer see this layout of weaving machines.

Since the 1990s, weaving **machines with a horizontal or slightly inclined weaving plane** have been exclusively used, whose inclination can be adjusted using a back rest (see Chapter 4.7). The warp beam is located in the rear part and the cloth beam is located in the front part of the machine.



Front view of the weaving machine Back view of the weaving machine

Figure 44: Current shuttleless weaving machine with a horizontal plane (source [14])

Figure 94 illustrates the general layout of the current, i.e. shuttleless weaving machine. All the main parts are drawn therein that are in contact with the textile material (warp and weft) and the final product (fabric). The figure represents the weaving machine in the position of open shed and after the weft insertion phase.

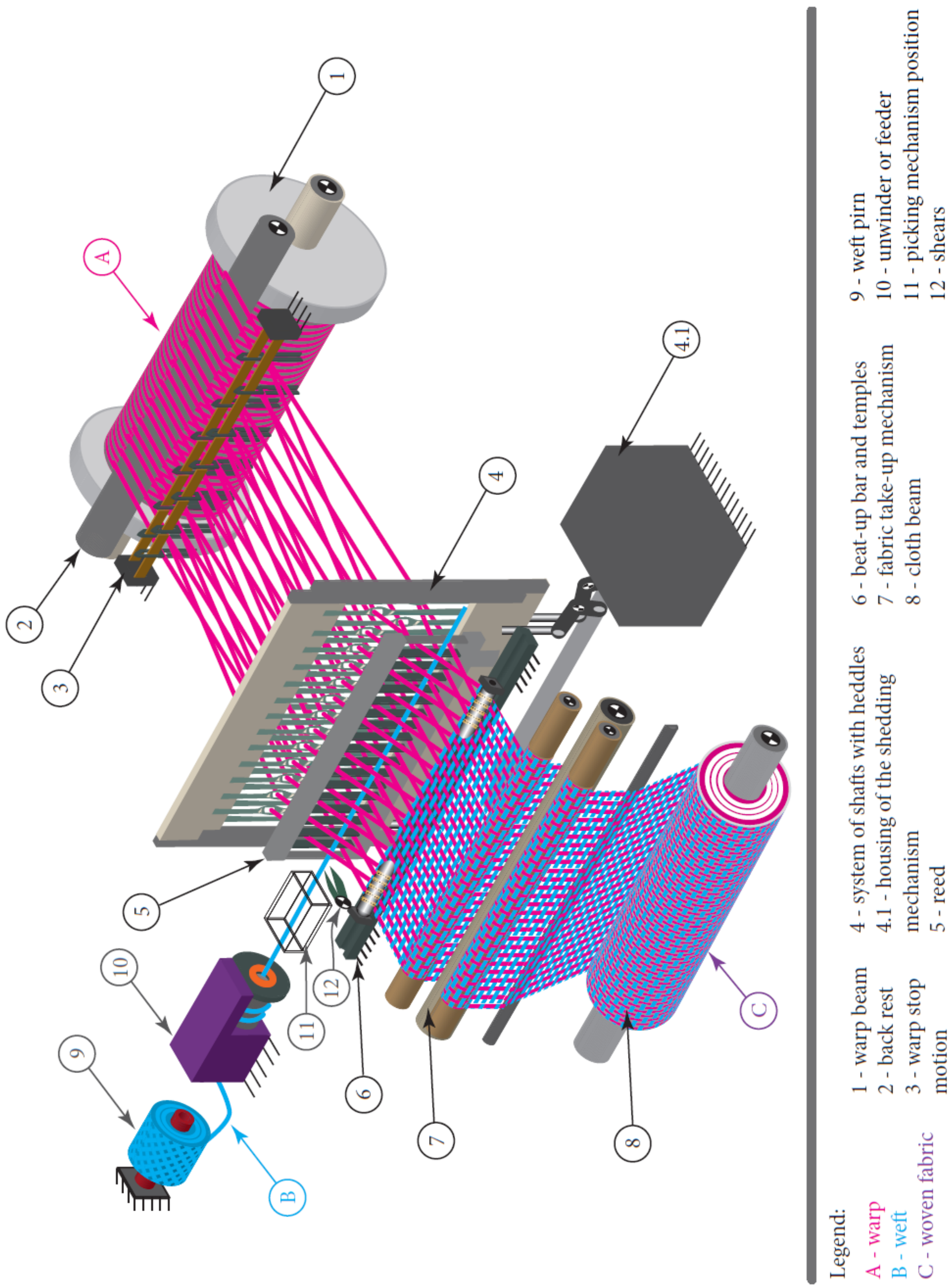


Figure 45: General layout and main parts of shuttleless loom

For teaching purposes, it is possible to simplify Figure 94 and draw schematically the weaving machine in the position of open shed in the form of a side view. This produces the so-called **basic diagram**, which is usually used for the representation of the general layout of a weaving machine and its main parts in terms of threading of warp threads, weft and fabric.

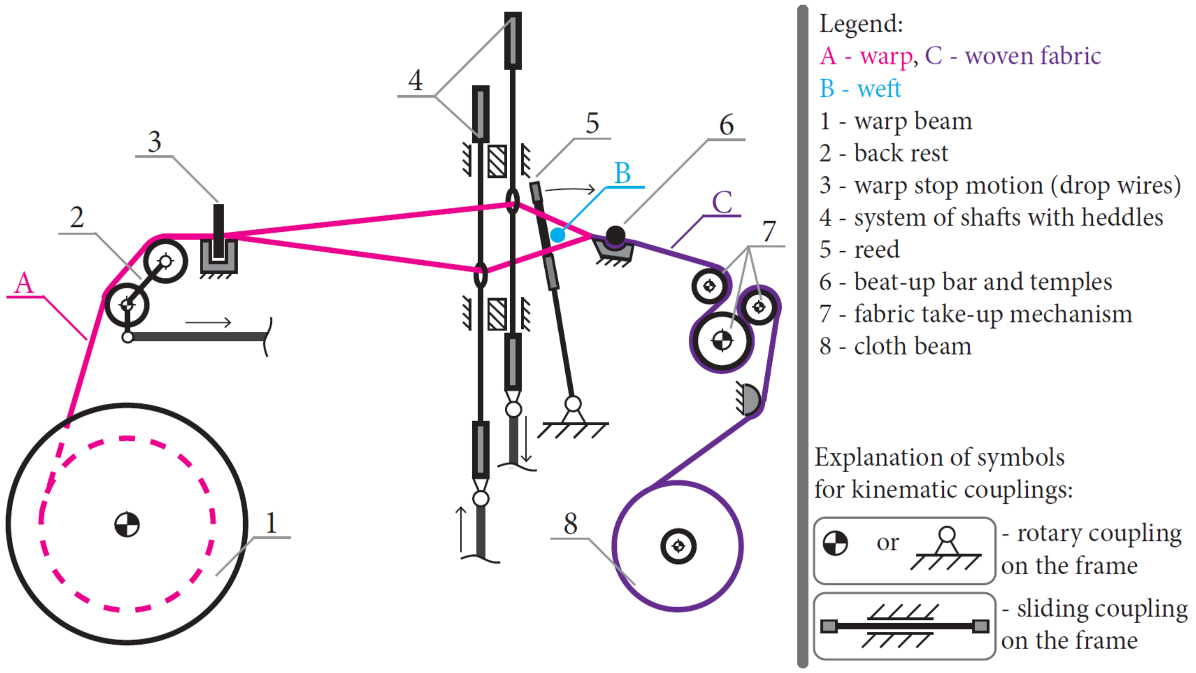


Figure 46: Basic diagram of the weaving machine

Frame

The frame of the weaving machine enables the spatial distribution of the functional members and mechanisms. They must have sufficient mass and rigidity, guaranteeing the capture of the reactions of working and inertial forces including the ability to dampen the vibrations caused by the dynamic forces that are generated by mechanisms with the machine running.

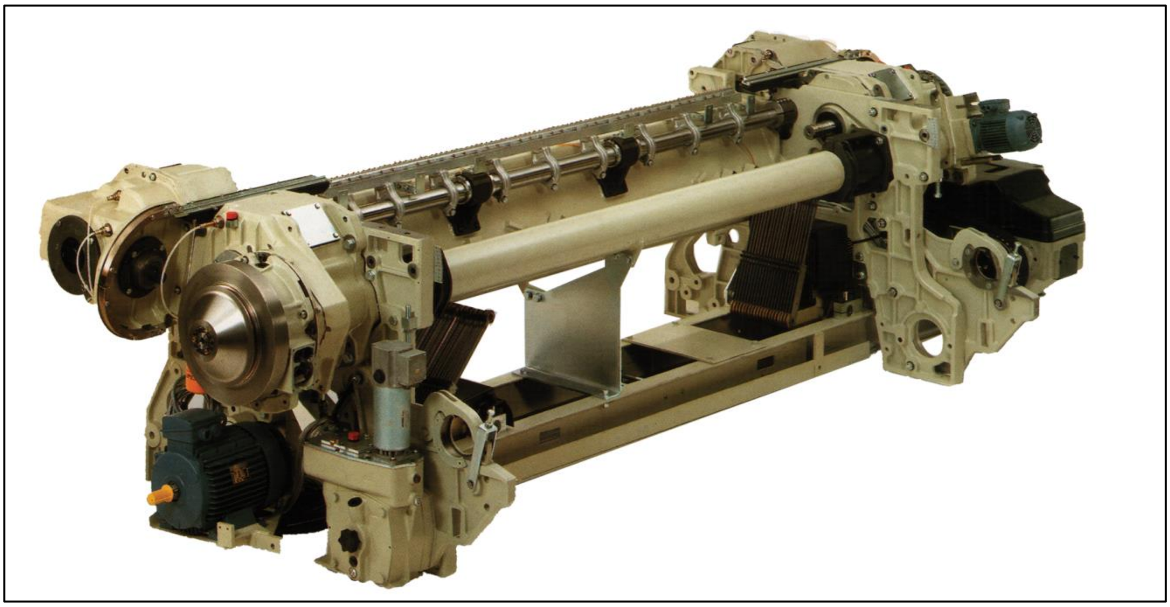


Figure 47: Weaving machine frame (source [15])

1 - Warp beam

The warp beam is composed of a central tube and a pair of selvedge discs - heads. The distance of heads defines the width of warp on the warp beam $Š_O$. The width of warp on the warp beam is about one to two percent greater than the reed width to prevent the warp threads from abrading against the selvedge discs.

A substantially parallel package of the required length and with the required warped pattern (see Chapter 3.3) is created between the selvedge discs. The total number of threads cpn_O in this package is determined by the product of the number of warp threads per unit length do (see Chapter 3.2) and reed width $Š_P$ (see Chapter 3.7), i.e.: $cpn_O = do(threads/1\ cm)\ .\ Š_P(cm)$.

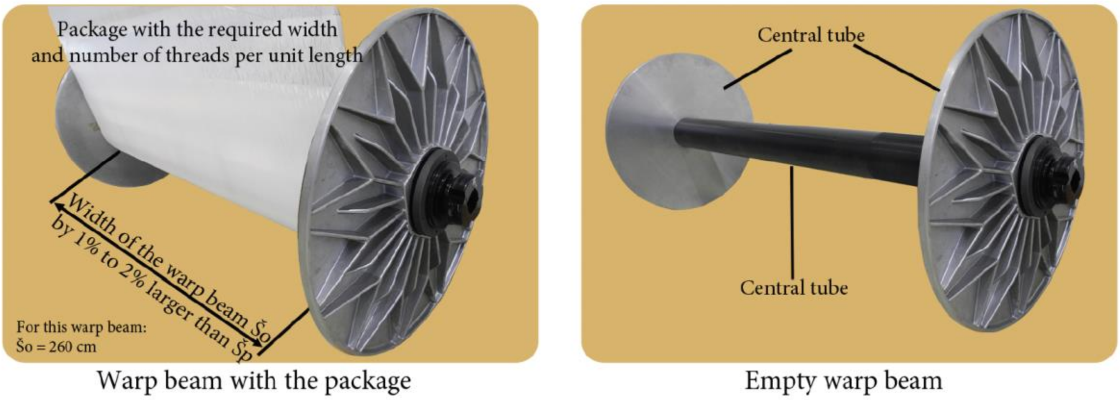


Figure 48: Warp beam

2 - Back rest

The back rest is able to compensate for the changes in tensile force in the warp caused due to opening and closing the shed or affect the weft beat-up process. It is often also used as a sensor of tensile force in the warp and forms a part of the feedback circuit of the warp controller. The basic functions include threading the warp in the weaving plane. The individual functions and design of back rest are discussed in more detail in Chapter 4. 7.

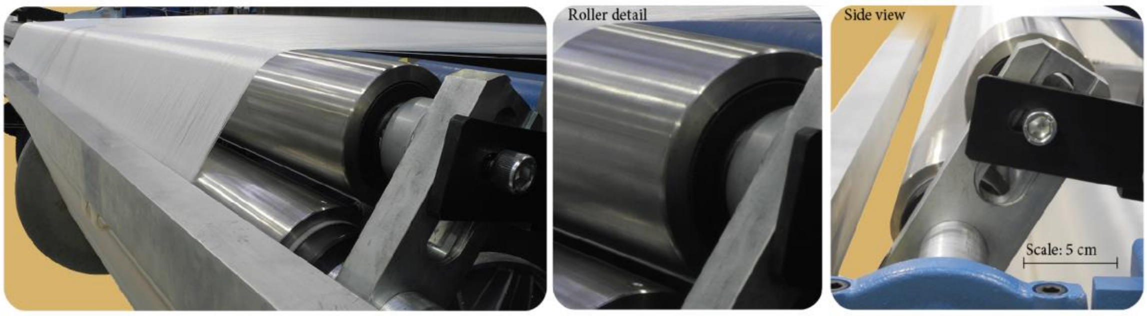


Figure 49: Back rest

3 - Warp stop motion

Warp stop motion is a control mechanism, which monitors the integrity of warp threads and in case of break of the warp thread, stops the weaving machine. The so-called “drop-wire type warp stop motions” are now solely used in industrial practice. The drop wires are mounted on each warp thread in several rows (the number of rows depends on the total number of threads in the warp). A guide bar, the so-called “serrated bar”, runs through the top opening of drop wires in each row. When any of the warp threads breaks, the appropriate drop wire will fall down, suspend from the serrated bar, thus interconnecting the electrical circuit. Electrical circuit interconnection is the signal to stop the machine. The machine must be stopped in a very short period of time to prevent other (surrounding) warp threads from breaking.

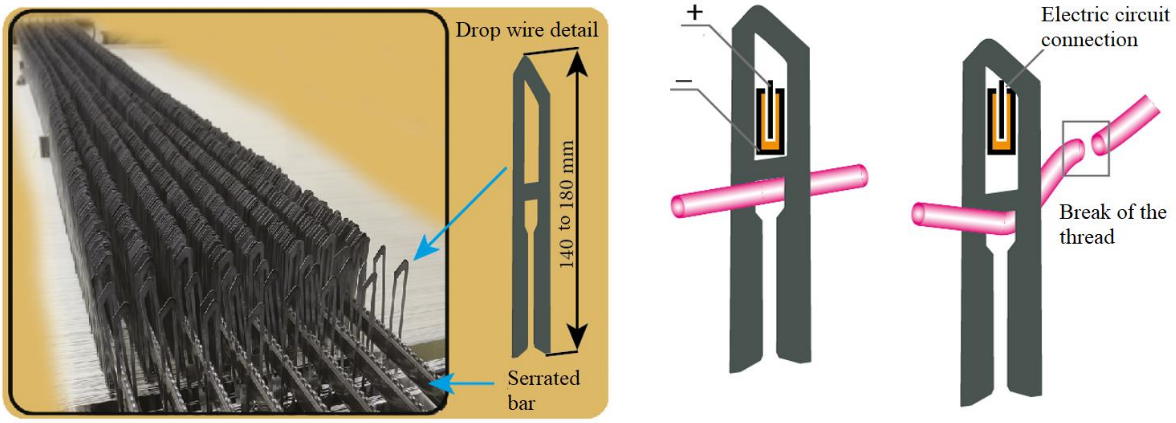


Figure 50: Drop wires of warp stop motion

Note: Fixing warp breaks has not yet been automated in any way. After the break, it is necessary to tie the warp thread by hand and thread it again in the drop wire of the warp stop motion, heddle and dent of the reed.

4 - Dobby and Jacquard healds: heddles

Threading the warp threads in the heddles allows the creation of the shed. Only the flat shaped heddles arranged in shafts, i.e. dobby heald or heddles of circular cross-section arranged in a Jacquard heald are currently used in industrial practice.

The shaft is basically a frame comprising heddles. The term "dobby heald" denotes the set of shafts installed on the weaving machine. The number of shafts determines the maximum number of different interlacing warp threads in fabric and thus the interlacing capabilities of the machine. For example, fabrics in plain weave contains two different interlacing warp threads and it is therefore possible to produce these fabrics under certain circumstances with the use of two shafts (see Figures 94 and 95). The dobby heald is used to produce fabrics in basic or derived weaves. This issue is described in more detail in Chapters 4.4, 4.4.1 and 4.4.2.

For Jacquard heald, the heddles are not arranged in shafts but are individually suspended on the harness cords. The order of heddles in the Jacquard heald ensures threading of the harness cords in the comber board (board with holes). Compared to fabrics in basic or derived weaves, Jacquard fabrics contain a large number of different interlacing warp threads (see Chapter 3.5.4). In this case, the maximum number of different interlacing warp threads in fabric is determined by the number of hooks of the Jacquard shedding device. This issue is addressed in detail in Chapters 4.4 and 4.4.3.

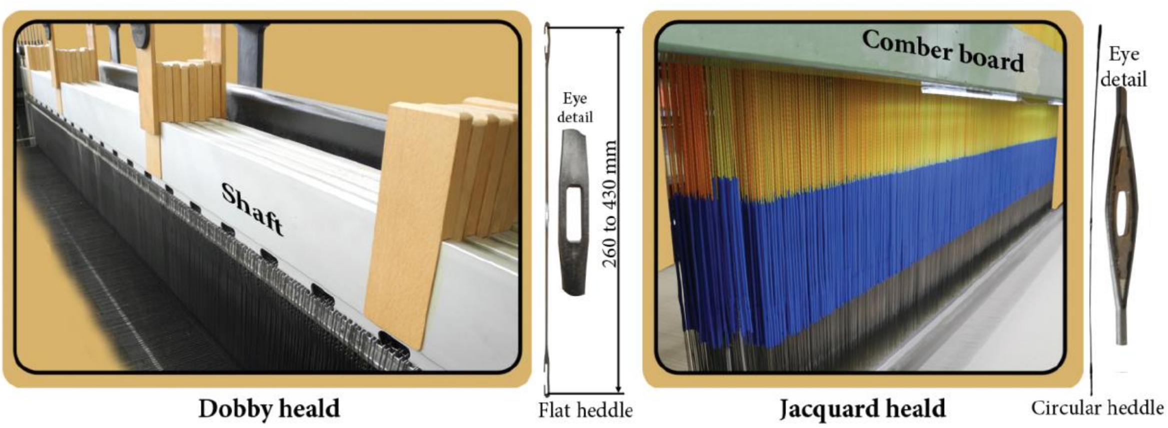


Figure 51: Dobby and Jacquard healds

5 - Reed

The reed performs two functions on the weaving machine: beats up the weft and guides the warp threads in the required number of threads per unit length. The first function (weft beat-up) is ensured by placing the reed on the so-called “slay”, which is a working output member of the beat-up mechanism with the oscillating motion. After insertion of the weft into the shed, the slay is swung toward the beat-up bar and beats up the weft to the face of fabric.

The second function (threading the warp threads in the required number of threads per unit length) is ensured by threading the warp threads through the dents of the reed. The reed is composed of the so-called “dents”, which are fixed in the top and bottom weaves at regular intervals. A certain number of warp threads is threaded in each space between the dents. Then, the number of dents of the reed per 10 cm of its length (the so-called “reed number” *Čp)* determines the number of warp threads per unit length: *Do (threads/10 cm) = Čp . n*, where *n* is the number of threads in one dent of the reed. This issue is addressed in more detail in Chapter 4.6.

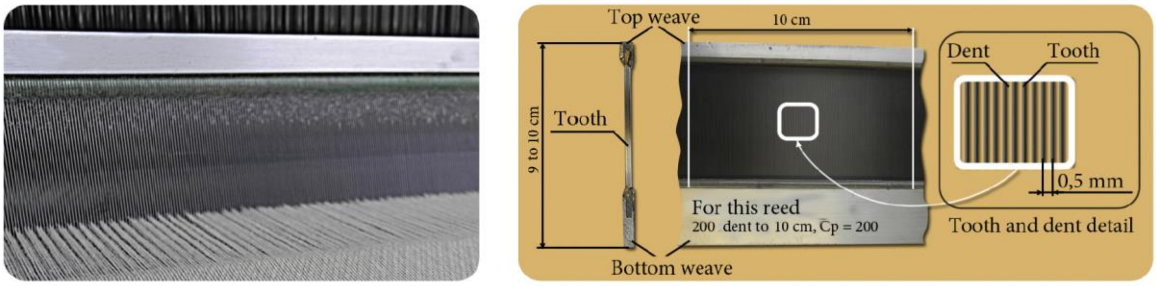


Figure 52: Reed

6 - Beat-up bar and temples

The function of the beat-up bar is to fix the fabric to the frame, especially in the vertical direction. Therefore, fabric is usually folded downwards on the bar, thus creating a component of forces that push the fabric toward the bar even if there is the unbalance of forces in the warp threads caused by the higher number of shaft in the upper position (see Chapter 4.6.3).

Temples are inserted in the beat-up bar on the left and right sides of the machine. The main function of the temples is to generate force reactions against tensile forces *U* in the weaving plane (see Chapter 3.7) and guide the fabric in the reed width so that all warp threads pass through the forming zone (space between the heddles and the beat-up bar) in parallel. If the temples are set incorrectly, the selvedge threads of the warp pass through the forming zone at an angle and the motion of the reed causes their abrasion and increased breakage rate.

The temple consists of a roller, which is composed of pinned and smooth rings. The pins of the temple are pushed into the fabric, thus generating a force coupling between the temple and the fabric. The desired reed width of fabric can be then adjusted in the forming zone by moving the temples. In the case of delicate materials (e.g. fine multi-filaments), pinned rings are replaced by a serrated roller and in this case, force coupling is formed by friction forces between the serrated dents of the temple and the fabric. In some cases, the so-called “full-width temples” are used.

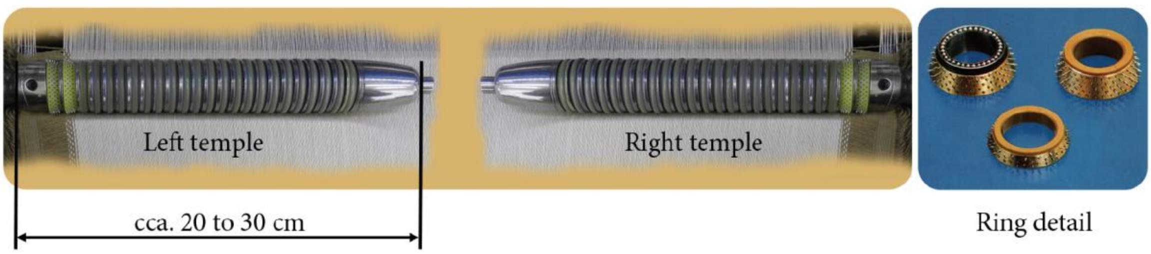


Figure 53: Temples

7 and 8 - Fabric take-up and cloth winding

The fabric take-up system is composed of a feed roller, a sand roller and a pressure roller. The arrangement must ensure a slip-free contact between the fabric and the sand roller, and fabric take-up at a constant velocity so as to ensure the required number of weft threads per unit length. The fabric produced is then wound on the cloth beam. This issue is described in more detail in Chapters 4.3 and 4.3.2.

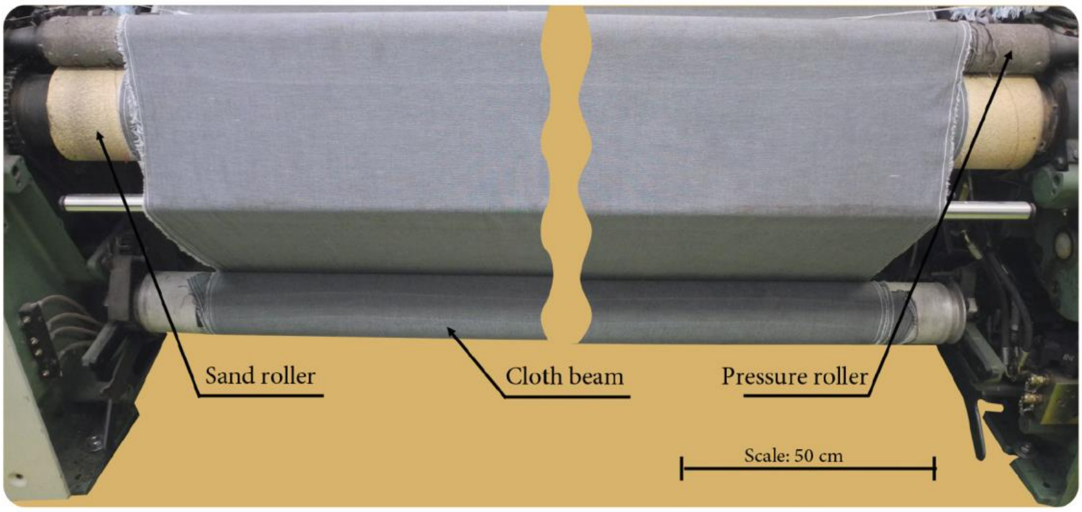


Figure 54: Fabric take-up and cloth beam

B - Weft carrier

Only shuttleless weaving machines (see Chapter 2.2.5) are currently used in industrial practice. The cone with weft package is located on the left side of the machine. The weft thread is unwound therefrom using an unwinder. The weft is then inserted, in a particular, manner, into the shed and cut off after interlacing. The individual methods of weft insertion used on current weaving machines are described in detail in Chapter 4.5.

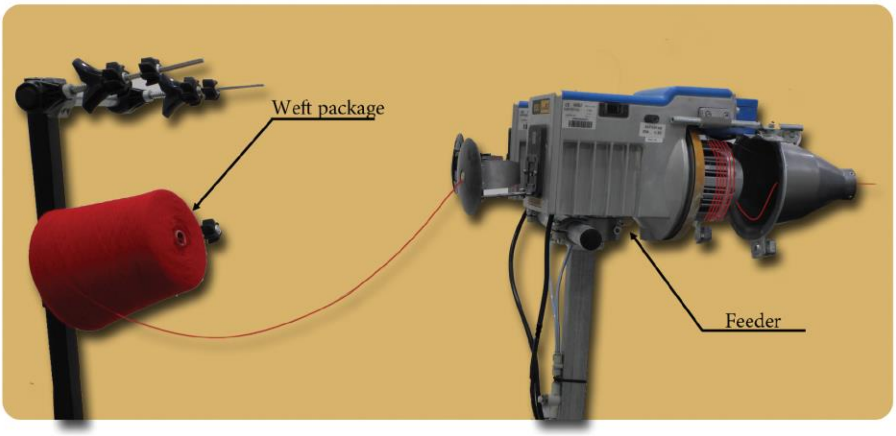


Figure 55: Cone with weft package and feeder

4.1.1 Weaving cycle and interdependencies between individual fabric production steps

Chapter 2.2.4 describes the principle of producing fabric on a hand loom. This principle is also used by current weaving machines. From this perspective, **weaving is a discontinuous process, which involves cyclic repetition of the following phases: opening the shed, weft insertion, and weft beat-up with simultaneous closing of the shed**. **Simultaneously, the warp is fed and the fabric is taken up in a continuous manner.**

The current industrially used weaving machines are, of course, mechanical machine (see Chapter 2.2.5), i.e. the energy required for their operation and implementation of the individual phases of the weaving cycle is not supplied by the operator (weaver) as in the hand looms, but a certain type of drive (see Chapter 4.2) is used. For hand looms, correct continuity of the individual phases of fabric production is ensured by the operator. The weaver first opens the shed, then inserts the weft and subsequently completes the weaving cycle by beating up the weft while closing the shed. Therefore, the mechanical weaving machines must replace human operators for hand looms not only in the area of energy supply but also in the area of controlling the operation of mechanisms for implementing the steps of fabric production so as to ensure their correct continuity. The methods of controlling the operation of current weaving machines are addressed in more detail in Chapter 4.8. The continuity of basic steps of fabric production during the weaving cycle is described here.

The beginning of the weaving cycle on all current types of weaving machines is defined by the position of the reed in front dead centre, i.e. the position in which the reed is closest to the beat-up bar. This position is referred to as 0°. Then, **the weaving cycle can be defined as a sequence of fabric production steps implemented within one period**, i.e. from 0° to 360°. The number of cycles completed per minute is referred to as the **speed of weaving machine** *n (rpm)* and the number of cycles completed per second is referred to as the **weaving frequency** f_T *(Hz) = n / 60*. The **angular velocity** of weaving machine is then determined as follows: ω *(rad/s)* $= 2.\ \pi.\ f_T$.

Figure 56 shows the basic diagram of a weaving machine during the individual phases of fabric production. Start from the position of 0°. In the first phase, it is necessary to slide the shafts to open the shed and to move the reed to back dead centre. Once a sufficient height of the shed is created as to accommodate the weft carrier, it is possible to initiate the phase of weft insertion. After completion of the phase of weft insertion, the weft is beaten up while closing the shed. When the shafts are in the same plane (the so-called “line of shafts”), the weft is interlaced with the warp. The position of the line of shafts can be adjusted in relation to the position of the reed. According to the parameters of the fabric produced, the position of the line of shafts is empirically chosen in the range of 320° to 350°. The values in this range ensure sufficient interlacing of the weft in the warp so as to minimise reverse motion of the weft woven in along the warp threads in the next cycle of motion of the reed from the position of 0° to back dead centre.

The graphs shown in Figure 57 represent the dependence of the position of the reed *Z*, shaft lifting *H1*, *H2* and the idealised (mean) velocity of weft carrier *V* on the angle during two weaving cycles, i.e. during two periods. Lifting of the reed Z determines its path in the weaving plane so that the zero value corresponds to the position of the reed in front dead centre and the position *Z* increases when the reed moves towards the back dead centre. The graph of lifting the individual shafts *H1* and *H2* indicates the height of shaft lifting above the weaving plane. The zero value corresponds to the position of the shaft in the weaving plane. Then, the positive values and the negative values determine the position of the shaft above and below the weaving plane, respectively. The graph of weft insertion velocity *V* is replaced by an idealised waveform, which corresponds to the mean velocity of the weft being inserted into the shed. In fact, the weft velocity depends on the picking mechanism used (see Chapter 4.5). The weft velocity during insertion is not constant. More advanced methods of mechanics should be applied to the investigation of the real velocity of the carrier or the weft and, therefore, this issue is addresses by the theory of weaving.

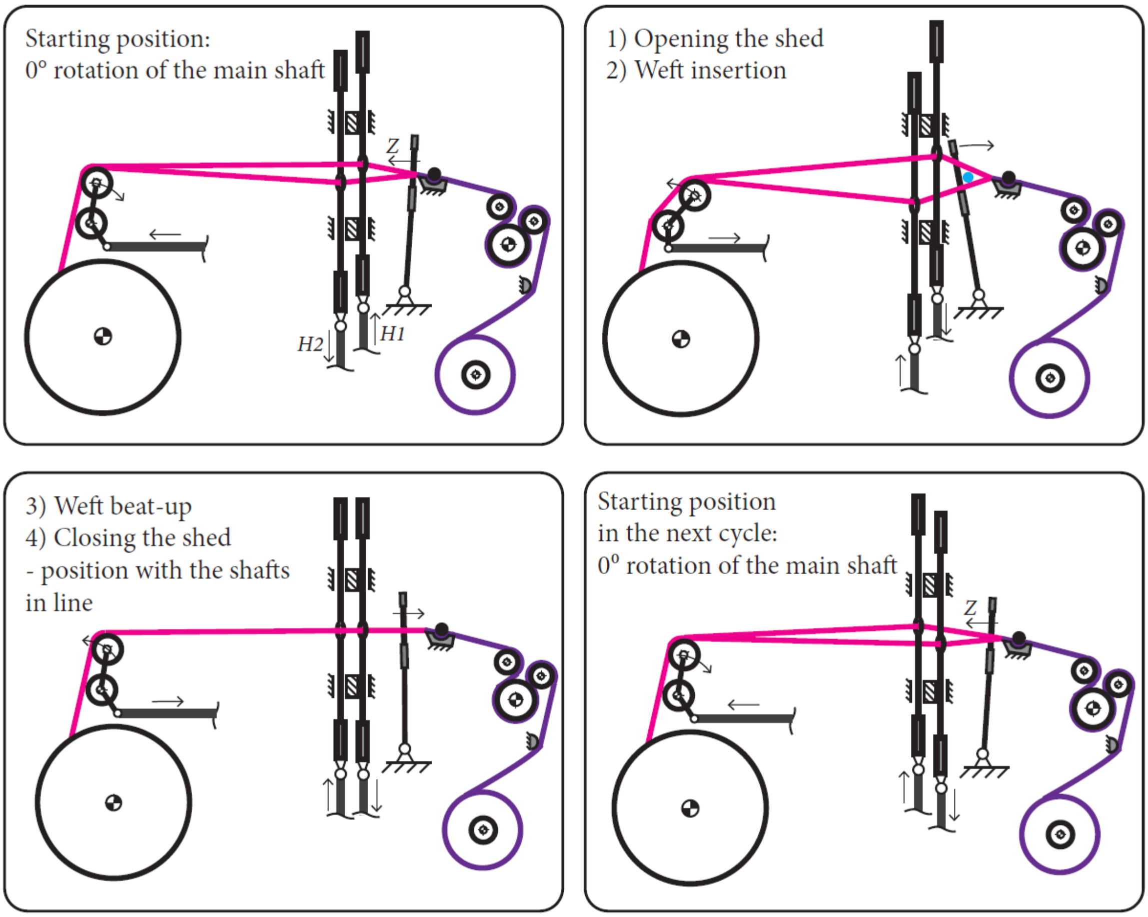


Figure 56: Phase of fabric production on the weaving machine

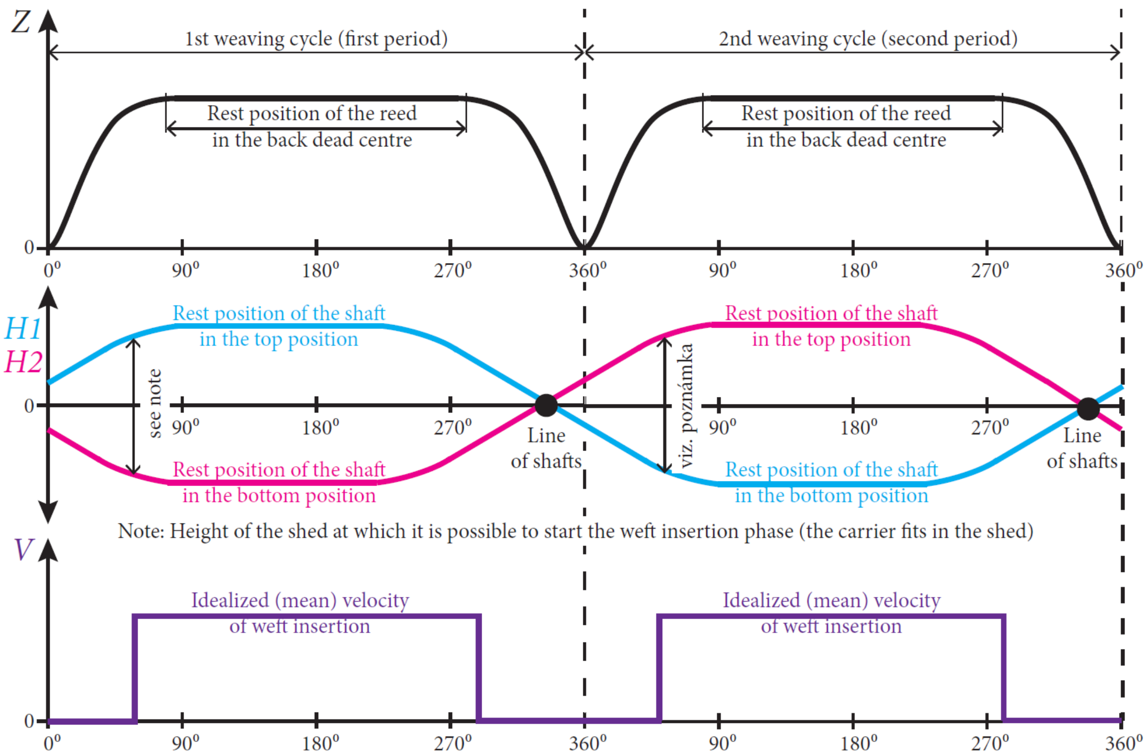


Figure 57: Dependence of reed position, shafts and carrier velocity on the angle during the two periods

The graph in Figure 57 shows that the action of the mechanisms for beating up a inserting the weft repeats cyclically with a period of one weaving cycle. The period of shaft lifting curve is generally determined by the pattern repeat in the weft. The shaft lifting curve plotted in the above graph corresponds to the production of plain weave fabric, having two wefts in the pattern repeat. Therefore, the shaft lifting curve is repeated with a period of two weaving cycles.

Important findings of the chapter:

1) We can draw a basic diagram of the weaving machine.
2) We know the functions of the individual parts of the weaving machine depicted in the basic diagram.
3) We know the definition of the term “weaving” as a cyclic process and the definition of the weaving cycle.
4) We understand the continuity of the phases of fabric production within the weaving cycle.
5) We know the definition of the terms “speed of weaving machine”, “weaving frequency” and “angular velocity of weaving machine”.

4.2 Drive

The drive train of the weaving machines provides a number of important functions. At the turn of the Millennium, this element has undergone a quite interesting development and there are currently drives, which are able to provide the following functions:

1) Power supply to drive the machine:

The drive provides power supply in the form of torque M at the given angular velocity ω, i.e. sufficient power $P = M \,.\, \omega$ needed to drive the machine.

In terms of drive, the weaving machine is the load with certain torque-speed characteristics M_Z. The drive must generate the sufficient torque M at the required angular velocity ω to ensure balance between the torque of the drive and the torque of the load $M = M_Z$ at any time. The torque-speed characteristic of the load (machine) is a relatively complicated non-linear function of angular velocity ω and its expression requires application of more advanced methods from the field of mechanics.

2) Synchronisation of the operations of individual machine mechanisms

As already stated in Chapter 2.2.4, synchronisation of the operations of individual mechanisms of the weaving machine is one of the basic functions of the drive. The means for ensuring this function are discussed in more detail in Chapter 4.2.1.

3) Ensuring the necessary characteristics during start-up and stop of the machine

The drive allows the weaving machine to be started and stopped. The signal to start the machine is usually generated by the operator. Machine start-up causes a transient process to take place, in which there is an increase in the angular velocity from zero to the value given by the desired speed $\omega_S = 2.\,\pi.\,(n\,/\,60)$. The angular velocity-time dependence is called the starting characteristic.

The stop signal is generated by the operator or the warp or weft stop motion. The angular velocity is then reduced to zero. The angular velocity-time dependence during stop of the weaving machine is called the stopping characteristic. For technological reasons, it is necessary to ensure that the machine is stopped (reduction of the angular velocity to zero) in the shortest period of time.

Figure 58 represents the time dependence of the angular velocity during startup, steady state operation and stop. The figure shows also the variation in the angular velocity $\Delta\omega$ in steady state operation. Implementation of the weaving process requires minimal variation in the angular velocity of the weaving machine.

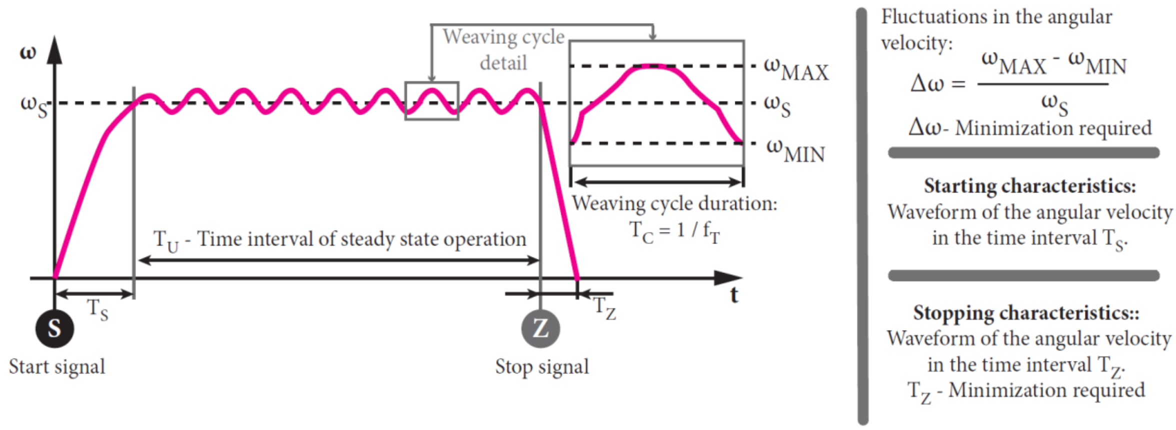


Figure 58: Angular velocity-time dependence: starting and stopping characteristics

4) Setting up the desired machine speed

In normal technological operation (for the given weaving machine), the maximum weaving frequency f_T, i.e. speed $n = 60 \cdot f_T$, is mainly limited by the parameters and quality of the textile material (warp and weft threads). The value of speed is chosen empirically based on operator's experience with that machine and textile material so as to ensure smooth operation with the minimum number of breaks of warp and weft threads. The drives make it possible to set the desired speed in different ways (see Chapter 4.2.1).

5) Ensuring slow running, positioning and reverse running of the machine

In some cases, it is necessary to operate the weaving machine in the so-called "slow running conditions", i.e. with substantially reduced speed. The operator can activate the slow running manually and in this mode, set the weaving machine to the desired position. When fixing warp breaks, it is the position with the shafts in line and when fixing incorrectly inserted weft, it is the position with the reed in back dead centre. The positioning process is started automatically on the current machines. When the warp stop motion sends the pulse to stop the machine, the weaving machine in slow running is set to the position with the shafts in line. When the pulse is sent by the weft stop motion, the weaving machine is set to the position with the reed in back dead centre.

The reverse running of the weaving machine (reversing) is necessary when removing an incorrectly woven-in weft (unweaving). In this case, the weaving machine makes one reverse revolution in slow running so as to release the incorrectly woven-in weft. The weft can then be removed from the shed manually or the automatic weft removal device is activated (see Chapter 4.9). Consequently, it is necessary, before restarting at the standard speed, to reverse the machine into the position before the start of picking.

6) Automatic change of speed with the machine in operation

The weaving machines equipped with the central drive by means of the computer-controlled servomotor (see Chapter 4.2.1) or the weaving machines equipped with the derives with higher levels of development generally allow the automatic changes of speed to be implemented with the machine in operation. In technological practice, this property might be used for various purposes (see Chapter 4.2.2).

7) Programmable course of angular velocity within a weaving cycle

Using motors with programmable angular velocity (motors of "electronic cam" type) for driving the individual mechanisms of the weaving machine (see Chapter 4.2.1) brings the advantages of a flexible modification of the lifting dependences of operating members of the individual mechanisms and their adaptation to the requirements of the weaving process (see Chapter 4.2.2).

4.2.1 Means for driving machines and developments in this area

Let's get familiar with the means that were used within the drive of the weaving machines at the turn of the Millennium. From the 1970s until today, the development of drives took place in order to ensure the above functions so as to extend the service life of weaving machines, reduce the consumption of spare parts and operating costs and ensure flexibility (easy adaptation of the production of fabrics of various parameters) with high operator comfort, the minimum proportion of manual work and high performance of the weaving machines. This chapter includes definitions and descriptions of the individual development stages of drive based on the means used and changes in the overall structure of the machine and the structure of individual mechanisms. To facilitate the description of individual developmental stages, the following terms are defined:

- **Main mechanisms:** mechanisms that implement the phases of fabric production (beat-up, shedding, picking) and the energy for their operation is supplied through the drive of the weaving machine.
- **Subsystems:** self-driven and self-controlled mechanisms, which are synchronised with the drive of the main mechanisms by electronic means. In addition to the controllers and unwinders or feeders in the development stage B described hereinafter, it is necessary to regard the picking mechanism of the air-jet weaving machines as a subsystem (see Chapter 4.5.2).
- **Main shaft:** A name for the shaft of the weaving machine, during the revolution of which the weaving cycle is implemented. It is usually the crankshaft or the shaft with cams to produce oscillating motion of the reed.
- **Central drive:** A name for such a drive arrangement, in which the energy required for operation of several main mechanisms is supplied by a single motor.
- **Individual (distributed) drive:** A name for such a drive arrangement, in which the energy required for operation of the individual main mechanisms is supplied by independent motors, which are integrated within these mechanisms.

Using the above defined terms, the development stages of the drive of the weaving machines in a given period of time may be divided into five categories:

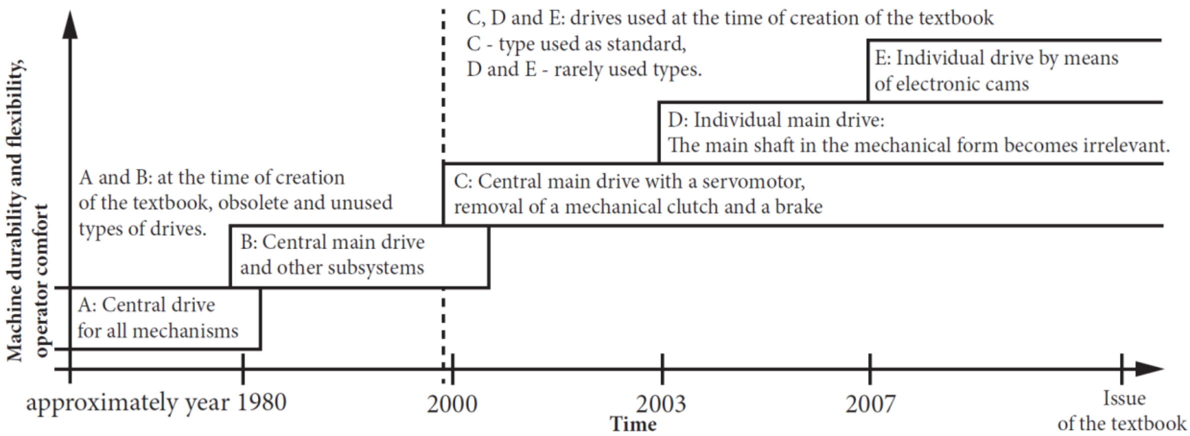


Figure 59: Development stages of drives at the turn of the Millennium

A. Central drive of machines with mechanical synchronisation and relay control,
B. Central main drive controlled by a programmable logic controller (PLC) and communication with other subsystems,
C. Central main drive with a servomotor controlled by a computer and communication with other subsystems,
D. Individual main drive controlled by a computer and communication with other subsystems,
E. Individual drive with programmable angular velocity at an interval of the weaving cycle (electronic cam) controlled by a computer and communication with other subsystems.

As for A) Central drive of machines with mechanical synchronisation and relay control

Structure: All mechanisms are driven by means of a single motor (**three-phase asynchronous motor**), which drives a **main shaft** through a mechanical (multi-plate) clutch with an integrated brake and the other mechanisms of weaving machine are driven by the main shaft by means of a **mechanical transmission system**. Starting the machine is performed by engaging the clutch. If the signal to stop the machine is sent, the clutch is disengaged and the brake is put into operation. In some cases, independent auxiliary motors are used to ensure slow and reverse running, which are not synchronised with the master motor.

Synchronisation: For synchronisation of the operation of individual mechanisms, mechanical means in the form of the following elements are solely used: transmission (belt, gear wheels), clutches, brakes, CVT, cams, mechanical reversing means, etc.

Control: The operation of the weaving machines is controlled by relay logic, which uses the switches and is thus able to work with only two states: 1 and 0 (ON and OFF). In this way, it is possible to generate, for example, a signal to start the machine by pressing the button (signal generated by operator) or stop the machine by means of warp and weft stop motion, or button.

Function: This type of drive is able to perform the above functions on a limited basis. Without operator intervention, only basic functions 1 and 3 are ensured. Functions 2, 4 and 5 are feasible only with a manual intervention of operator and functions 6 and 7 on weaving machines with this type of drive are not feasible.

Technical operational characteristics: Disadvantages of this outdated type of drive result from the relatively large moment of inertia of the weaving machine. In operation, there are fluctuations in angular velocity, oscillations and vibrations, which causes wear on the mechanical parts. This fact is reflected in increased consumption of spare parts and a large proportion of manual work in the adjustment and operation of the machine.

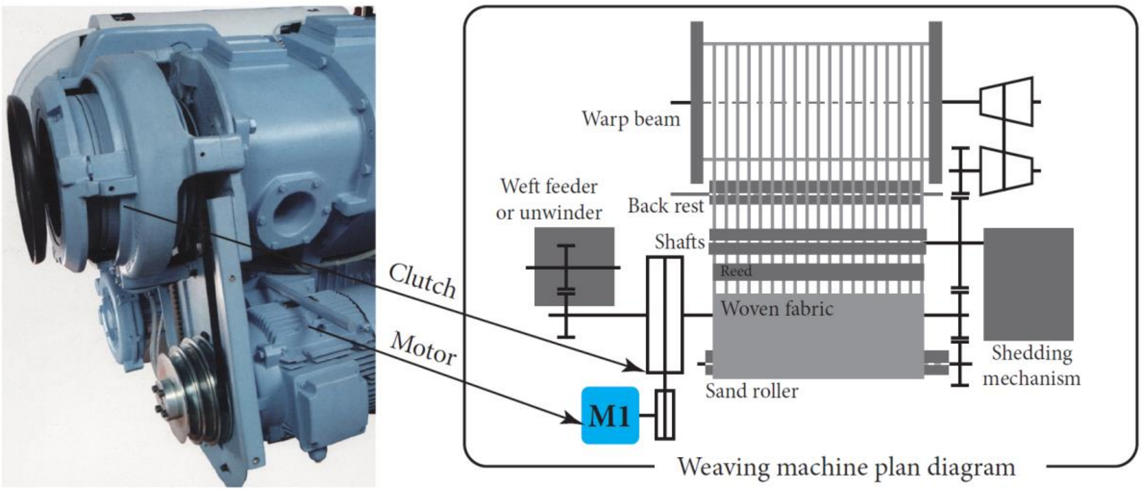


Figure 60: Structure of the drive type A, photographs of the motor and the mechanical clutch on the main shaft (source [14])

as for B) Central main drive controlled by a programmable logic controller (PLC) and communication with other subsystems

Structure: The main **three-phase asynchronous motor with frequency converter** is used for driving only the main mechanisms of weaving machine. On the weaving machine, there are **self-driven and self-controlled subsystems**: warp and cloth controller, weft unwinder or feeder and in some cases, picking mechanism. The drive still includes the **main shaft with a mechanical clutch and a brake** and independent motors are used to ensure service running **(**slow and reverse running).

Synchronisation: Synchronisation of the operation of main mechanisms (beat-up, shedding or picking mechanism or back rest) is ensured by mechanical means. Where synchronisation with the other subsystems (e.g. weft feeder or picking mechanism) is required, it is implemented by a binary electronic signal, which is able to take values 1 and 0, i.e. ensure two states of the subsystem: run - stop.

Control: The weaving machine is controlled by means of a programmable logic controller (PLC), which controls the operation of mechanisms by the rotation angle of the main shaft. The rotation angle of the main shaft is detected in the Gray code or by means of an incremental (IRC) sensor.

Function: Operator comfort is improved when adjusting speed of the weaving machine, which can be realized by entering the desired values through the PLC. The quality of the weaving process is also improved by using controllers (see Chapter 4.3) and unwinders or feeders (see Chapter 4.5) in the form of independent subsystems. But functions 5-7 are not feasible even with this type of drive.

Technical operational characteristics: Compared to the machines equipped with the drive type “A”, dynamic properties do not change much and, therefore, the problems related to wear and spare parts remain.

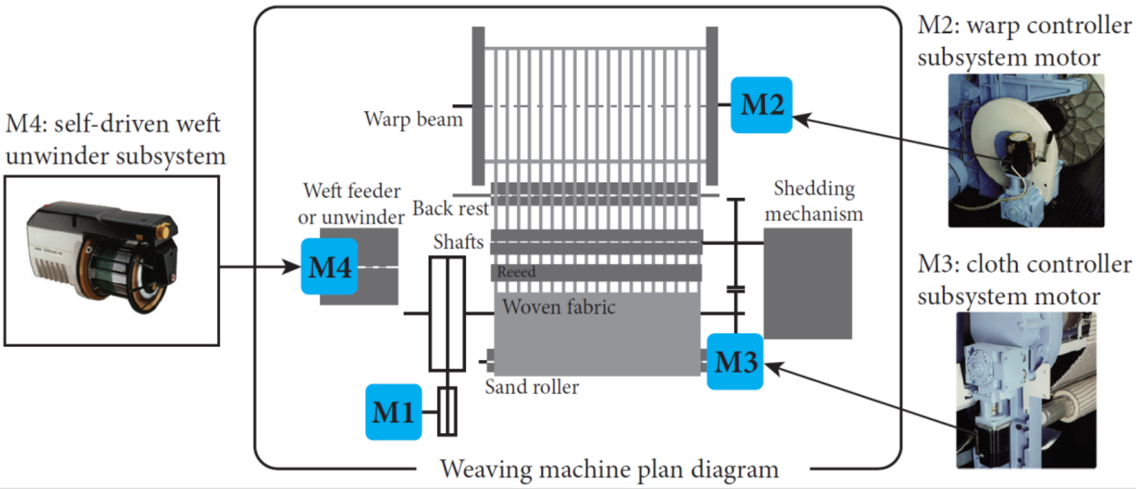


Figure 61: Structure of drive type B, subsystem photographs (source [18], [33])

As for C) Central main drive with a servomotor controlled by a computer and communication with other subsystems

Structure: In this case, the **main shaft is driven directly** (without a mechanical clutch and a brake) **by means of a variable speed servomotor**. Therefore, this drive is regarded as a “direct drive” by weaving machine manufacturers. The drive concept for other subsystems remains identical with the drive type B. Starting and stopping the weaving machine are executed by an electronic speed control of the servomotor. Therefore, it is possible to control starting and stopping characteristics electronically or implement automatic speed variation in steady state operation of the machine.

Synchronisation: In this case, synchronisation of the operation of main mechanisms is ensured by mechanical means as with the drive type B. Synchronisation with the subsystems is ensured via an industrial serial communication bus (CANBUS, PROFIBUS).

Control: The weaving machine is controlled by a computer with terminal and peripherals. The signal sent by the IRC sensor serves as the control signal, which detects the rotation angle of the main shaft. As mentioned above, communication with the subsystems is implemented via an industrial serial communication bus.

Function: This type of drive is capable of fulfilling all the above functions except function 7. The comfort and the degree of automation depend on the installed means and are not limited. The dynamic properties result from the performance and characteristics of the servomotor.

Technical operational characteristics: The problems related to wear of mechanical parts and maintenance of the machine are reduced. The dynamic properties of the machine are improved particularly in the non-stationary modes during start-up and stop.

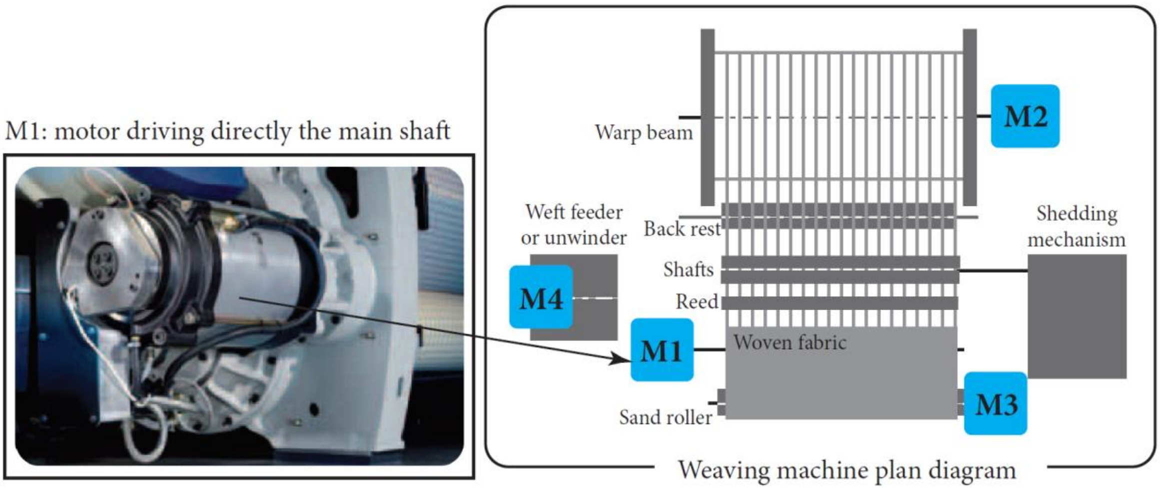


Figure 62: Structure of the drive type C, photographs of the motor for direct drive of the main shaft (source [16])

As for D) Individual main drive controlled by a computer and communication with other subsystems

Structure: Compared to the previous types of drives, there is a radical change in the structure of the weaving machine. The main shaft becomes irrelevant. **The main mechanisms (beat-up and shedding) are driven by independent motors.** The beat-up mechanism motor acts as the master motor and its rotation angle is used to synchronise the operation of other mechanisms during the weaving cycle. Therefore, the shedding mechanism motor is regulated in a cascade (master - slave), or the two motors are regulated from a single “virtual” timeline. In case of using a cascade (less sophisticated method of regulation with looser parameters), an asynchronous motor with frequency converter can be used as the master motor and the shedding mechanism can be driven by a servomotor. In the case of time control, the beat-up and picking mechanisms are driven by servomotors.

Synchronisation: Synchronisation between the main mechanisms (beat-up, shedding) is implemented via a cascade or electronically controlled regulation. Synchronisation with the subsystems is ensured via an industrial serial communication bus.

Control: An industrial computer is used for the purposes of control, which controls the operation of mechanisms by the rotation angle of motor shaft of the beat-up mechanism. Communication with the subsystems is ensured by an industrial serial communication bus.

Function: The drive is capable of fulfilling all the above functions except function 7.

Technical operational characteristics: The individual, or rather distributed drives of main mechanisms are important for improving the mechanical properties of the weaving machine (not the textile-technological properties), mainly in two aspects:

1. They reduce the reduced moment of inertia of the machine by removing gears, pulleys, belts and clutches.
2. They eliminate the reciprocal excitation of the oscillations and vibrations caused by energy transfer of the individual mechanisms.

Eliminating oscillation has a positive influence on the running of the weaving machine and the quality of the product and will also lead to a reduction in operating costs. Reducing the moment of inertia is positively reflected in non-stationary modes of starting or stopping the weaving machine, but has a negative effect on the fluctuation in the angular velocity in the steady state operation. This disadvantage should be solved by using motors that are capable of minimising the fluctuations in the angular velocity by changing the torque so as to prevent the inertial force from increasing due to the tangential acceleration.

Note: Compared to the previous development stages, the individual drives bring significant benefits. However, their application on the weaving machines can only be implemented using suitable means, which in this case include digitally controlled high output servomotors. At the time of creation of the textbook, an individual drive of the weaving machines is not yet a standard and it can only be seen on the Vera (or Vega) machine from the VÚTS Liberec company, the ONE machine from the SMIT Textile company and the machines of the type P1 or A1 from the Dornier company (see [17]).

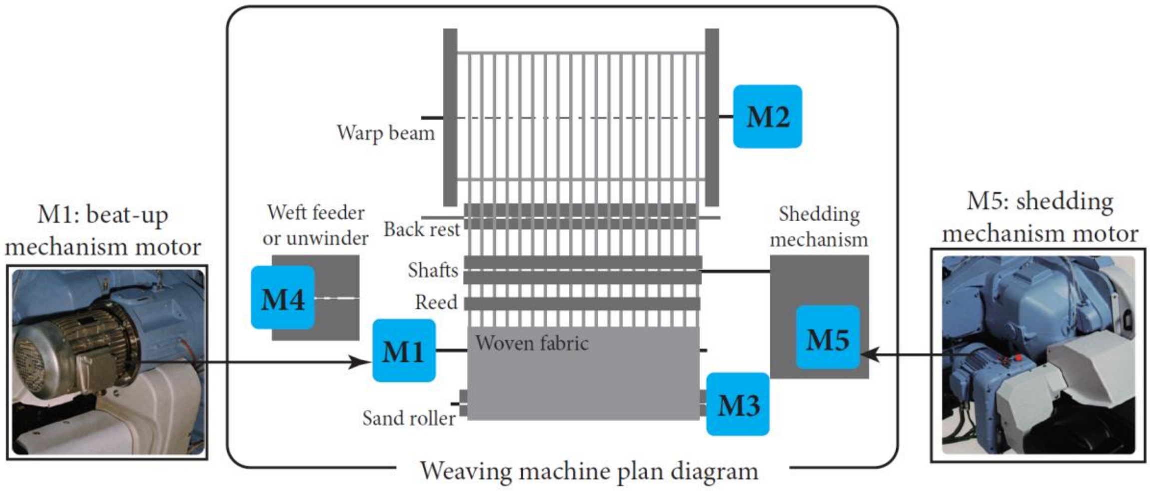


Figure 63: Structure of the drive D, photographs of motors for driving the beat-up and shedding mechanisms (source [18])

As for E) Individual drive with programmable angular velocity at an interval of the weaving cycle (electronic cam) controlled by a computer and communication with other subsystems

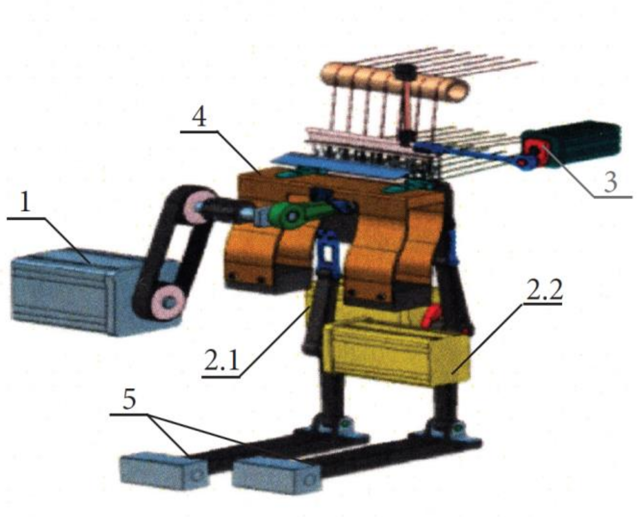
Structure: There is a change in the kinematic structure of the main mechanisms. **The main mechanisms are driven with the use of motors with electronically adjustable angular velocity within the weaving cycle, which are connected to the crank of the four-bar mechanism.** Thus, the motor used is capable of replacing a mechanical cam and, therefore, is referred to as an “electronic cam”. One motor is installed within the beat-up mechanism and several motors should be generally used within the shedding mechanism. The number of shedding mechanism motors depends on the required interlacing capacity of the weaving machine. **The structure of the drive allows a flexible change in the lifting dependencies of working members of the main mechanisms** (reed, shafts).

Synchronisation: Synchronization is solely ensured by electronic means. The main mechanisms are synchronised via computer and communication with the subsystems is again ensured via an industrial serial communication bus.

Control: The industrial computer controls the operation of mechanisms of the weaving machine by the rotation angle of motor shaft of the beat-up mechanism.

Function: This type of drive is able to provide all seven of the above functions.

Note: Designing the desired lifting dependencies of the operating members of mechanisms is based on the assumption that the angular velocity of the crank or the cam shaft is constant. For example, for four-member crank-rocker mechanisms, the behaviour of the lifting functions may only be affected by the ratio between the length of the crank and the connecting rod, and the creation of the rest position of operating members is practically impossible. Therefore, the cam mechanisms are used, which in designing the lifting functions provide considerably wider possibilities and are able to ensure the required rest position of operating members. But the creation of the cam shape according to the desired lifting function and its subsequent manufacture are relatively difficult. In addition, the lifting dependence of operating member of the mechanism already manufactured cannot be modified in any way. Therefore, there is the solution in the form of the motor with electronically adjustable angular velocity (electronic cam), which is mounted on the crank of the four-member mechanism. It is then possible to create the required lifting dependence including rest positions of the operating member using suitable course of the angular velocity of the motor during the weaving cycle. This enables flexible modification of the lifting dependence of the operating member by changing the course of the angular velocity of the motor within the weaving cycle. This change is implemented through a computer, which allows easy modification of the lifting dependence of operating members of the weaving machines (reed and shafts). The individual drive by means of electronic cam extends the benefits of the individual drive (see D) to include the possibility of flexible adaptation of lifting dependencies of the reed and shafts. In technological practice, this property might be used for various purposes (see Chapter 4.2.2). But the application of these drives on the weaving machines is conditioned by using suitable motors with sufficient power. Moreover, the structure of the weaving machine needs to be modified in a certain way and, if applicable, elastic members should be added to it, which are able to accumulate and recover energy. Therefore, this drive is not universally applicable. At the time of creation of the textbook, it was used on one type of the weaving machine: Combine from the VÚTS Liberec company.



Legend:

1 - servomotor for driving the beat-up mechanism
2.1 - servomotor for driving the first shaft
2.2 - servomotor for driving the second shaft

3 - servomotor for driving the rapier bar, i.e. heddles for rotating threads (see note)

4 - slay with recuperating springs
5 - recuperating springs of the shedding mechanism

Figure 64: Drive of the Combine weaving machine (source [19])

Note: The Combine machine is a special weaving machine for production of leno weave fabric or a combination of plain and leno weave fabric. This machine is addressed in more detail in Chapter 6.

4.2.2 Properties of new types of drives usable in technological practice

At the time of creation of the textbook, the drive types A and B represent the already obsolete and unused concept with a number of negative properties, which mainly result from the large number of mechanical parts and a high moment of inertia of the machine. Therefore, this chapter focuses on the properties provided by drive types C, D and E.

At the time of publication of the textbook, the drive type C represents the standard used on most weaving machines. The advantage in the form of electronically adjustable starting and stopping characteristic is especially useful in the construction of weaving machines. During normal operation, removal of the mechanical drive components, i.e. clutch and brake, shows a positive impact. Compared to the older types of drives, the consumption of spare parts and the manual proportion of operator during operation of the weaving machines are reduced. Machine life and operator comfort are improved.

A great benefit to the technological practice is the automatic speed change without stopping the machine. This feature is used in the production of fabrics that contain sections with different design parameters. Speed change can be controlled for example by the mechanism for colour change, a device that is able to weave in wefts with different parameters into fabric (see Chapter 4.5). For individual wefts of the pattern repeat for picked pattern (see Chapter 3.4), speed can be entered in the appropriate computer interface and the individual wefts are then woven in at different speeds so as to minimise their breakage rate while maintaining maximum production rate. Furthermore, it is possible to program speed change depending on the pattern or the pattern repeat of the fabric to be produced. A typical example of the use of this feature is the production of terry towels. When weaving difficult to contract sections, which are represented here by the edge of towel with a high number of weft threads per unit length, the speed is automatically reduced and when weaving sections with loops, the speed is automatically increased to the original value.

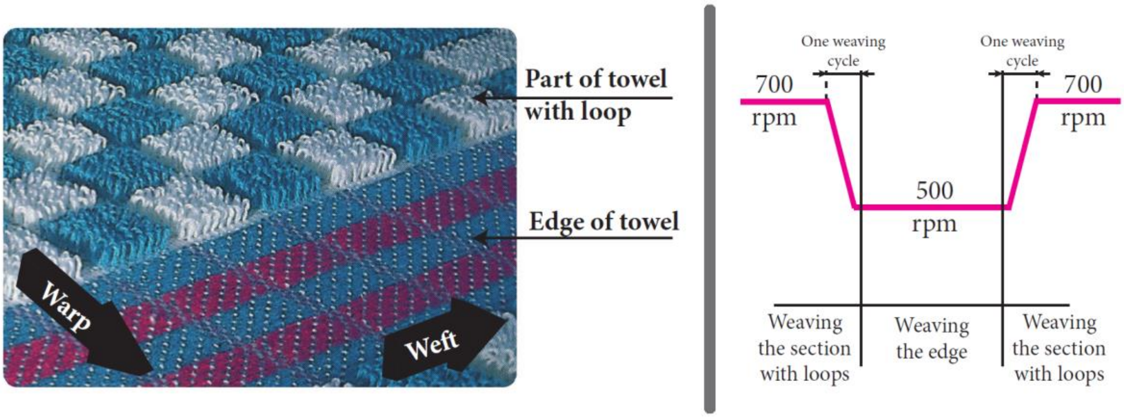


Figure 65: Example of automatic speed change in the production of terry cloth (source [20])

At the time of creation of textbook, the drives of higher development stages (D and E) are not used as widely as the drive type C, but due to their characteristics, their greater application may be expected in the coming years. In addition, the drive type D decreases the moment of inertia of the weaving machine and, in particular, eliminates vibrations by separating the main mechanisms. Therefore, further increase in service life and reduction in the consumption of spare parts and operating costs may be expected for weaving machines with this drive.

In addition to the above benefits, the drive type E provides the possibility of flexibly changing the lifting dependencies of operating members. In the current technological practice, the change in lifting dependence of the reed will probably not be used very often, but **the possibility of changing lifting dependencies of shafts or heddles appears to be very practical and useful**. For example, the above mentioned special weaving machine Combine allows to electronically adjust the period of lifting function of the shafts, thus selecting either combination of leno weave and plain weave, or normal leno weave of the fabric to be produced (see Chapter 6). For the same reason, independent servomotors are used by Japanese manufacturers (Tsudakoma and Toyota companies) for driving the individual shafts on their weaving machines. In this case, these are the machines for the production of fabrics in standard weaves and the use of servomotors facilitates weave change of the fabric to be produced even in this case. These mechanisms are addressed in more detail in Chapter 4.4.4.

Table of functions provided by individual types of drives:

	Drive A	Drive B	Drive C	Drive D	Drive E
Function 1	YES	YES	YES	YES	YES
Function 2	OBS	YES	YES	YES	YES
Function 3	YES	YES	YES	YES	YES
Function 4	OBS	YES	YES	YES	YES
Function 5	OBS	YES	YES	YES	YES
Function 6	NO	NO	YES	YES	YES
Function 7	NO	NO	NO	NO	YES

Explanatory notes: If the function is performed automatically or via a computer without manual operator intervention, the cell indicates YES, if the function is feasible only with manual operator intervention, the cell indicates OBS and if the function is not feasible, the cell indicates NO.

Important findings of the chapter:

1) We know all the functions that can be provided by drives of current weaving machines.
2) We know what are the starting and stopping characteristics.
3) We know the technical means that are used in the drives.
4) We can describe developments and trends in drives at the turn of the Millennium.
5) We know how the properties of the drives are used in technological practice.

4.3 Warp feed, fabric take-up and winding

Unwinding of the warp and fabric take-up determine the important parameters of the weaving process (pretension, i.e. the required tensile force in the warp during weaving) and the final product (the number of weft threads per unit length of fabric).

Different means have been used in ensuring the above functions in the past. By 1980, the following mechanical means were primarily used: transmission, CVT, clutches and ratchet mechanisms (see Chapter 4.2 - drive type A). These mechanisms are described in detail in previously published literature (see [1], [3] and [21]) . This textbook describes warp unwinding and fabric take-up mechanisms as independent self-driven and self-controlled subsystems (see Chapter 4.2 - drive types B, C, D and E). This concept is applied more significantly after 1980 and is currently the standard on all weaving machines.

On the weaving machines, feed (unwinding) of the warp is ensured by an independent warp controller subsystem, which regulates tensile force in the warp and in fabric Q through the angular velocity of the warp beam ω_V, i.e. the velocity of warp feed to the weaving plane $v_O = \omega_V \cdot r_V$, where r_V is the radius of warp package on the warp beam. The tensile force in the warp and in fabric Q represents the so-called "controlled quantity" and the angular velocity of the warp beam ω_V is the "manipulated variable" (see [22]). **Therefore, the warp controller provides the desired tensile force in the warp during weaving** (for more details see Chapter 4.3.1).

Fabric take-up is ensured by the controlled drive for sand roller, which is known as the "cloth take-up motion" in the technological practice. However, this is not the controller with feedback to the regulated system but the regulated drive with an internal feedback, which takes up the fabric at a constant velocity v_T. The take-up velocity determines the number of weft threads per unit length of fabric. **The controlled drive for sand roller thus ensures the desired number of weft threads per unit length** (for more details see Chapter 4.3.2).

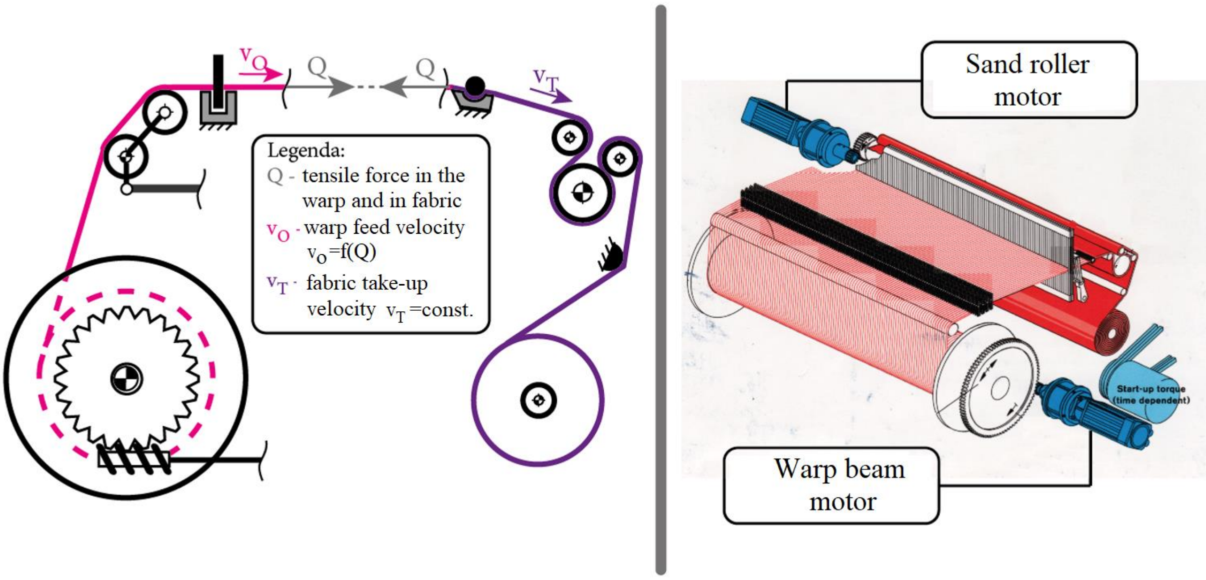


Figure 66: Warp unwinding and fabric take-up

The warp is fed to the weaving plane in time at a variable velocity $v_o(t)$ and the fabric is taken up at a constant velocity $v_T = const$. The warp beam is driven by the servomotor with electronically adjustable speed, which is part of the feedback circuit. The sand roller is also driven by the servomotor with electronically adjustable speed, which allows to set the desired number of weft threads per unit length.

4.3.1 Warp controller

As previously mentioned, the warp controller regulates the tensile force in the warp and in fabric *Q* through the manipulated variable represented by the angular velocity of the warp beam ω_V. If we use the symbol Q_P to denote the tensile force at the identical velocities of fabric take-up v_T and warp feed v_O ($v_T = v_O$) and the symbol *C* to denote the stiffness of the warp-fabric system, we can express the time dependence of the force *Q* as follows:

$$Q(t) = Q_P + C.\int[v_T - v_O(t)].dt,$$

where Q_P is the tensile force at the identical fabric take-up and warp feed velocities, *C* is the stiffness of the warp-fabric system, v_T is the fabric take-up velocity, v_O is the warp feed velocity and *t* is the time.

The warp feed velocity $v_O(t)$ can be determined as the product of the angular velocity of the warp beam $\omega_V(t)$ and the radius of warp package on the warp beam $r_V(t)$, i.e.: $v_O(t) = \omega_V(t) . r_V(t)$. The equation will be obtained by substituting into the above relation, which defines the relationship between the controlled variable (tensile force in the warp and in fabric *Q*) and the manipulated variable (angular velocity of the warp beam ω_V).

$$Q(t) = Q_P + C.\int[v_T - r_V(t).\omega(t)].dt,$$

where ω_V is the angular velocity of the warp beam and r_V is the radius of package on the warp beam.

The controlled variable, i.e. the tensile force *Q*, can be detected, for example, using a strain gauge (see [23]). The strain gauge is basically a conductor with suitable properties (with low temperature coefficient of resistance), whose electrical resistance *R* is the function of length *l*, cross-section *S* and specific resistance *ρ*: $R = f(\rho, l, S)$. Where the strain gauge is attached to the component, which is deformed as a result of application of the force *Q*, its resistance *R* changes. The strain gauge can be connected to the electrical circuit and the electric voltage *U* in this circuit then changes by Ohm's law: $U = R . I$. Therefore, the voltage *U* is proportional to the applied force *Q*. For measuring tensile forces in the warp, it is possible to use the so-called "three-pin sensor" (see Figure 116). The strain gauge is mounted on the central pin and the warp threads are guided by the sensor so as to create a certain angle of wrapping on this pin. As a result of application of the tensile force in the warp *Q*, the central pin is bent and the strain gauge is deformed. With the change in its electrical resistance *R* the voltage *U* changes in its circuit and this voltage is proportional to the tensile force in the warp *Q*.

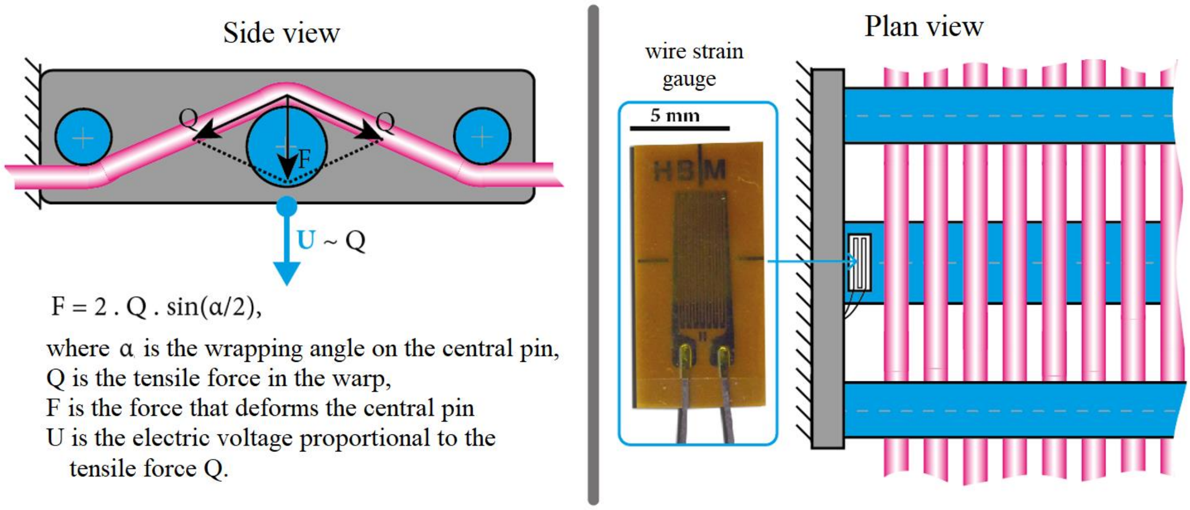


Figure 67: Strain gauge of the tensile force in the warp

The tensile force in the warp Q is detected only in a specific position of the weaving machine (for example, position with the shafts in line) or changes are filtered out of the voltage signal U with the frequency close to or higher than the weaving frequency. Thus processed signal U is applied to the comparator term of the warp controller (see Figure 117). Another input to the comparator term is the signal U_P, whose value corresponds to the desired tensile force in the warp Q_P. The desired tensile force in the warp Q_P is entered by the operator using the computer keyboard. The comparator term generates the control deviation ΔU as the difference of the two input signals:

$$\Delta U(t) = U(t) - U_P,$$

where ΔU is the control deviation, U is the signal proportional to the tensile force Q and U_P is the signal, which corresponds to the desired tensile force Q_P.

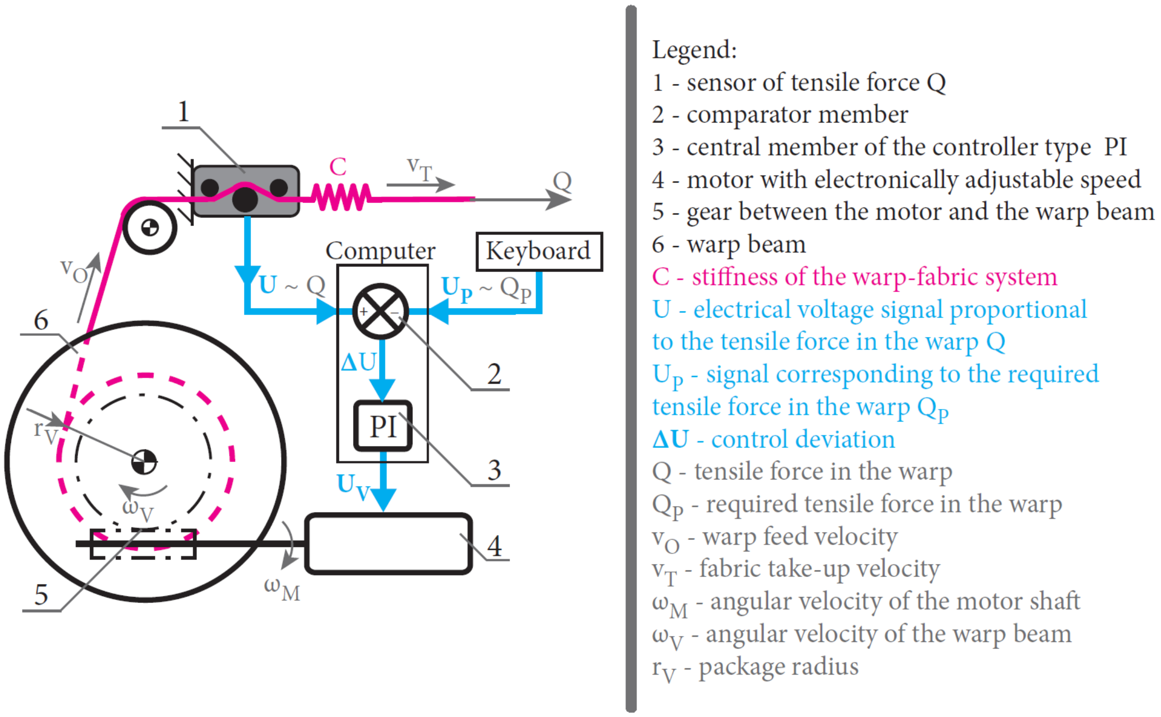


Figure 68: Diagram of the feedback circuit of the warp controller

The control deviation ΔU is processed by the controlling element, which is usually the type *PI*. The proportional component *P* of the controlling element provides sufficient amplification of the control deviation by multiplying this deviation by the constant K_P:

$$\Delta U_P(t) = K_P . \Delta U(t),$$

where ΔU_P is the proportional component of the output signal of the controlling element, K_P is the constant of proportionality and ΔU is the control deviation.

The integral component *I* integrates the control deviation in time and multiplies it by the constant of integration K_I:

$$\Delta U_I(t) = K_I . \int \Delta U(t) . dt,$$

where ΔU_I is the integral component of the output signal of the controlling element and K_I is the constant of integration.

The integral component is a matter of key importance in compensating for changes in the radius of warp package on the warp beam during the weaving process, which is explained in greater detail below.

The output signal of the controlling element U_V is determined by the sum of the proportional ΔU_P and integral ΔU_I terms, i.e.:

$$U_V(t) = \Delta U_P(t) + \Delta U_I(t) = K_P.\Delta U(t) + K_I.\int \Delta U(t).dt,$$

where the constant of proportionality K_P and the constant of integration K_I represent the adjustable parameters of the feedback control circuit. With the use of advanced methods in cyber area (see [22]), their values can be optimised according to the specific requirements.

The output signal of the controlling element U_V controls the angular velocity ω_M of the motor:

$$\omega_M(t) = k.U_V(t),$$

where ω_M is the angular velocity of the motor, k is the constant of the motor and U_V is the output signal of the controlling element.

Through the self-locking gear, the motor drives the warp beam, thus determining its angular velocity ω_V:

$$\omega_V(t) = \mu.\omega_M(t),$$

where ω_V is the angular velocity of the warp beam, μ is the gear ratio between the motor and the warp beam, ω_M is the angular velocity of the motor.

The feedback circuit of the warp controller works as follows: If, for example, there is an increase in the tensile force Q above the required value Q_P, the control deviation ΔU as well as the value of output signal of the controlling element U_V increase also, causing an increase in the angular velocity of the motor ω_M and the warp beam ω_V. This results in an increase in the warp feed velocity $v_O = \omega_V . r_V$ and longer section of the warp is fed to the weaving plane at a given time interval. Feeding longer section of the warp will result in decrease in the tensile force Q, reduction in the control deviation ΔU as well as the output signal of the controlling element U_V, indicated by reduction in the angular velocity of the warp beam ω_V and the warp feed velocity v_O will drop.

Compensation for reduction in the radius of package on the warp beam

During the weaving process, the radius of warp package r_V on the warp beam is reduced. In case that reduction in the package radius is not compensated in any way, according to the equation

$$Q(t) = Q_P + C.\int [v_T - r_V(t).\omega(t)].dt$$

the tensile force Q increases with the gradual emptying of the warp beam, which is inadmissible in technological practice.

As already mentioned above, appropriate compensation can be ensured by means of an integral component of the controlling:

$$\Delta U_I(t) = K_I.\int \Delta U(t)\,.dt.$$

during decrease in the package radius r_V, this component gradually integrates (sums up) the control deviations and increases the output signal of the controlling element U_V with the increasing time:

$$U_V(t) = K_P\,.\,\Delta U(t) + \underbrace{K_I\,.\int\Delta U(t).dt}_{\substack{\text{component increasing} \\ \text{with decreasing package radius}}},$$

this also causes a gradual increase in the manipulated variable in the form of the angular velocity of the warp beam.

$$\omega_V(t) = \mu \,.\, k \,.\, U_V(t)\,,$$

It means that the angular velocity of the warp beam ω_V increases with the decreasing radius of package r_V.

Therefore, it can be ensured that with decreasing radius of package r$_V$, there is a corresponding increase in the manipulated variable ω_V so that the tensile force Q is the same at any radius r$_V$, i.e. at appropriate setting of the constants of proportionality and integration, the warp controller is capable of ensuring the required tensile force during unwinding of the entire length of the warp from the warp beam.

In conclusion of the description of the feedback circuit of warp controller, it should be noted that the controller must respond to the so-called “failure”, which may, for example, comprise a change in the feed velocity v_T, relatively “slow”. The warp controller responds to the change in the feed velocity v_T by generating a certain transient in the form of time dependence of the tensile force Q. The time T_P, in which the required value of the tensile force Q_P (time required for the transient to end) returns, is an order of magnitude greater than the time required to implement the weaving cycle determined by the weaving frequency $T_C = 1/f_T$, i.e.: $T_P >>> T_C$. This is mainly due to the fact that the circuit of the warp controller includes the heavy warp beam. Therefore, the warp controller is not capable of rapid responses to fault inputs. Although changes in the tensile force Q have a very slight effect on the structure of fabric (see [21]), at certain periodic occurrence, they may cause visual defects perceivable by the human eye. Therefore, there is the possibility of optimising the time constant of the transient T_P in terms of perception of the defects by the human eye. This issue is addressed in detail in reference [21].

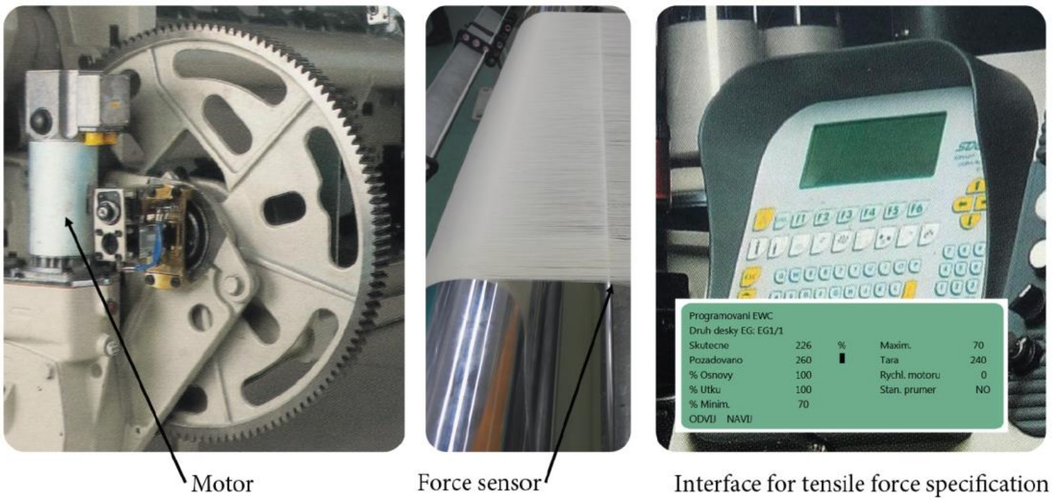


Figure 69: Photographs of the parts of warp controller of the Somet Excel machine

4.3.2 Fabric take-up and winding

Fabric is taken up at a constant velocity v_T, which at the given speed of the weaving machine n ensures the desired number of weft threads per unit length of fabric du:

$$du = \frac{n}{v_T . 100},$$

where du *(threads/1 cm)* is the number of weft threads per unit length, n *(rpm)* is the speed of the weaving machine (the number of the wefts woven in per minute) and v_T *(m/min)* is the fabric take-up velocity.

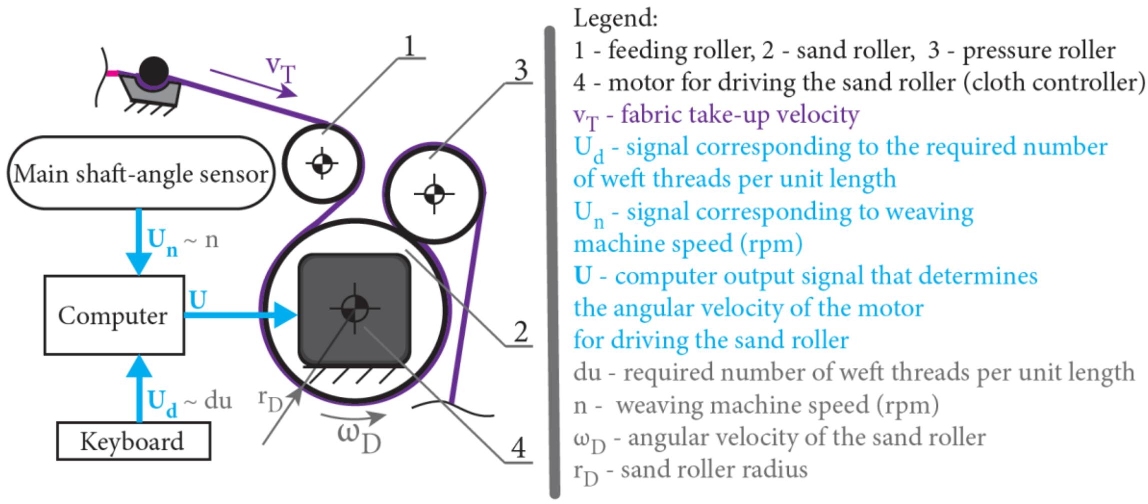


Figure 70: Fabric take-up (cloth controller) diagram

The desired number of weft threads per unit length is entered by the operator using the computer keyboard. Another input is the information about speed of the weaving machine, which is provided by the main shaft-angle sensor. Based on these inputs, the computer determines the tangential velocity of the sand roller, i.e. fabric take-up velocity v_T so as to ensure the required number of weft threads per unit length at the given speed:

$$v_T = \frac{n}{d_U.100}$$

and then sets this velocity through the angular velocity of the motor for driving the sand roller:

$$v_T = \omega_D.r_D,$$

where ω_D (rad/min) is the angular velocity of the sand roller and r_D (m) is the radius of the sand roller.

Ensuring the fabric take-up without slip

The arrangement of feed, sand and pressure rollers must ensure the fabric take-up without slip. If fabric slips on the weaving machine, it would cause changes in the take-up velocity v_T and thus uncontrolled local changes in the number of weft threads per unit length, i.e. occurrence of visual defects in the form of the so-called "weft stripiness".

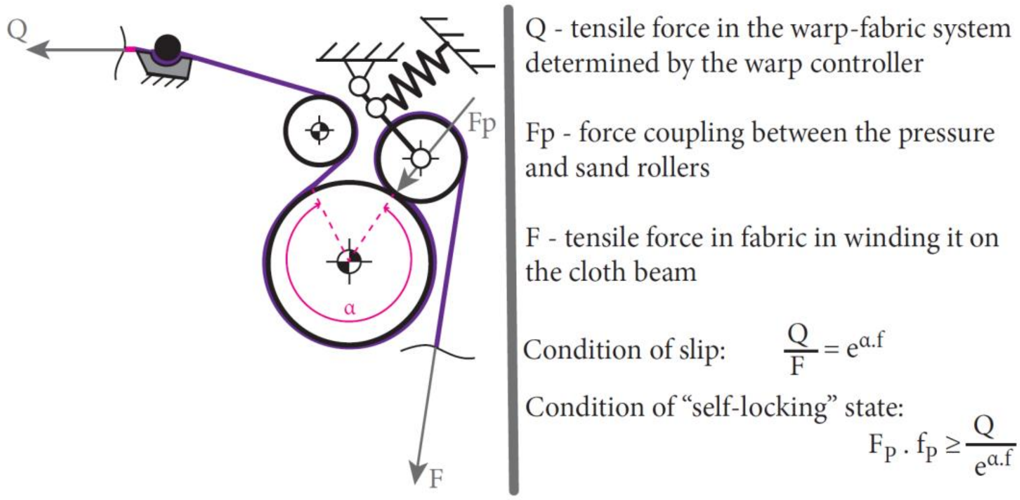


Figure 71: Force relations in the fabric take-up system

The condition of fabric "slip" on the sand roller results from the Euler's equation for belt friction:

$$Q = F . e^{\propto . f} \rightarrow \frac{Q}{F} = e^{\alpha . f},$$

where Q is the tensile force in the warp-fabric system determined by the warp controller, F is the tensile force in fabric between the sand and cloth rollers, α(rad) is the angle of wrapping of fabric around the sand roller and f is the coefficient of friction between the fabric and the sand roller.

The equation shows that to ensure the fabric take-up without slip, it is necessary to maximise the angle of wrapping α and the coefficient of friction f.

In technological practice, it is often necessary to remove the full cloth beam with the machine in operation, i.e. cut off the fabric between the sand roller and the cloth beam. Then the force F is equal to zero and the fabric take-up without slip on the sand roller is ensured by the pressure roller. The force coupling Fp is formed between the pressure and sand rollers, which, according to the Coulomb's law for sliding friction, generates the friction force $T = Fp . fp$ between the fabric and the pressure roller and the "self-locking" condition is then determined by the relation:

$$F_p . f_p \geq \frac{Q}{e^{\propto . f}},$$

where Fp is the force between the pressure and sand rollers, fp is the coefficient of friction between the pressure roller and the fabric, Q is the tensile force in the warp-fabric system determined by the warp controller, α (rad) is the angle of wrapping of fabric around the sand roller and f is the coefficient of friction between the fabric and the sand roller.

Fabric winding

Fabric is usually wound onto the cloth beam, which is placed in the frame of the weaving machine. The cloth beam is driven by the sand roller by mechanical means (chain drive, gears).

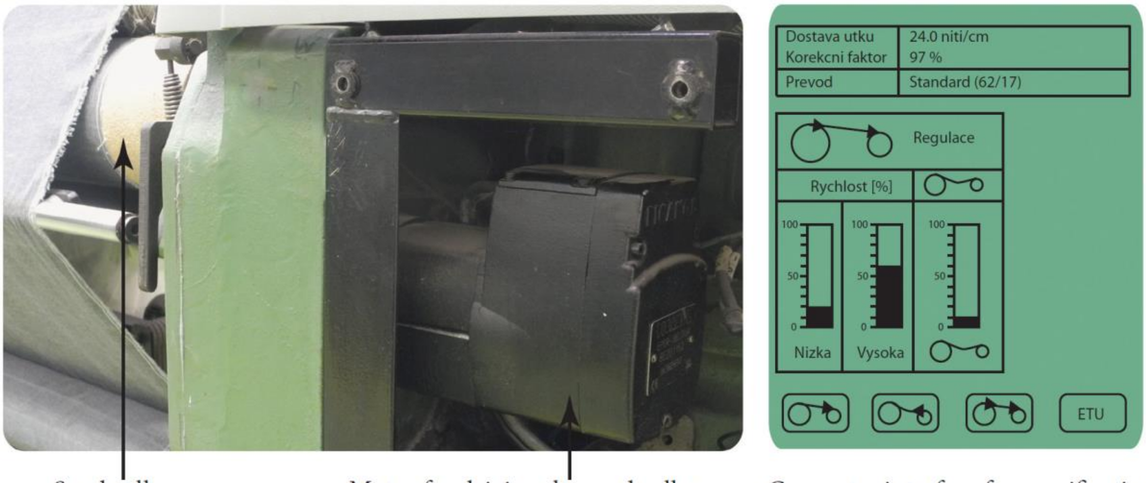


Figure 72: Photograph of the main parts of the fabric take-up system of the Picanol Gamma machine

In the production of industrial fabrics (tarpaulins, geotextiles, etc.), it is often necessary to produce packages with a great length, i.e. packages with a large diameter. In this case, fabric is wound outside the weaving machine using the subsystem referred to as the winder. This subsystem provides the peripheral drive of the cloth beam using an independent motor and a pair of cylinders.

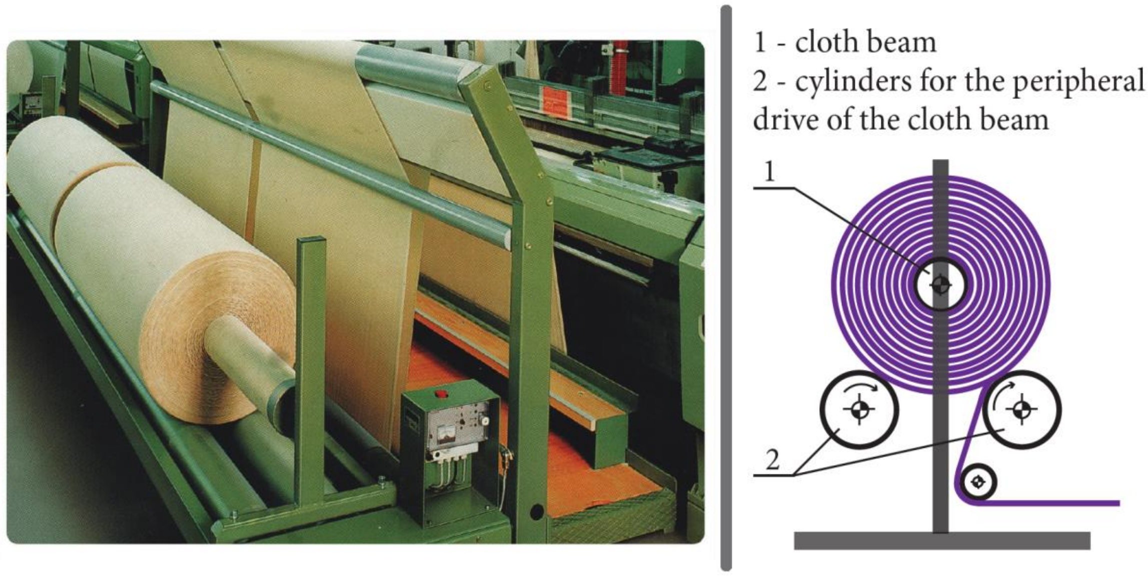


Figure 73: Winding fabric outside the weaving machine (winder)

4.3.3 Using the warp feed and fabric take-up mechanisms in practice

The basic use of the warp feed and fabric take-up mechanisms in technological practice has been previously described. The warp controller is used by the operator to set the desired values of tensile force (pretension) in the warp-fabric system. The setting of the constants of proportionality and integration of the warp controller, which affects the behaviour of the feedback circuit, should be implemented with the use of advanced methods in cyber area and, therefore, is not available in common technological practice. The controlled drive of the sand roller (cloth controller) is used for setting the desired number of weft threads per unit length.

Additional features of the warp feed and fabric take-up mechanisms

The subsystems of the warp and cloth controller are able to react to the unweaving process and after this process, adjust automatically the face of fabric (last woven-in weft) to the standard position so that the next weft beat-up ensures the spacing between weft threads given by the desired number of weft threads per unit length. This eliminates the formation of weft stripiness, which can result from unweaving.

In some cases, the weft stripiness is caused by pause in the weaving process. The warp and weft are viscoelastic materials (see [24]). Therefore, relaxation phenomena appear with the machine at rest, i.e. there is a change in the tensile force in the warp-fabric system and thus change in the position of the face of fabric. Given that the time dependence of the change in the position of the face of fabric cannot be exactly determined for specific textile materials in technological practice and the pause of the weaving process has a different length, the elimination of the weft stripiness formed due to pause of the weaving process is relatively difficult. Some means for the elimination of weft stripiness are provided by the warp controller, which allows the operator to enter not only the desired tensile force in the warp-fabric system during the weaving process, but also the desired tensile force in pause of the weaving process. The tensile strength in pause of the weaving process is generally chosen smaller, i.e. smaller elongation is created in the warp-fabric system in pause. Therefore, less influence of relaxation phenomena on the change in the position of the face of fabric can be expected. Successful use of these means is conditional upon empirical knowledge and experience of the operator in the field of the given weaving machine and textile material.

The controlled drive of the sand roller (cloth controller) allows automatic change in the fabric take-up velocity and thus automatic change in the number of weft threads per unit length. This feature is useful in the production of fabrics that contain sections with the different number of weft threads per unit length.

Important findings of the chapter:

1) We know the features of the warp feed and fabric take-up mechanisms.
2) We can draw a diagram of the feedback circuit of the warp controller and explain its function.
3) We can draw a fabric take-up diagram and explain the method for setting the desired number of weft threads per unit length on the weaving machine.
4) We know the ways of winding the fabric on the cloth beam.

4.4 Creating the shed

The shed is a wedge-shaped space (see Chapter 2.2.3) for weft insertion. This space is defined by the reed and the warp threads in the top and bottom shed position.

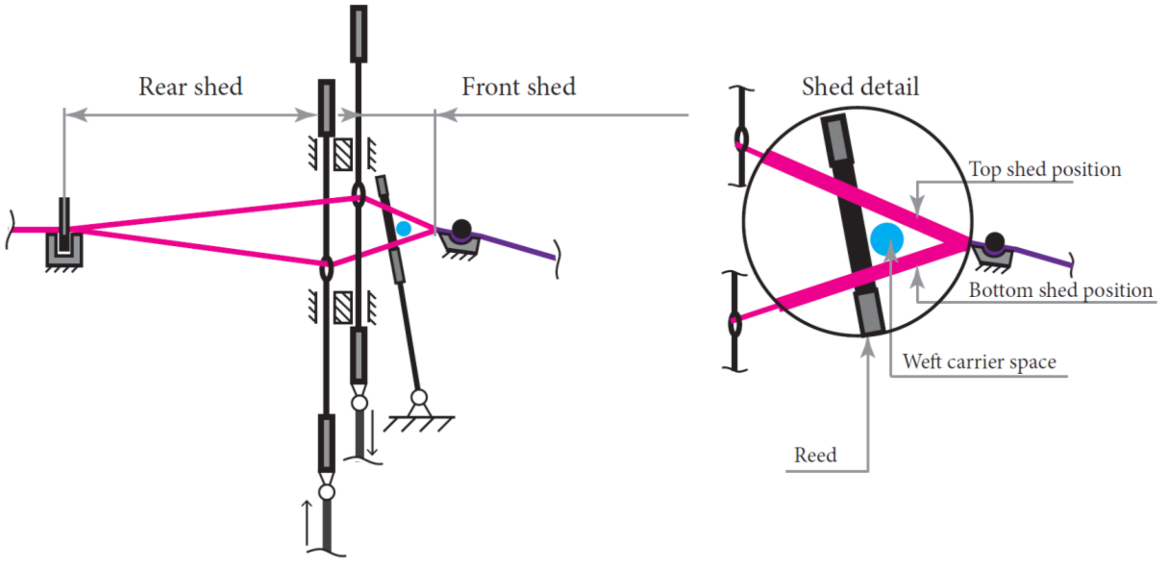


Figure 74: Diagram of the shed with dobby heald, which consists of two shafts

The warp threads from the top shed position create warp interlacing points and the warp threads from the bottom shed position create weft interlacing points in fabric. Depending on the desired textile weave, the shedding mechanism separates in the individual weaving cycles the warp threads into top and bottom shed positions by sliding the heddles. **Therefore, the function of the shedding mechanism is the creation of the shed according to the desired textile weave.** As previously mentioned (see Chapter 4.1), the heddles are arranged in shafts (dobby heald) or suspended individually on the harness cords (Jacquard heald).

Dobby heald

The dobby heald comprises a certain number of shafts and thus separates the heddles into individual groups so as to allow the production of fabrics with the desired weave. The heddles made of flat steel strip with a different shape of eyes for threading the warp thread are currently used. Plastic heddles are used rarely, but due to the short lifetime, these heddles are not yet applied in technological practice.

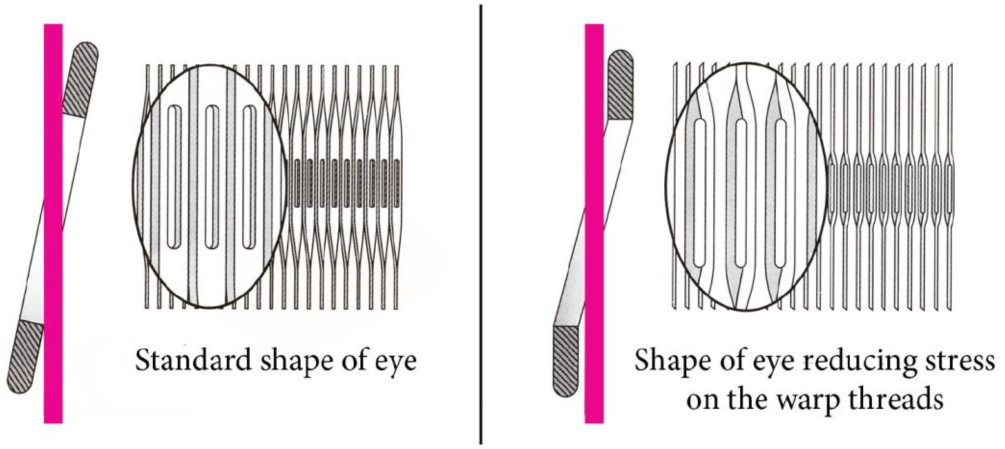


Figure 75: Different shapes of heddle eye

To ensure proper function of creating the shed according to the required weave, each warp thread must be threaded through just one heddle. Only those warp threads can be threaded through the heddles placed in one shaft, which interlace in fabric in the same manner. This shows that **the number of shafts in the heald determines the maximum number of differently interlacing warp threads, which may occur in the fabric**.

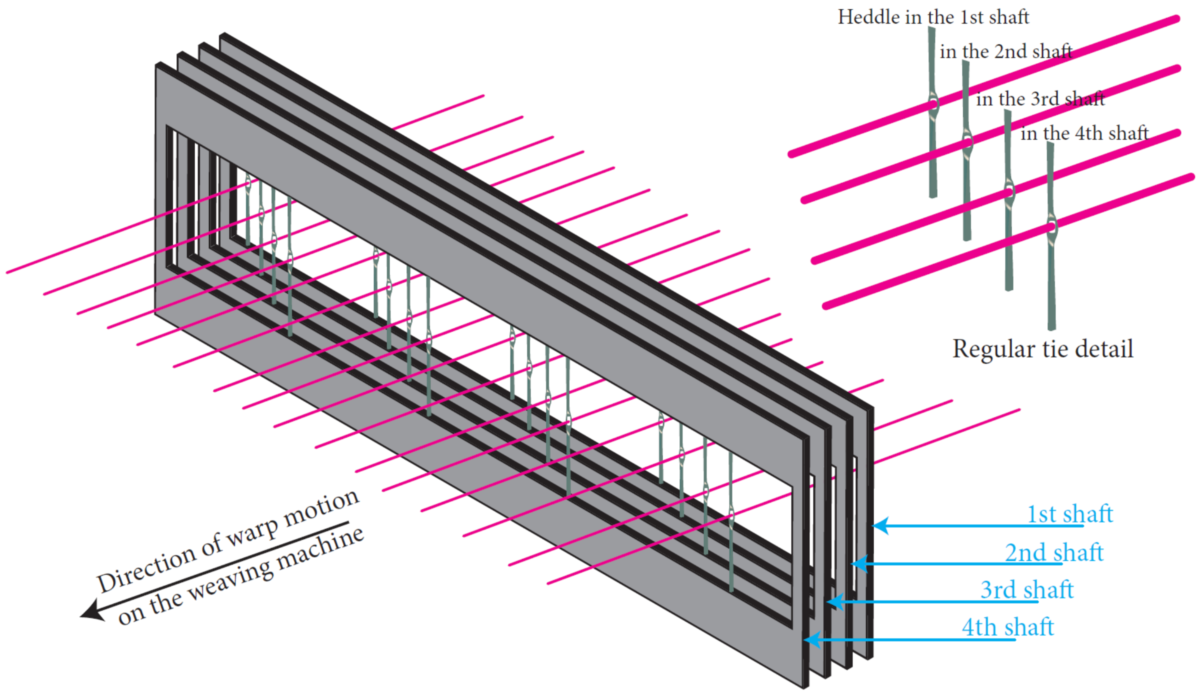


Figure 76: 3D diagram of the dobby heald with regular tie in four shafts

Note to the numbering of shafts: In this textbooks, the shafts are always numbered in the direction of warp motion. But the numbering of shafts is not governed by any standard. Therefore, in practice, you can see the opposite way of numbering.

Figure 76 shows the dobby heald, which is composed of four shafts and the so-called "**plain draft**" is used to thread the warp threads, which in this case means that the individual warp threads are threaded as follows:

- The first warp thread is threaded through the heddle eye in shaft 1 and passes freely through the frame of shafts 2, 3 and 4.
- The second warp thread passes freely through frame of shaft 1, is threaded through the heddle eye of shaft 2 and then passes freely through the frame of shafts 3 and 4.
- The third warp thread passes freely through the frame of shafts 1 and 2 It is then threaded through the heddle eye of shaft 3 and then passes freely through the frame of shaft 4.
- The fourth warp thread passes freely through the frame of shafts 1, 2 and 3 and is then threaded through the heddle eye placed in shaft 4.
- threading all remaining warp threads is repeated regularly, i.e. the fifth warp thread is threaded in the same way as the first thread, the sixth warp thread is threaded in the same way as the second thread, etc.

The regular tie in the dobby heald distributes the warp threads regularly (in this case, every four warp threads) into groups. The individual groups of warp threads can then be moved in the creation of the shed by sliding the shafts to the top or bottom shed position, thus determining what type of interlacing points (warp or weft) will be created in the weaving cycle.

In technological practice, the plain draft is used in most cases and can be applied to any number of shafts. Occasionally, other ways of threading in the dobby heald can be found. This issue is discussed in more detail in Chapter 4.4.2 - the section on technical pattern of fabric.

The position of shafts in the individual weaving cycles is controlled by the shedding mechanism and the **type of the shedding mechanism determines** also **the maximum number of shafts that can be used in the heald** (for more details see Chapters 4.4.1 and 4.4.2).

As mentioned above, each warp thread is threaded just in one heddle. The maximum number of heddles, which can be placed in one shaft, is dependent on the parameters of the fabric to be produced and usually does not exceed 1,000 heddles. Therefore, the heald, which contains two shafts, is encountered quire rarely in practice. With two shafts, it is possible to produce only plain weave fabrics (containing two different interlacing warp threads) with the warp, which has a relatively low number of warp threads (up to about 2,000 threads). **Depending on the total number of warp threads, healds with a large number of shafts are typically used so as to achieve the optimum number of heddles in each shaft.** Plain weave fabrics are then produced by means of more shafts: four, six, eight, ... shafts.

The following figures illustrate the position of the shafts in the insertion of single wefts from the pattern repeat for particular weaves. The diagrams represent the longitudinal section of fabric (see Chapter 3.5.1) on the weaving machine including a reed and heddles. The section is made along first warp thread and the plain draft is used in all cases.

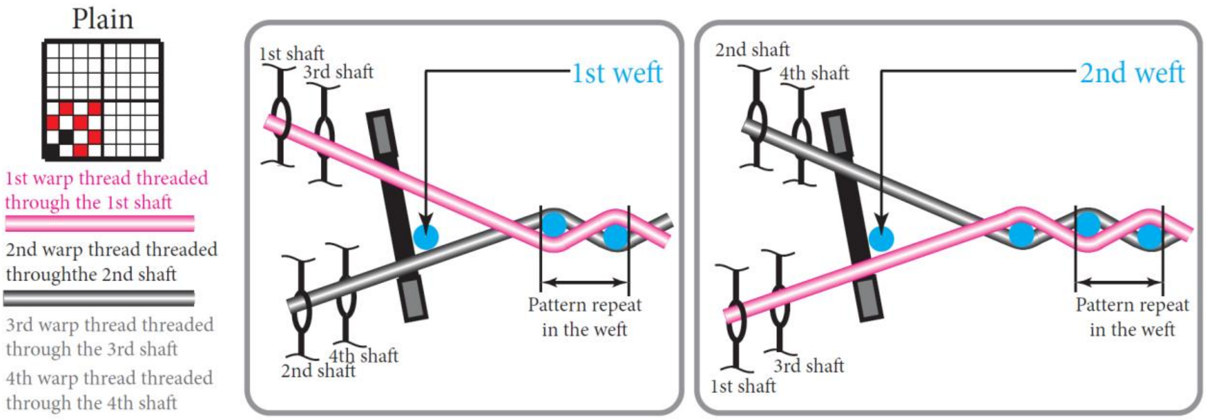


Figure 77: Diagram of the position of shafts in making a plain weave using four shafts with plain draft

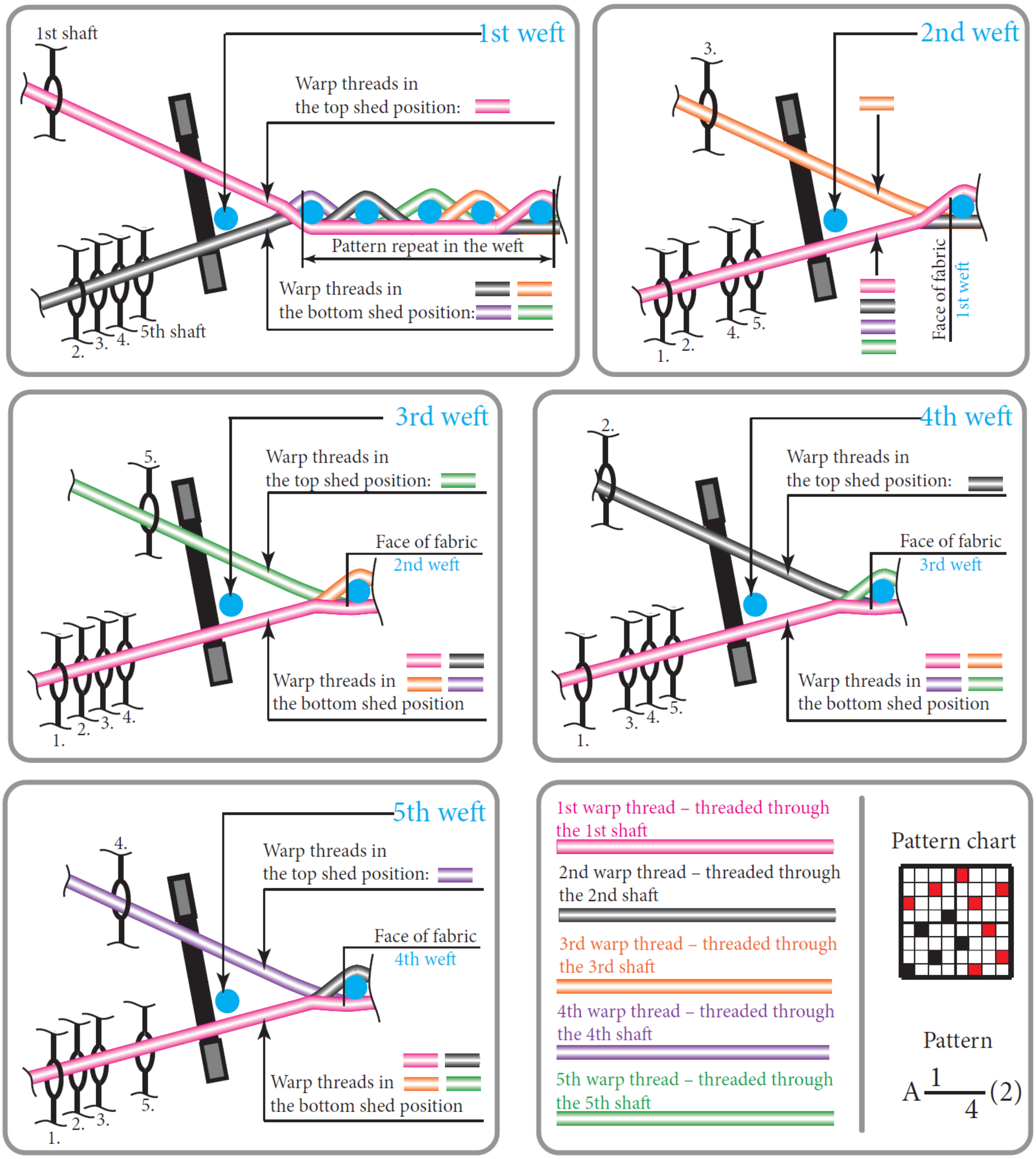


Figure 78: Diagram of the position of shafts in making a 5-harness satin using five shafts with plain draft

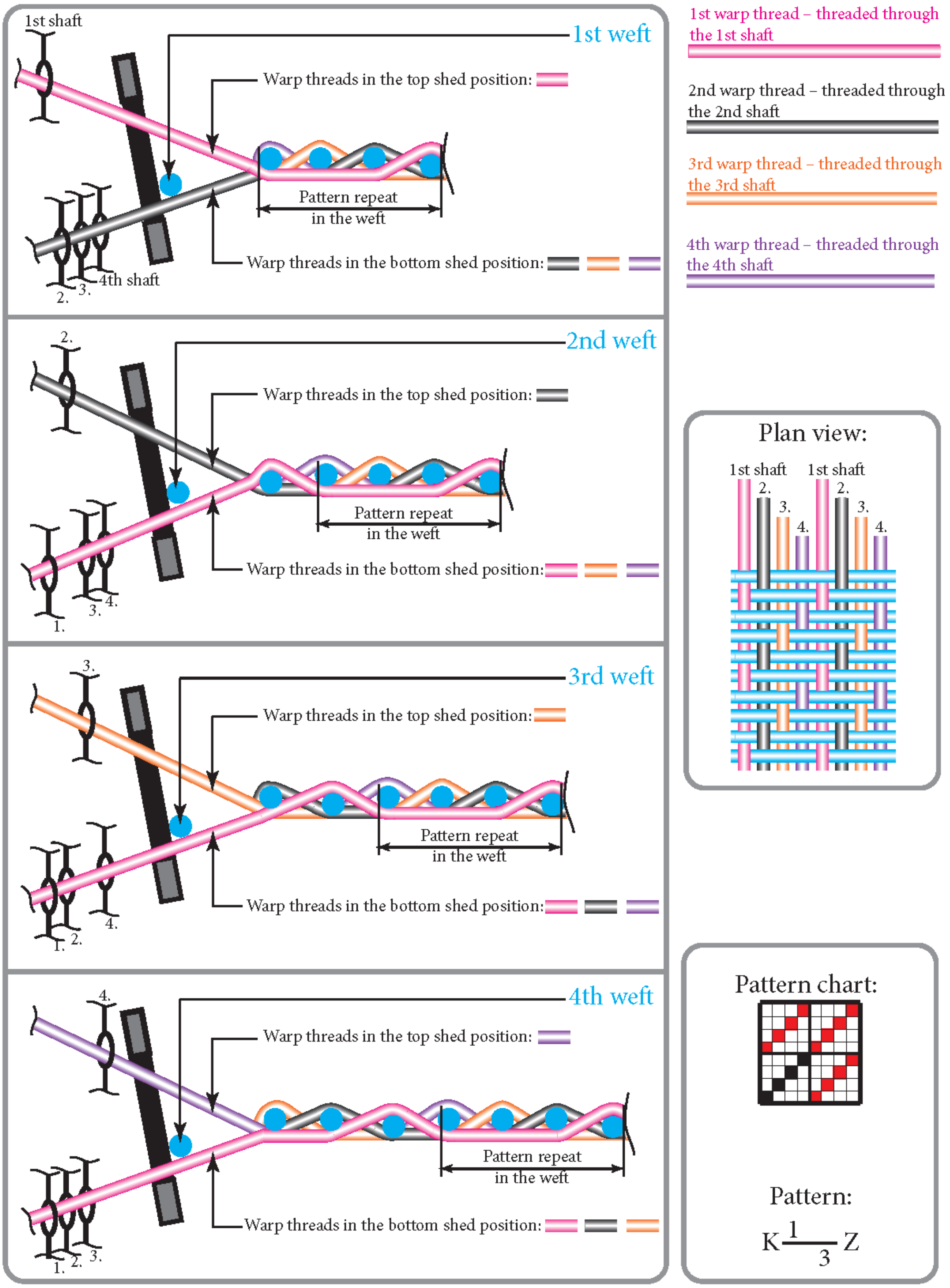


Figure 79: Diagram of the position of shafts in making a ground 4-harness twill using four shafts with plain draft

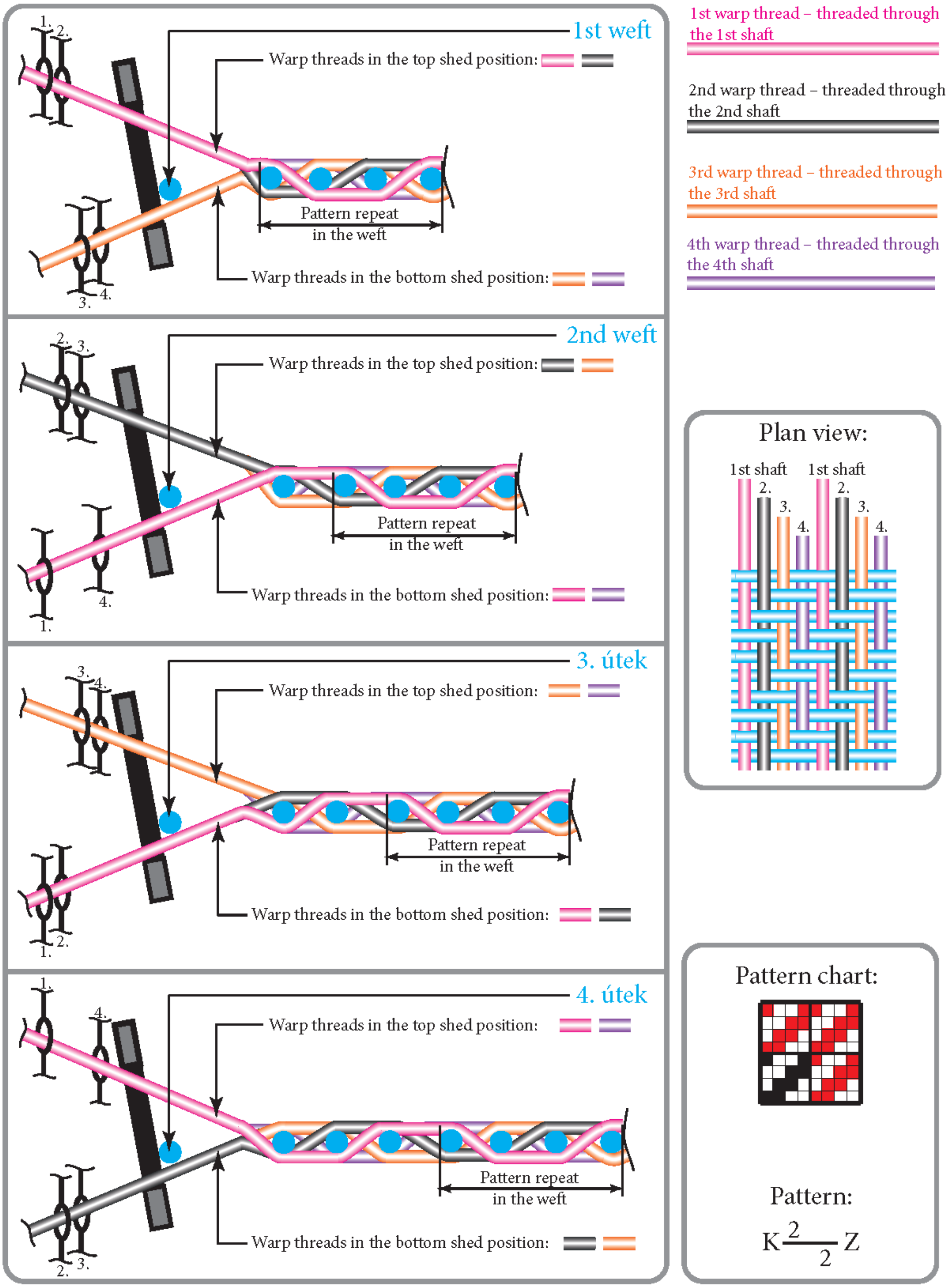
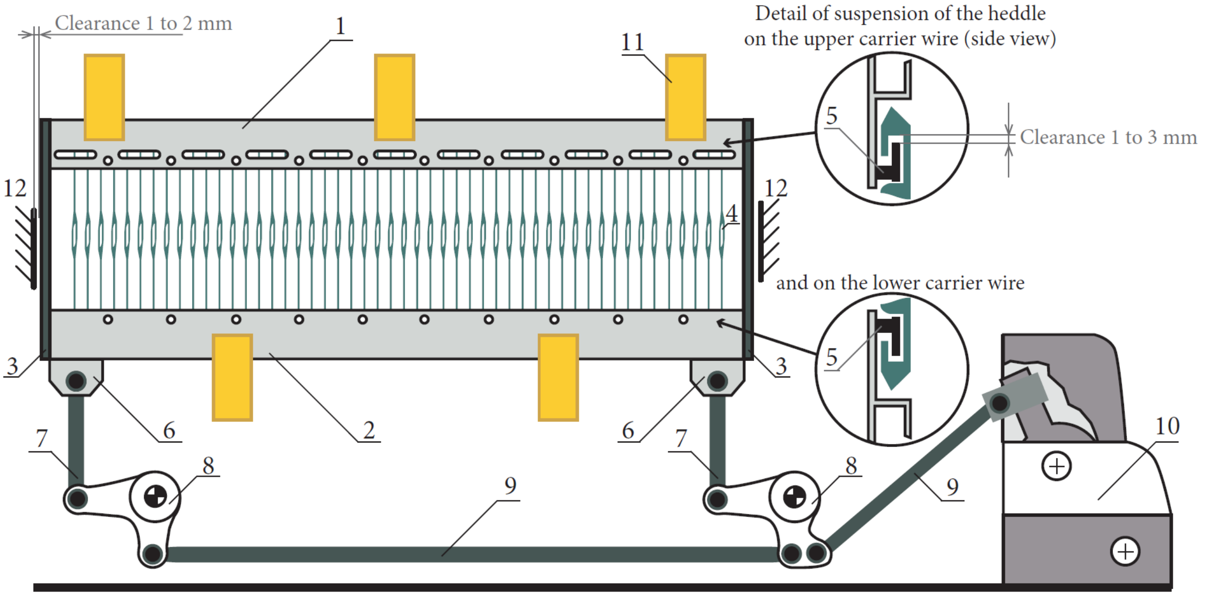


Figure 80: Diagram of the position of shafts in making a stitched 4-harness twill using four shafts with plain draft

Note: The above figures are included only to illustrate correlations between the creation of the shed and the forming of fabric in a certain weave. In technological practice, the so-called “technical pattern of fabric” is normally used to represent the fabric (its weave) on the weaving machine and the threading through the reed and heddles of the dobby heald, which is described in detail in Chapter 4.4.2.

With respect to the design, a sufficient stiffness and low weight of the shaft frame must be ensured in order to minimise its deflection and vibration during the weaving process. **From technological point of view, the shaft frame ensures easy placement of the required number of heddles as well as suspension of the whole shaft on the lifting rods of the shedding mechanism.**

Figure 81 shows the **main parts of the heald shaft**. The shaft frame consists of upper and lower rods and lateral supports. The heddles are suspended on carrier wires of rectangular cross-section, which are fastened to the upper and lower rods. There is no force coupling between the heddles and the shaft frame and the heddles can be moved sideways, which is required for technological reasons. In the preparation, the warp threads can be seamlessly threaded (manually or automatically) and, in the weaving process, the heddles allow the warp threads to pass through the dobby heald. The shaft is attached on the lifting rods of the shedding mechanism by means of suspension, which are positioned on the lower rod or to facilitate manipulation of the dobby heald, on the upper rod. The lifting rods are mounted, by means of mechanical elements (angular levers and rods), on the shedding mechanism, which is located in the housing on the right side of the weaving machine. The shaft also includes the so-called “heald frame guides”, which are made of wood or plastic so as to minimise their coefficients of sliding friction. The heald frame guides prevent the shafts from deflecting in the direction perpendicular to their motion.



1 - upper rod, 2 - lower rod, 3 - lateral support, 4 - heddle, 5 - carrier wire, 6 - suspension, 7 - lifting rod, 8 - bent lever, 9 - rod, 10 - housing of the shedding mechanism, 11 - heald frame guide, 12 - shaft guide.

Figure 81: Main parts of the heald shaft and its configuration

The design of the heald shaft shows that this element comprises relatively large clearances. This is especially the clearance between the carrier wire and the heddles or the shaft frame and the lateral guide. The clearances in the shaft may negatively influence their behaviour during the weaving process. Therefore, there is currently a number of different design solutions for the heald shafts that minimise these negative characteristics.

Jacquard heald

Each warp thread is threaded through the heddle made of steel wire of circular cross-section. The heddle is connected to the harness cord, which is basically a rope of synthetic material. The harness cord is mounted on the hook that is able to move the heddles suspended thereon to the upper position (see Chapter 4.4.3). The hooks are arranged in the housing of the Jacquard shedding mechanism. This housing is attached to the special structure above the weaving machine. The springs positioned between the bottom part of the heddles and the machine frame generate a tensile force in the harness cords and in the creation of the shed, pull down the heddles to the lower position. The order of heddles of the Jacquard heald ensures guiding the harness cords in the comber board, which is a wooden or plastic board with drilled holes.

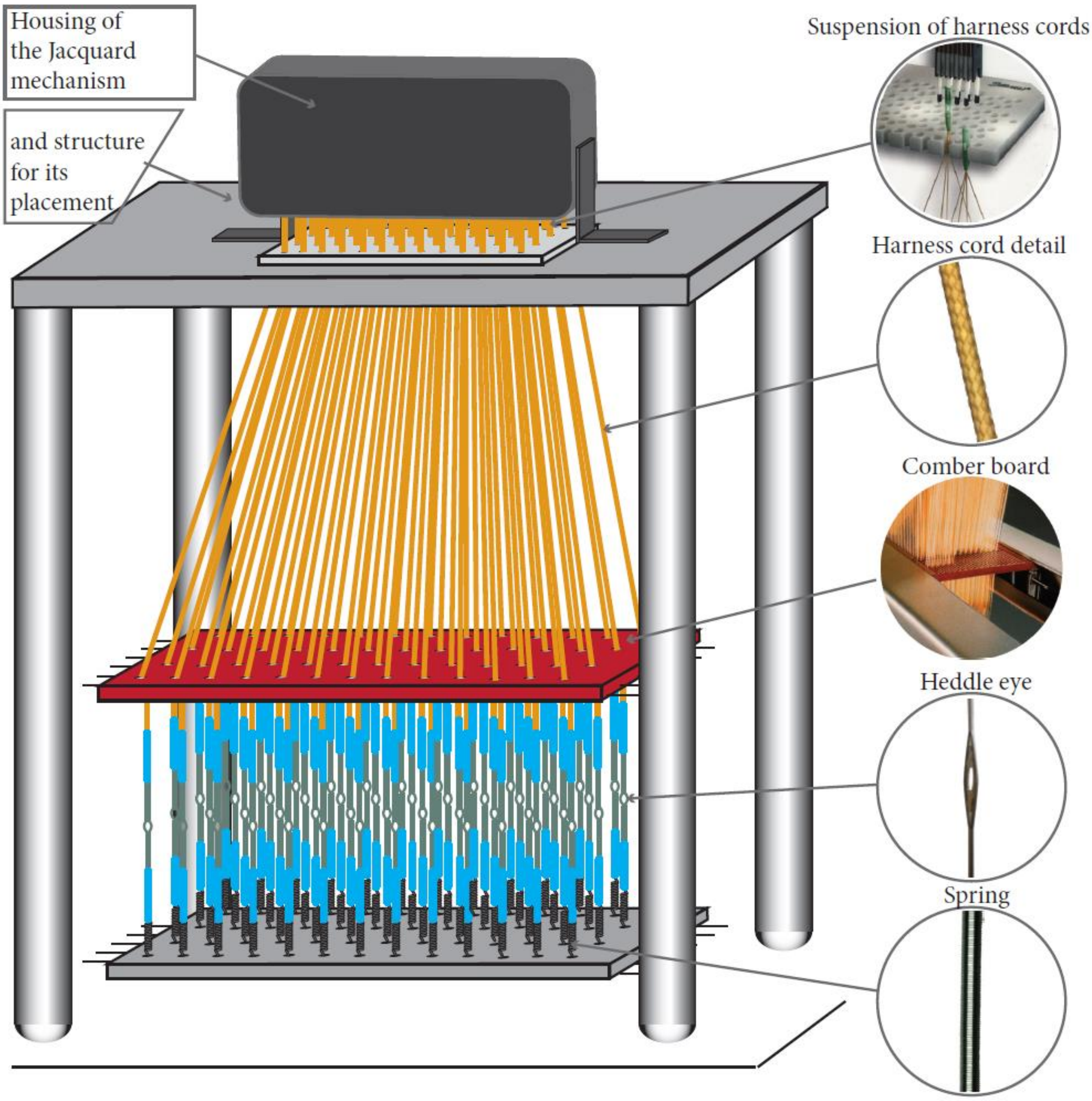


Figure 82: 3D diagram of the Jacquard heald - main parts and configuration

The warp threads are threaded through the heddles of the Jacquard heald in a similar way as in the regular tie in the shaft heald, i.e. the first warp thread is threaded through the eye of the first heddle, the second thread is threaded through the second heddle, etc. (see Figure 83).

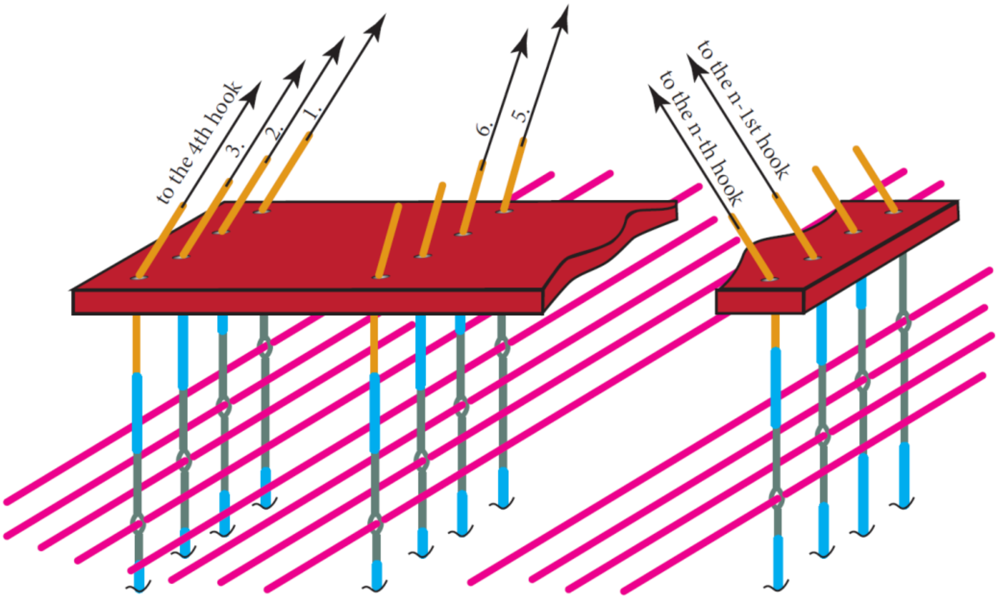


Figure 83: 3D diagram of threading the warp threads in the Jacquard heald

For Jacquard pattern fabrics, the **maximum number of differently interlacing threads is determined by the number of hooks of the Jacquard shedding mechanism**. With the sufficient number of hooks (the number of hooks is equal to or greater than the total number of threads in the warp), it is possible to suspend only one heddle on each hook using the harness cord. The warp threads are then operated individually in the creation of the shed, i.e. each warp thread in the fabric is able to interlink in a different manner and the pattern repeat of the Jacquard pattern fabric (see Chapter 3.5.4) may constitute the whole of its width. Figure 84 schematically shows the method of producing this fabric by means of 64 hooks with the result that one heddle is suspended on each hook.

For most Jacquard pattern fabrics, the pattern repeats periodically in the direction of the width of fabric, i.e. fabric contains groups of the threads interlacing in the same manner. Therefore, the above described arrangement can be seen relatively infrequently in practice. Several heddles are usually suspended on each hook. The warp threads, which are threaded through the heddles suspended on one hook, are operated together in the creation of the shed and interlace in fabric in the same manner. This ensures repetition of the pattern in the direction of the width of fabric. In this case, the number of pattern repetitions is determined by the number of heddles suspended on one hook and the warp pattern repeat is determined by dividing the number of patterns in the width of fabric *Pvz* and the total number of threads in the warp cpn_o. The diagram in Figure 85 shows the principle of production of fabric with the repeating pattern by means of 16 hooks with the result that four heddles are suspended on each hook.

The method of guiding the harness cords in the holes of the comber board, shown in Figure 85, is referred to as the **regular tie**. The harness cords are guided in the comber board in each pattern repeat in the same manner, i.e. the harness cord of the first hook is guided in the first hole in the comber board, the cord of the second hook is guided in the second hole, etc., until the last cord of the n-th hook is guided in the last hole in the pattern repeat. For other pattern repeats, the way of guiding the harness cords is repeated. The regular tie allows the creation of patterns, in which the number of threads in the pattern repeat does not exceed the number of hooks of the Jacquard shedding mechanism.

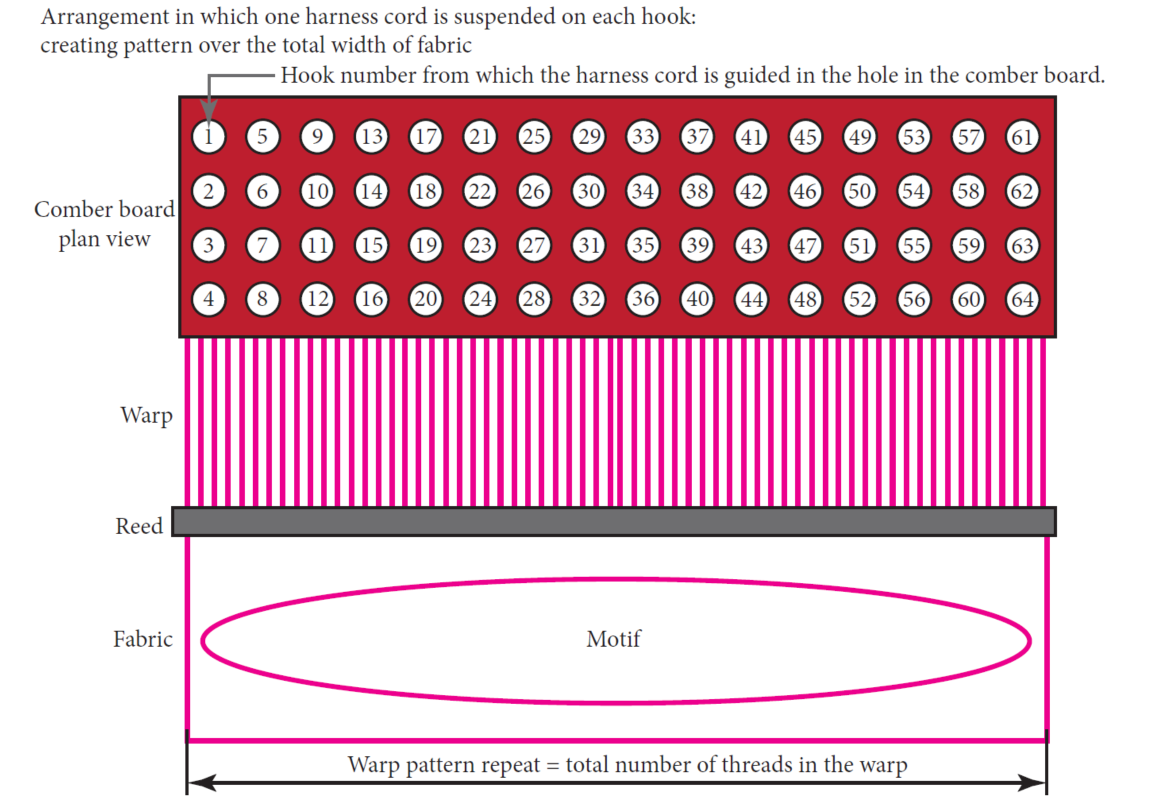


Figure 84: Plan view showing the guide of the harness cords in the comber board in case of creating a pattern across the width of fabric

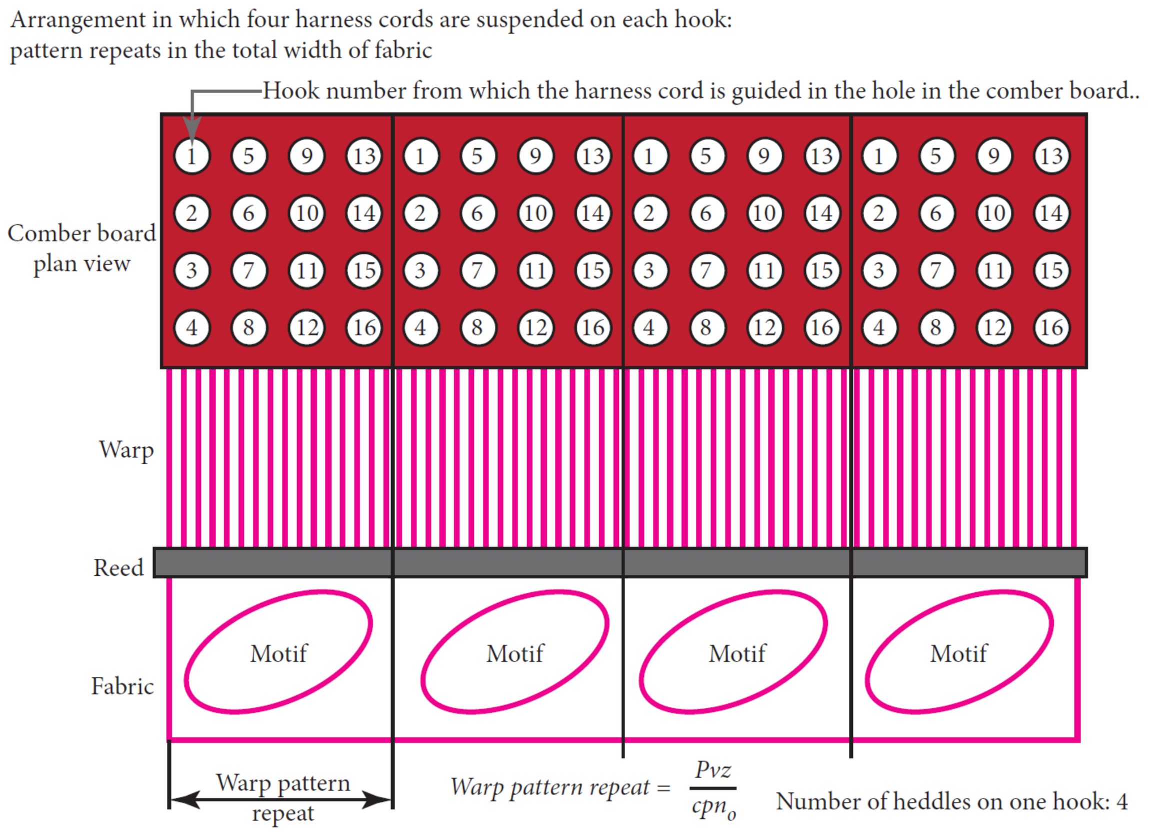


Figure 85: Plan view showing the guide of the harness cords in the comber board in case of repeating patterns (regular tie)

The so-called **point tie** is designed for the creation of larger symmetrical patterns, which have double the number of warp threads in the pattern repeat than the number of hooks of the Jacquard shedding mechanism. In the first half of the pattern repeat, the harness cords are guided using the regular tie and in the second half of the pattern repeat, the harness cords are guided using the point tie so that the cord of the last n-th hook is not used and the first hole in the second half of the warp repeat remains empty. For other pattern repeats, this way of guiding the harness cords is repeated. Figure 86 illustrates the method of using the point tie in the production of fabric with symmetrical pattern using 16 hooks with the result that four heddles are suspended on each hook.

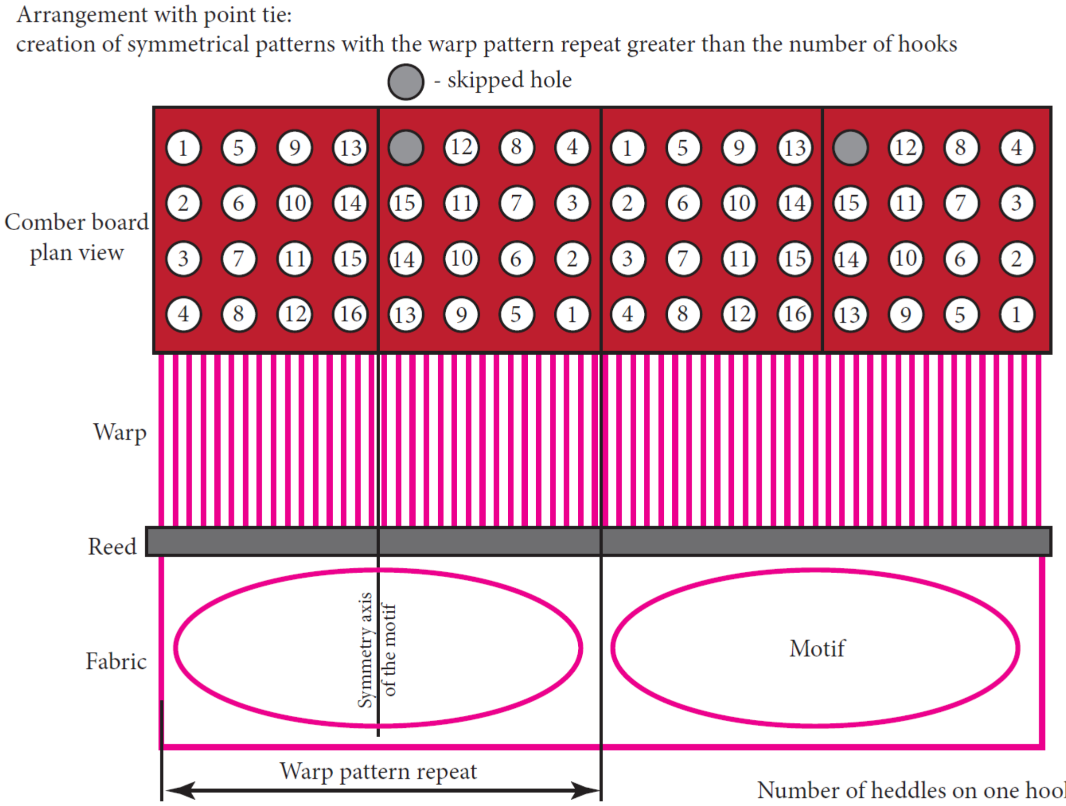


Figure 86: Plan view showing the guide of the harness cords in the creation of symmetrical patterns using the point tie

Note: The **number of hooks** in the above plan views do not represent real values. These figures are adapted for teaching purposes and clear illustration of the effect of guiding the harness cords (i.e. cording) on the distribution of patterns in fabric. For real Jacquard mechanisms, the number of hooks ranges from about 200 (in smaller and older types of mechanically controlled Jacquard mechanisms) to 14,000 (in the current larger types of electronically controlled Jacquard mechanisms). This is why the point tie is today virtually not seen and the regular tie clearly prevails. For more information about the number of hooks of the Jacquard shedding mechanisms see Chapter 4.4.3.

Advantages of Jacquard heald: The configuration of the Jacquard heald completely eliminates clearances, which are characteristic for the dobby heald. In case of using the electronic Jacquard shedding mechanisms (for more information see Chapter 4.4.3), it is often possible to achieve higher weaving frequencies in long-term operation and thus higher production rates than on the machines equipped with the dobby heald. Other unquestionable advantages include wide interlacing capacities and the ability to produce fabrics with figural patterning (see Chapter 3.5.3).

Disadvantages of Jacquard heald: On the other hand, in case of Jacquard shedding mechanisms, higher acquisition costs must be taken into account. Furthermore, the Jacquard heald complicates, compared to the dobby heald, the process of threading the warp threads. The dobby heald allows this operation to be implemented outside the weaving machine using the method of manual or mechanical threading. In case of Jacquard heald, the operation of threading the warp threads can only be implemented manually directly on the weaving machine.

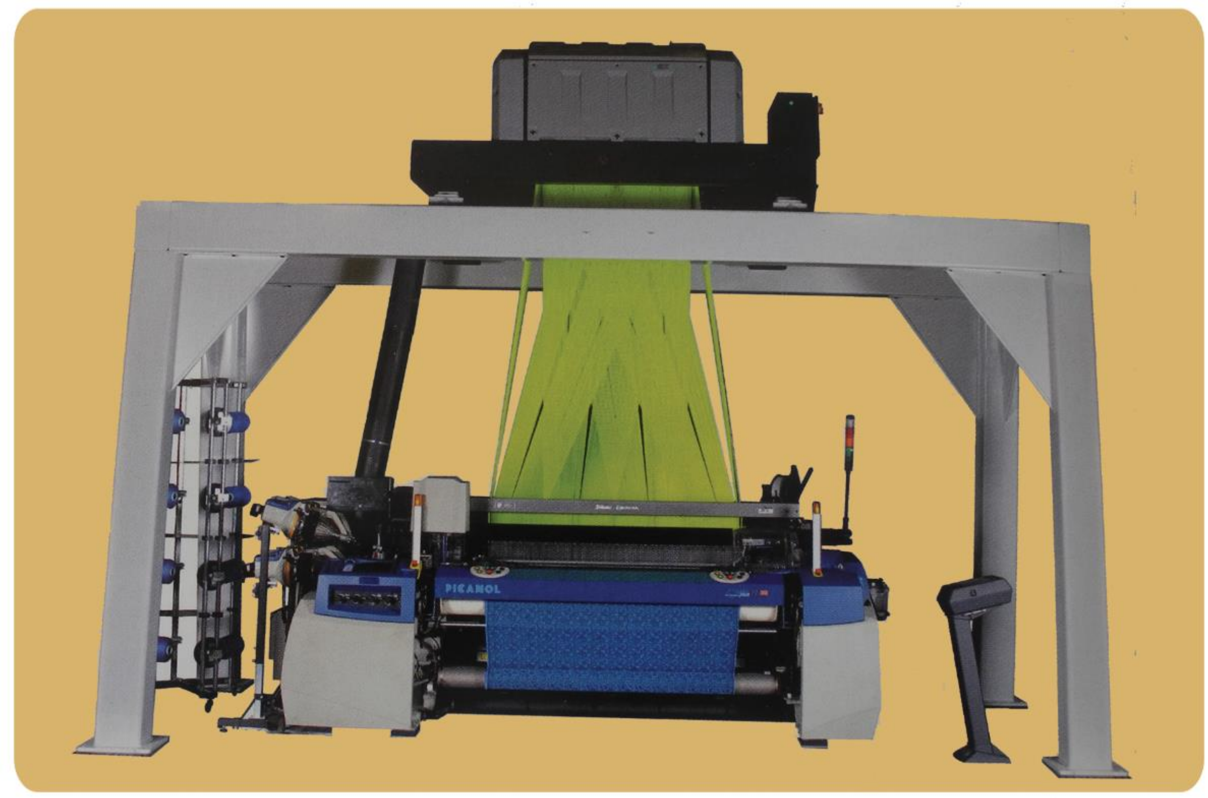


Figure 87: Weaving machine equipped with the Jacquard shedding mechanism (source [16])

Important findings of the chapter:

1) We know the function of shedding mechanism.
2) We know how shedding relates to method of interlacing the warp and weft threads in fabric (to textile weave).
3) We know what is the regular tie in the dobby heald.
4) We know the main parts of the shaft and its configuration.
5) We know the main parts of the Jacquard heald and its configuration.
6) We know what is the cording and we know the regular and point ties.
7) We know the advantages and disadvantages of dobby and Jacquard healds.

In technological practice, three types of shedding mechanisms predominate today. When the dobby heald is used on the weaving machine, the individual shafts are controlled by a cam or dobby shedding mechanism. For Jacquard heald, the heddles are controlled by a Jacquard mechanism.

Specialised companies are involved in the production of shedding mechanisms and, as a general rule, the manufacturers of weaving integrate their products in their designs. At the time of creation of the textbook, the significant manufacturers of shedding mechanisms include the Stäubli company that has shedding mechanisms of all the above mentioned types in its production program. The Fimtextile company is involved in the production of cam and dobby shedding mechanisms the Bonas company is specialised in the production of electronically controlled Jacquard shedding mechanisms.

4.4.1 Cam shedding mechanisms

The cam shedding mechanisms are designed for the **suspension of four to ten shafts**. Therefore, their interlacing capacity is relatively limited and **allows the production of fabrics in basic weaves or in simpler derived weaves**. The disadvantage is also the relatively high proportion of manual work of the operator in the change in weave of the fabric to be produced. But due to lower acquisition costs (compared to other types of shedding mechanisms), the cam shedding mechanisms are still widespread in technological practice. For example, they are used in the production of industrial fabrics, linings and other products that do not require high flexibility in the area of interlacing capacity.

The lifting dependence of individual shafts of the heald is determined by the shape of the cams and the way of their assembly on the shaft. The shaft of the shedding cams is mounted in the oil housing on the right side of the machine and is driven by the main shaft by mechanical means (see Chapter 4.2.1, drive types A, B and C). In some cases, the cam shedding mechanism includes an auxiliary motor to ensure reverse running of the shedding mechanism in the release of incorrectly woven-in weft (unweaving).

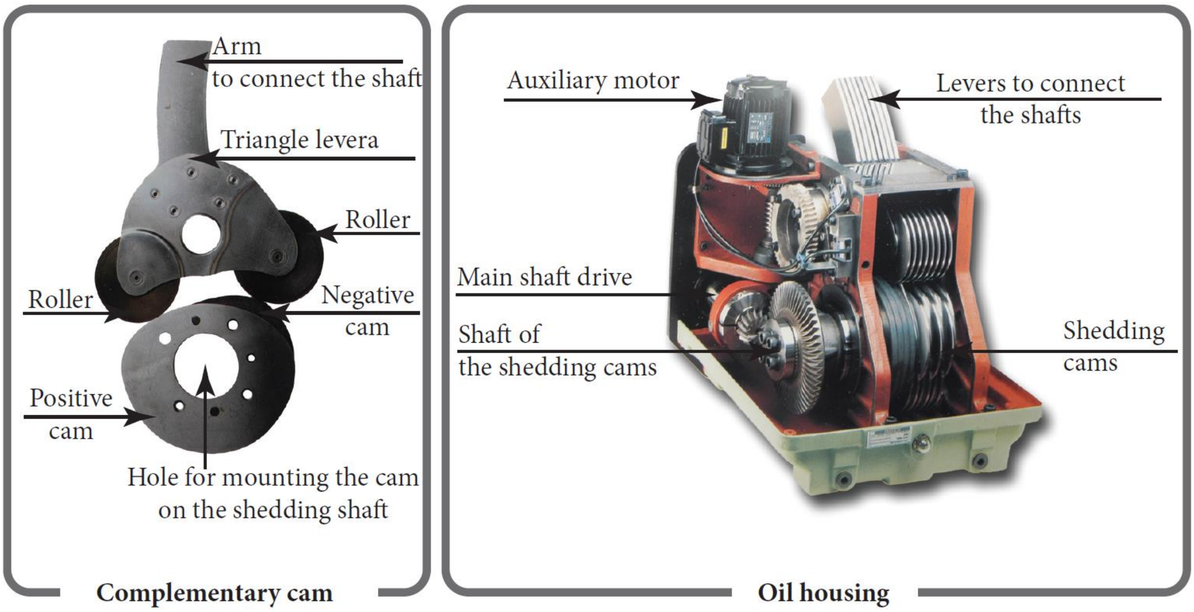


Figure 88: Main parts of the cam shedding mechanism (source [25])

Different types of cams: radial, grooved, were used as shedding cams in the past (see [1] and [3]). The so-called **"complementary cams"** (see Figure 88) are predominantly used today, which allow to minimise the load on shedding cams. It is basically a pair of cams, which is composed of positive and negative cams. Two rollers are placed at the bottom pair of the arms of the triangle lever. One of the rollers is in contact with the positive cam and the other roller is in contact with the negative cam. The third lever arm is brought out of the housing of the shedding mechanism and allows the connection of the shaft. The shape of the positive cam is determined by the desired textile weave and the shape of the negative cam is designed to form a force coupling between the surfaces of the two cams and their rollers throughout the revolution of the shedding shaft. Therefore, the rollers follow exactly the shape of cams in the rotation of the shedding shaft. The reduction of force load on the complementary cam is achieved by removing the regenerative member (spring), which is used to create a force coupling between the roller and the single radial cam.

The number of complementary cams on the shaft of shedding cams is equal to the number of shafts in the heald, i.e. each cam controls one shaft. During rotation of the shaft of shedding cams, the position of the individual triangle levers changes by the shape of the respective cams, thus changing the position of the shafts suspended on these levers. **Therefore, the shape of shedding cams and the way of their assembly on the shaft constitutes a program for creating the shed according to the desired textile weave.**

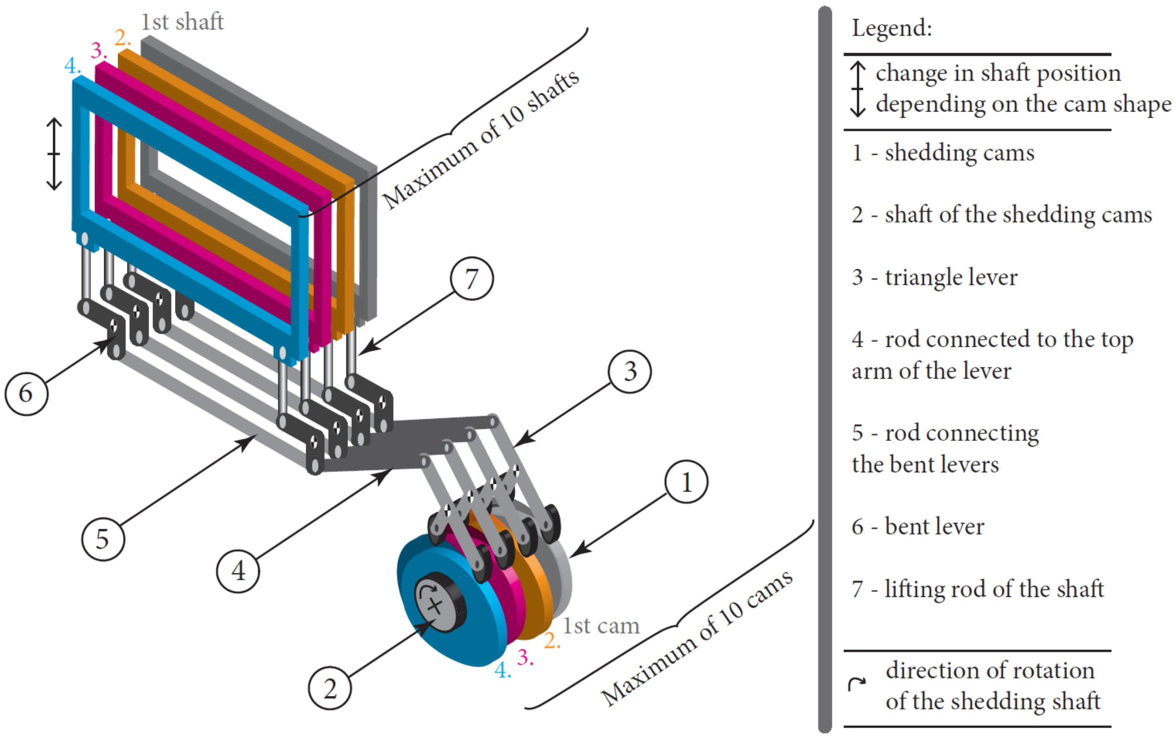


Figure 89: 3D diagram of the cam shedding mechanism with four shafts

Therefore, in technological practice, cams of the appropriate shape must be chosen for the given weave and these cams must be properly assembled on the shaft. For this purpose, it is appropriate to divide the shape of the positive part of the complementary cam using a pair of concentric circles with the centre in shaft bearing (see Figure 90). Furthermore, it is necessary to determine (from the arrangement of the mechanical elements used to connect the shafts to the levers of the shedding mechanism) correlation between the position of the roller on the large and small circles and the position of the appropriate shaft in the bottom and top positions. In this textbook, we assume an arrangement in which the position of the roller on the large circle corresponds to the top position of the appropriate shaft and the position of the roller on the small circle corresponds to the bottom position of the shaft.

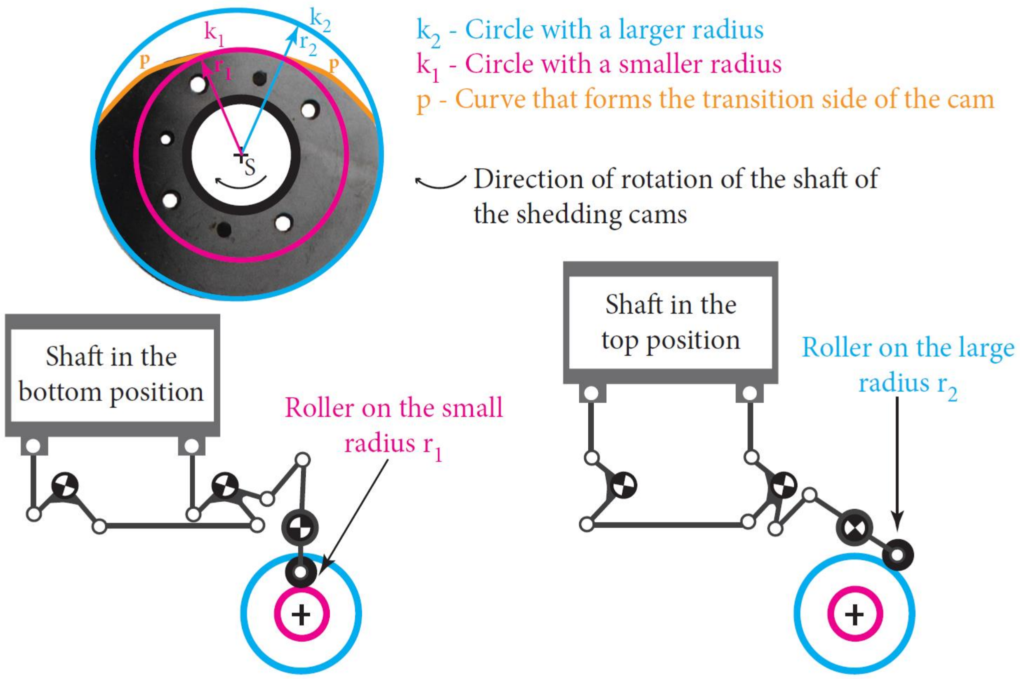


Figure 90: Parts of the shedding cam in the system of a pair of concentric circles

It is then possible to draw in the system of concentric circles an approximate shape of the shedding cam for each shaft according to the pattern chart for specific weave. As an example, here is the **procedure for drawing the shapes of cams for plain weave, which will be made using two shafts**. We assume that the first thread of the pattern repeat is threaded through the first shaft and the second thread is threaded through the second shaft.

1) For each cam, draw a separate pair of concentric circles. For plain weave, which is made using two shafts, draw two pairs of concentric circles. Indicate such a number of points on the circles on a regular basis as is the number of wefts in the pattern repeat and number these points by wefts. For plain weave, indicate the two points with numbers 1 and 2 in 180°.

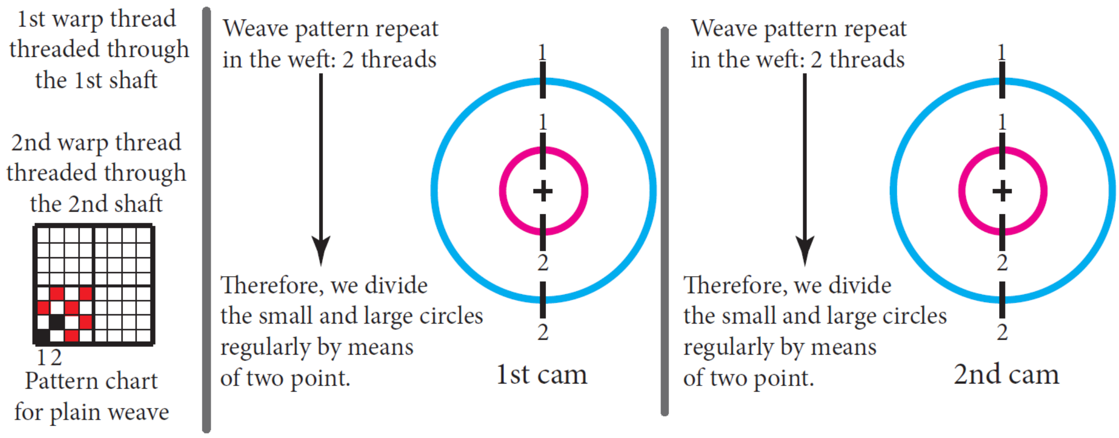


Figure 91: First step of the procedure for drawing the shapes of cams for plain weave

2) The method for interlacing the first warp thread shows that in the insertion of the first weft, the first shaft must be in the top position (the threads threaded through it form the warp interlacing points), i.e. the roller is on the circle with a larger radius. Therefore, indicate point 1 for the first cam on the large circle in the system of circles. In the insertion of the second weft, the first shaft is in the bottom position (the threads threaded through it form the weft interlacing points), i.e. the roller must be on the circle with a smaller radius. Therefore, indicate point 2 for

the first cam on the small circle in the system of circles. Follow similar procedure in indicating points in the system of circles for the second cam and choose the points on a large or small circle according to the way of interlacing the second warp thread, i.e. points 1 and 2 must be indicated on the small and large circles, respectively.

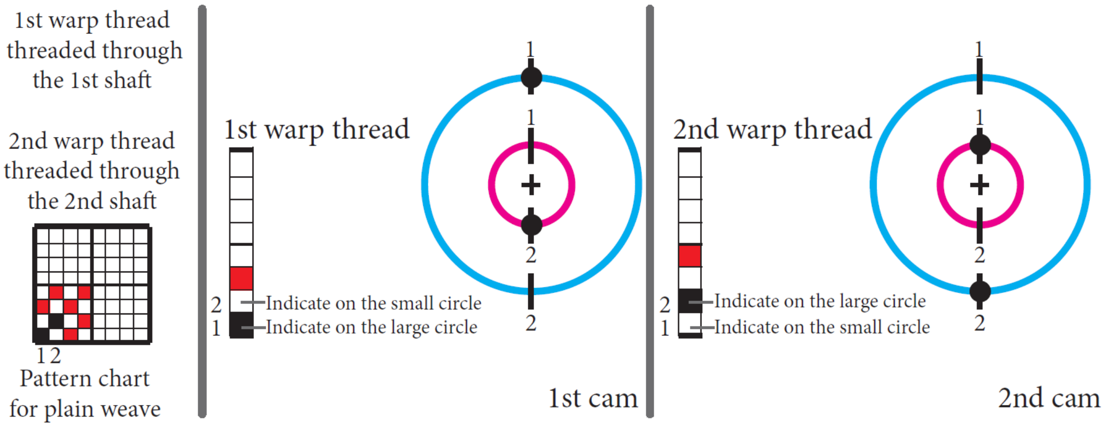


Figure 92: Second step of the procedure for drawing the shapes of cams for plain weave

3) Around the indicated points, plot symmetrically the angle determined by dividing the so-called “static angle” (see note below) and the number of wefts in the pattern repeat, or the number of points on circles. The points on large and small circles are thus obtained, which, after connection by curve, determine the approximate shape of the so-called “transition side of the cam” (see also note below). The result allows to choose cams with the correct shape and, in particular, assemble the cams properly on the shaft so as to produce the desired weave (in this case, the plain weave). The above procedure shows that choosing cams with the appropriate shape and their correct assembly on the shaft of the shedding cams are not the only condition for creating the desired weave. In addition, it is necessary to ensure the correct gear ratio between the main shaft and the shaft of the shedding cams, which depends on the number of the points plotted on the circles, i.e. on the pattern repeat in the weft. During one revolution of the main shaft, the shaft of the shedding cams must be rotated by just one point, i.e. in case of plain weave, by 180°. This means that, in our case, it is necessary to ensure the gear ratio between the main shaft and the shaft of the shedding cams: 2:1.

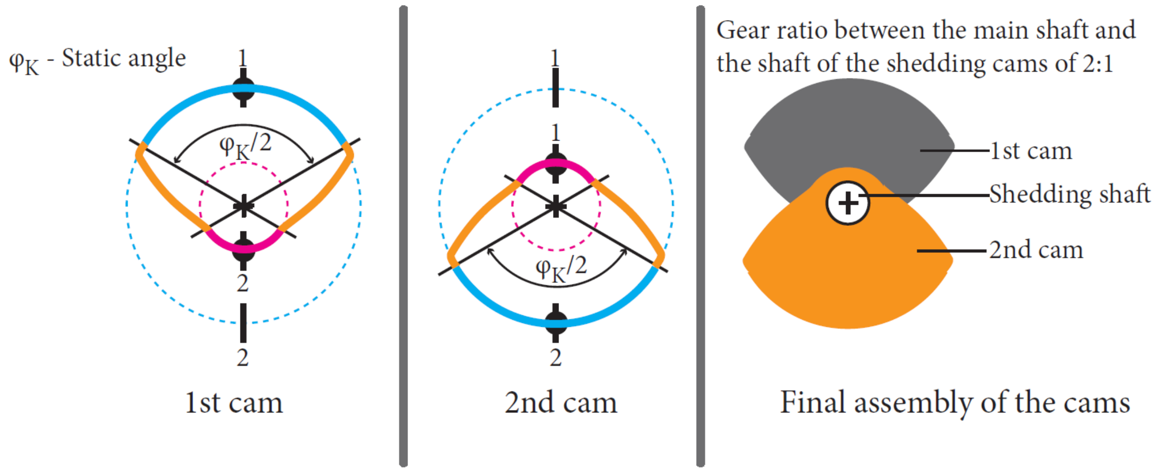


Figure 93: Last step of the procedure and final assembly of the cams for plain weave

Using the cam with the appropriate shape, assembling them on the shaft of the shedding cams in the manner indicated and ensuring the gear ratio between the main shaft and the shaft of the shedding cams of 2:1 will produce fabric in plain weave. The course of lifting the shafts depending on the rotation angle of the main shaft is shown in the following graph.

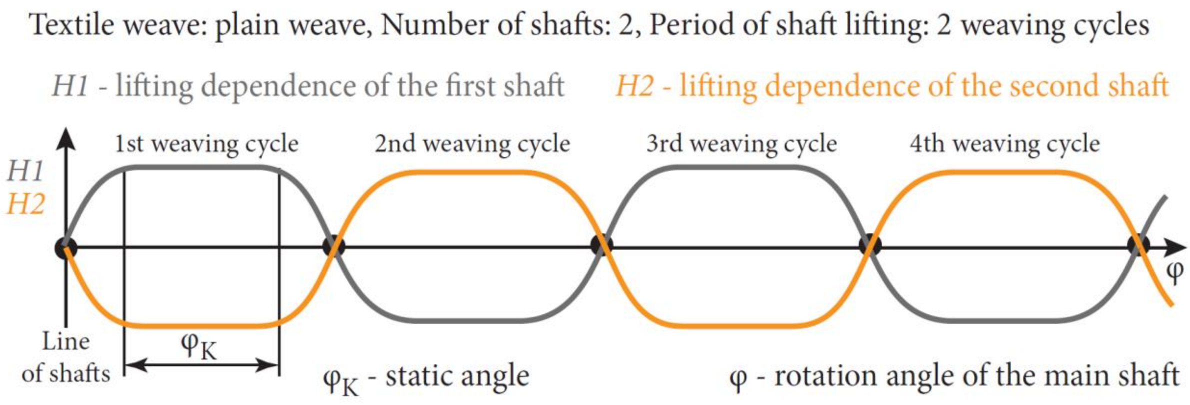


Figure 94: Lifting dependence of shafts during four weaving cycles for plain weave

Note to the term "static angle": The weaving process (see Chapter 4.1.1) generally requires the creation of the rest position of the shaft in the top and bottom positions. In this case, the static angle is the rotation angle of the main shaft, in the interval of which the shaft remains motionless in the top or bottom position. Therefore, in this interval, the roller is located on the trajectory consisting of large or small circle.

Note to the term "transition side of the cam": If the roller in on the curve that connects the points on the large and small circles (i.e. the transition side of the cam), the position of the shaft changes and the dynamic forces act in the shedding mechanism, which depend on the mass and acceleration of the shaft. These dynamic forces must be minimised. Therefore, the transition sides of the cams are designed so that the time characteristic of acceleration is harmonic or the Fourier analysis is used for optimisation.

Now, apply the **procedure for drawing the shapes of cams for stitched 4-harness twill** (as shown in Figure 95) with **regular tie in four shafts**. First, create four concentric circles. Because the pattern repeat contains four weft threads, indicate four points on the circles always in 90°.

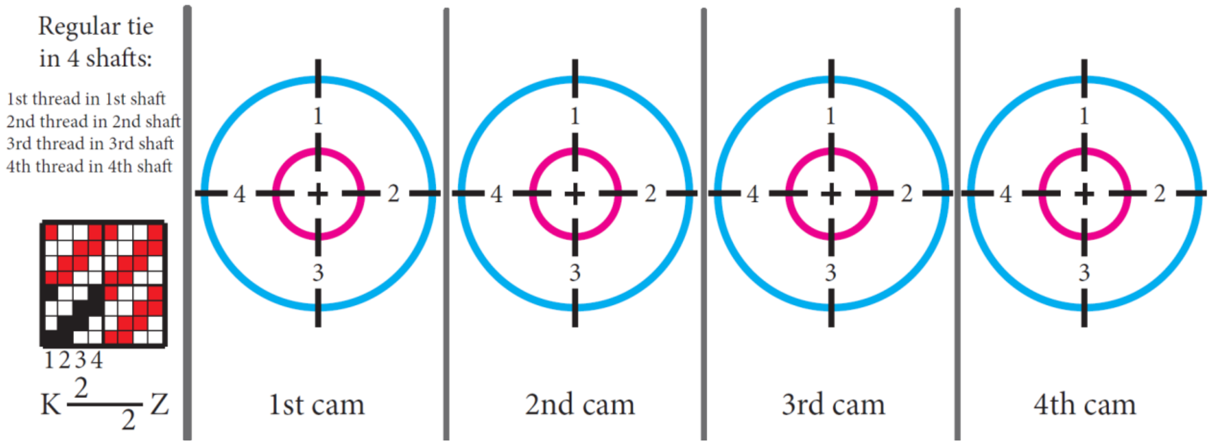


Figure 95: First step of the procedure for drawing the shapes of cams for stitched 4-harness twill

According to the method of interlacing the individual warp threads, indicate the points on large or small circle so as to choose the point for the warp and weft interlacing points on the large and small circles, respectively. Therefore, on the first cam, the first point is indicated on the large circle, the second and third points on the small circle, and the fourth point again on the large circle. For the second cam, the first and second points are indicated on the large circle, and the third and fourth points on the small circle. For the third cam, the first point is indicated on the small circle, the second and third points on the large circle, and the fourth point is indicated on the small circle. For the fourth cam, the first and second points are indicated on the small circle, and the third and fourth points are indicated on the large circle.

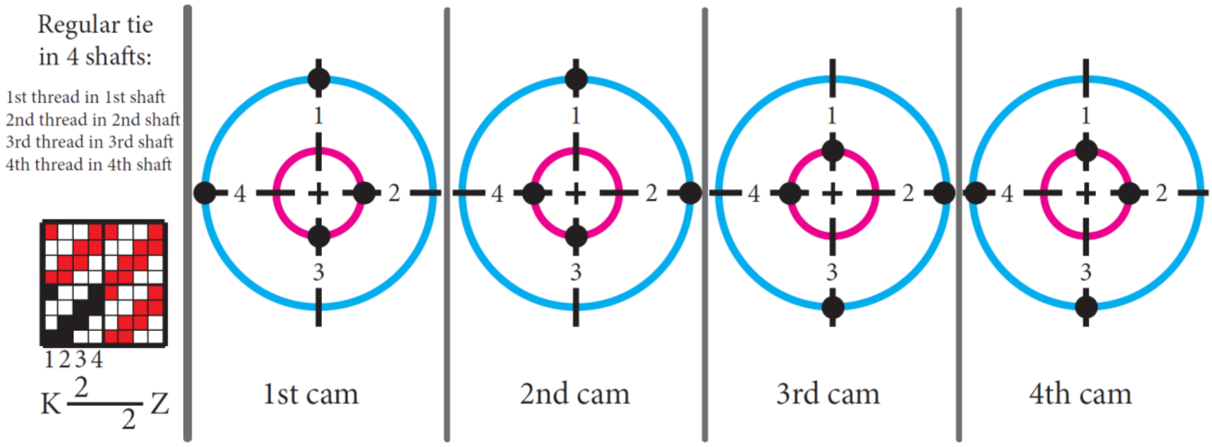


Figure 96: Second step of the procedure for drawing the shapes of cams for stitched 4-harness twill

Around the indicated points, plot symmetrically one quarter of the required static angle. Interconnect the points, which lie next to each other on the large or small circle. This means that, for the first cam, interconnect the points, which lie between number 1 and 4 on the large circle, and the points, which lie between number 2 and 3 on the small circle. For the second cam, interconnect the points, which lie between number 1 and 2 on the large circle, and the points, which lie between number 3 and 4 on the small circle. The third cam has interconnected the points, which lie between number 2 and 3 on the large circle and the points, which lie between number 4 and 1 on the small circle. The fourth cam has interconnected the points, which lie between number 3 and 4 on the large circle and the points between number 1 and 2 on the small circle. Thus, two edge points are obtained on the large and small circles. The curves that interconnect these points form the transition sides of the cam.

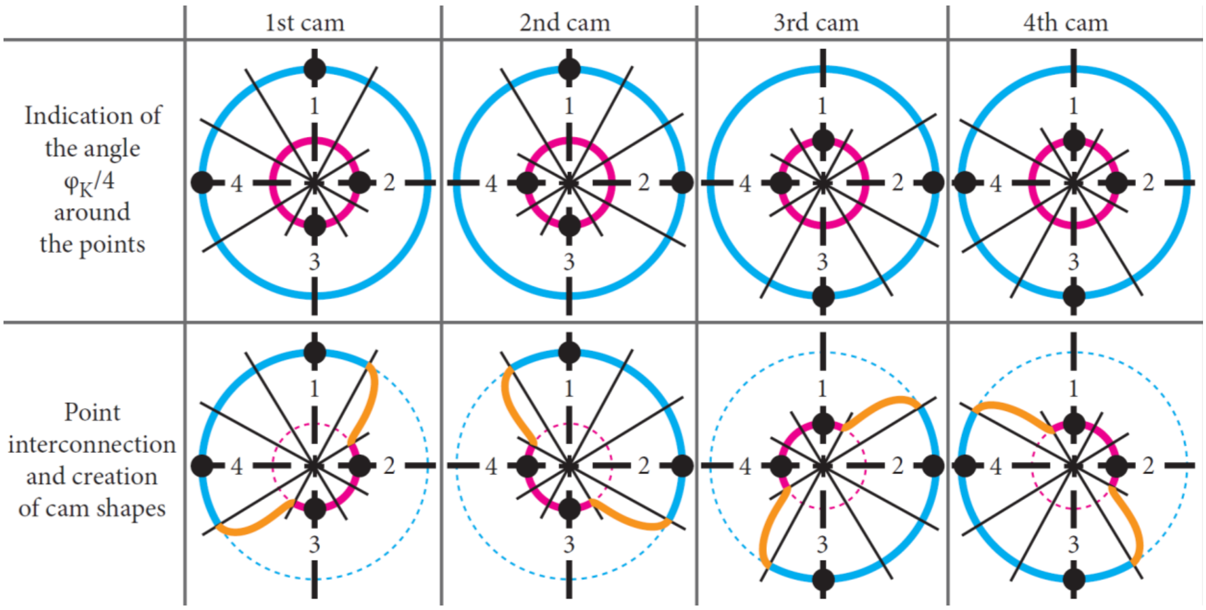


Figure 97: Last step of the procedure for drawing the shapes of cams for stitched 4-harness twill

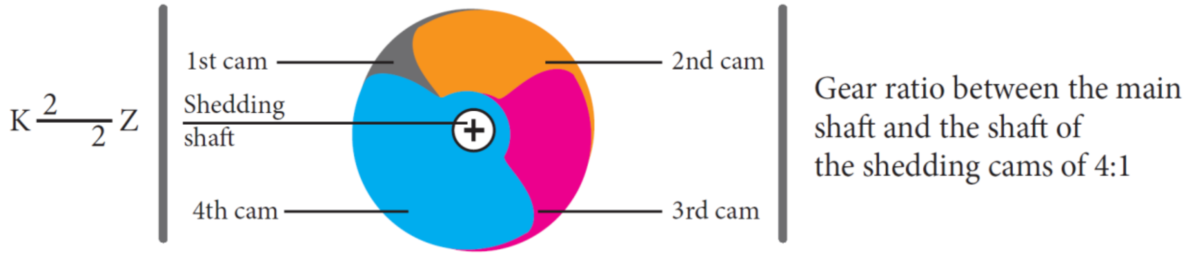


Figure 98: Final assembly of the cams for stitched 4-harness twill

The above procedure shows that each shaft changes its position only in the case where the threads threaded through it change the type of interlacing points (from the warp threads to the weft threads or vice versa). For example, in our case, the roller of the second cam is on the large radius in the insertion of the first and second wefts. This means that during the two weaving cycles, the second shaft remains motionless in the top position. This shaft moves to the bottom position in the third cycle and remains there also in the fourth cycle. Changing the position of the individual shafts within four weaving cycles is illustrated in the following graph:

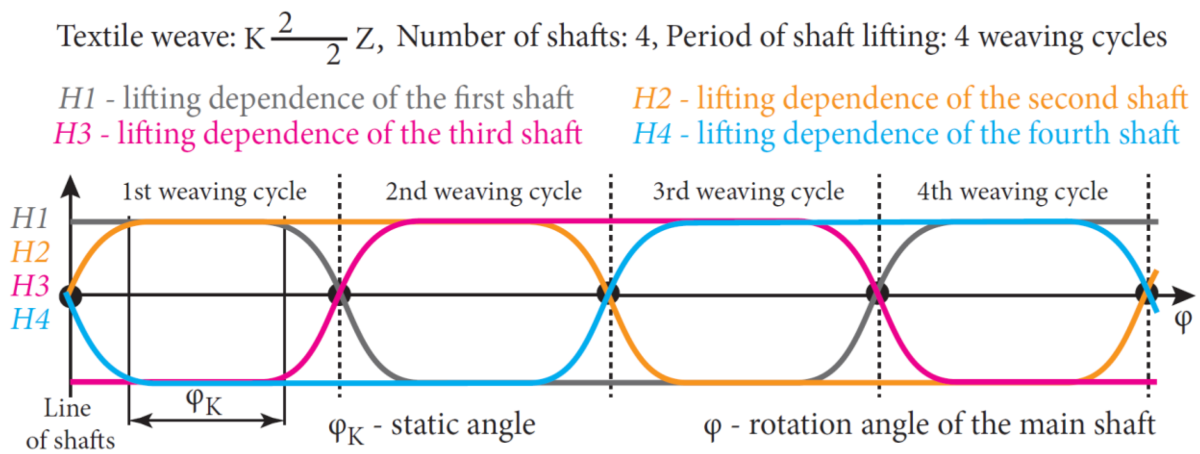


Figure 99: Lifting dependence of shafts during four weaving cycles for stitched twill

The graph shows that in the production of the above mentioned stitched twill, all warp threads are not in the weaving plane with the shafts in line. Each heald shaft moves to the position indicated as the “line of shafts”, i.e. in the weaving plane, every two weaving cycles and in the weft beat-up, one shaft always remains in the top position and one shaft in the bottom position. The beat-up is then made in the so-called “open shed”. The problem related to the weft beat-up in the closed and open shed is outlined in more detail in Chapter 4.6.3.

The above described method can be applied to assembling the shedding cams for all types of basic weaves and derived simpler weaves.

Important findings of the chapter:

1) We know the principle of function of the cam shedding mechanism and its configuration.
2) We know what constitutes the program for creating the desired weave for cam mechanisms.
3) We know what is the complementary cam.
4) We can assemble shedding cams for different weaves.

4.4.2 Dobby shedding mechanisms and technical pattern of fabric

The dobby shedding devices are designed to **suspend sixteen to twenty-eight shafts**, which, with regard to the cam shedding mechanisms, extends the interlacing capacity. On the weaving machines with dobby shedding mechanism, **it is possible to create even more complex derived weaves or different interlacing techniques** for multi-warp, multi-weft or tubular fabrics [9]. Another advantage of dobby shedding mechanisms is a relatively high operator comfort when changing the weave of the fabric to be produced. In technological practice, the electronically controlled dobby mechanisms are predominantly used today, which allow to make the change in weave using a computer and thus without manual operator intervention.

In general, the dobby shedding mechanisms can be divided by the mode of operation into two groups: **single-lift and double-lift mechanisms**. The single-lift mechanism discontinues its operation within one revolution of the main shaft, i.e. the operating frequency of the shedding mechanism is identical with the weaving frequency. Therefore, in the weft beat-up, all warp threads are always in the weaving plane, regardless of the weave of the fabric to be produced. This means that on the weaving machines with single-lift mechanism, the beat-up is always made in the closed shed. The double-lift mechanism discontinues its operation within two revolutions of the main shaft. The operating frequency of the shedding mechanism is thus half the weaving frequency. The position of the shaft changes only when the warp threads threaded through it change the type of interlacing points. The double-lift mechanism thus changes the position of shafts in a manner similar to the cam shedding mechanism (see Chapter 4.4.1) and in case of certain weaves, the beat-up is made in the open shed.

The properties of double-lift shedding mechanisms may adversely affect the weaving process in certain aspects. These are mainly the problems related to the weft beat-up in the open shed (for more information see Chapter 4.6). On the other hand, the weaving machines equipped with the double-lift shedding mechanism are able to operate at a higher weaving frequency than the weaving machines equipped with the single-lift mechanism. This is because using the double-lift device decreases the dynamic forces (see note below) acting in the shedding mechanism. The ability to achieve higher weaving frequencies is currently preferred over the above mentioned negative phenomena. Therefore, **double-lift dobby shedding mechanisms prevail significantly in practice**. For teaching purposes, the mode of operation of both types of dobby mechanisms (double-lift and single-lift) is described hereinafter.

Note: As previously mentioned (see Chapter 4.4.1), the dynamic forces in the shedding mechanism are determined by the product of mass and acceleration of the shaft. Since the angular velocity of the double-lift shedding mechanism at the given weaving frequency is half as large as for the single-lift mechanism, the acceleration values in creating periodic lifting dependencies of shafts are smaller. To get a better idea, the time dependence of the shaft lifting can be expressed approximately by means of a harmonic function:

$$H(t) = A.\cos(\omega.t),$$

where H is the shaft lifting, t is the time, A is the amplitude (maximum value) of the shaft lifting and ω is the angular velocity of the weaving machine, i.e. the main shaft.

Then, the acceleration is determined by the second derivative of lifting by the time and is expressed by the relation:

$$\frac{d^2H(t)}{dt^2} = a(t) = -A.\omega^2.\cos(\omega.t).$$

The relation for acceleration may be used to express the amplitude, i.e. the maximum value of acceleration of the single-lift mechanism:

$$a_{MAX} = A.\omega^2.$$

Since the angular velocity of the double-lift mechanism is half the angular velocity of the main shaft, the maximum value of acceleration in the double-lift shedding device can be expressed by the relation:

$$a_{MAX} = A.\left(\frac{\omega}{2}\right)^2 = A.\frac{\omega^2}{4}.$$

The comparison of the relations for the maximum acceleration of the single-lift and double-lift mechanisms shows that, assuming identical weaving frequency, mass of the shafts and their harmonic motion, the dynamic forces in the double-lift mechanism are four times less than in the single-lift mechanism. Therefore, the weaving machines with double-lift dobby mechanisms are able to work at the weaving frequencies significantly higher than those of the machines with single-lift mechanisms.

Dobby shedding mechanisms

The dobby shedding device is essentially a **mechanical amplifier**, which is **composed of two main parts: pulse and power modules**. The pulse module of the mechanism includes a program for creating the desired textile weave, i.e. information on the interlacing methods for individual wefts. Furthermore, the pulse module comprises mechanical elements (needles, electromagnets), which, with a relatively small energy, transmit information on the interlacing method for individual wefts to the power module. The mechanical elements in the power module are then able to ensure change in the position of individual shafts with high energy.

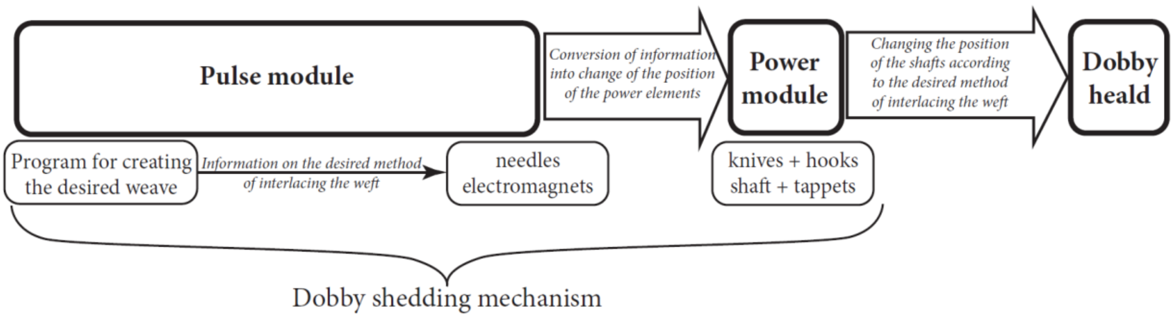


Figure 100: Block diagram of the main parts of dobby shedding mechanisms

Depending on the means that are used in the power module, the **dobby shedding devices can be divided into two groups**. The systems, which are in the literature referred to as the **Hattersley dobby shedding devices**, use knives and hooks to implement the motion of the shafts. The disadvantages of the Hattersley dobby mechanisms result from the so-called "tying clearances", which must be provided between the knives and the hooks. These clearances negatively affect the behaviour of the shedding mechanism during the weaving process and reduce the weaving frequency. Therefore, **in current technological practice, rotary dobby mechanisms predominate**, which in their power modules use the shaft with variable angular velocity and tappets. This arrangement virtually eliminates clearances in the shedding mechanism and by eliminating the impact forces, it allows to achieve higher weaving frequencies.

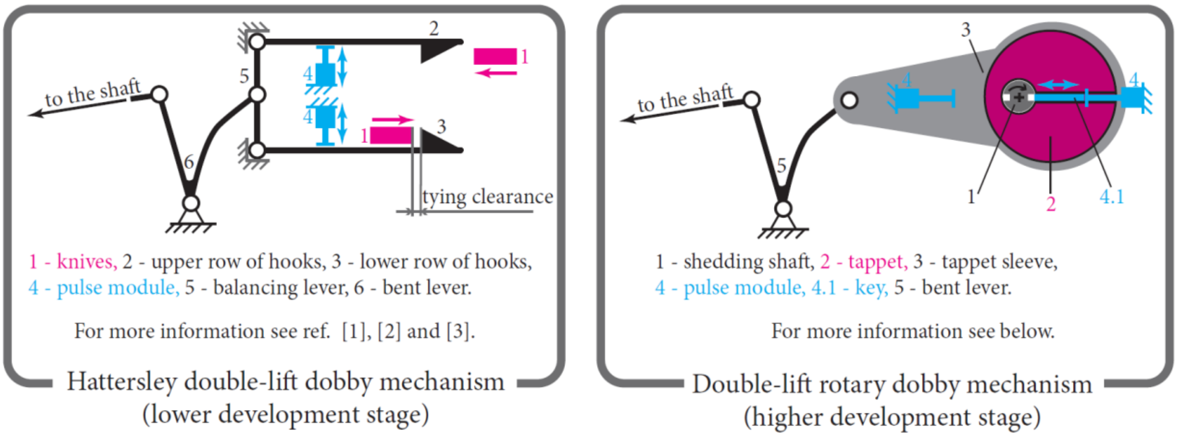


Figure 101: Distribution of the dobby mechanisms by the means used in the power module

The design and function of the Hattersley type shedding devices are described in detail in previously published literature: [1], [2] and [3]. This textbook provides only a brief description of this type of mechanisms with respect to the differences between the single-lift and double-lift mechanisms.

Hattersley dobby mechanism: single-lift and double-lift

Figure 102 shows the diagram of Hattersley single-lift and double-lift mechanisms. The **single-lift mechanism** is equipped with one knife and one row of hooks (the number of hooks corresponds to the number of shafts in the heald). The knife is driven and performs sliding oscillating motion with a period of one weaving cycle. The pulse module of the mechanism controls the individual hooks by moving the appropriate hook towards or away from the knife. The shaft is connected with the hook through a bent lever.

The **double-lift mechanism** is equipped with two rows of hooks. The pairs of hooks from the upper and lower rows are connected together through a balancing lever. The shaft is connected to the balancing lever through the bent lever. The mechanism is equipped with two knives that perform opposing sliding oscillating motion with a period of two weaving cycles. The pulse module of the mechanism again controls the appropriate hooks and they are moved towards or away from the knife depending on the desired textile weave.

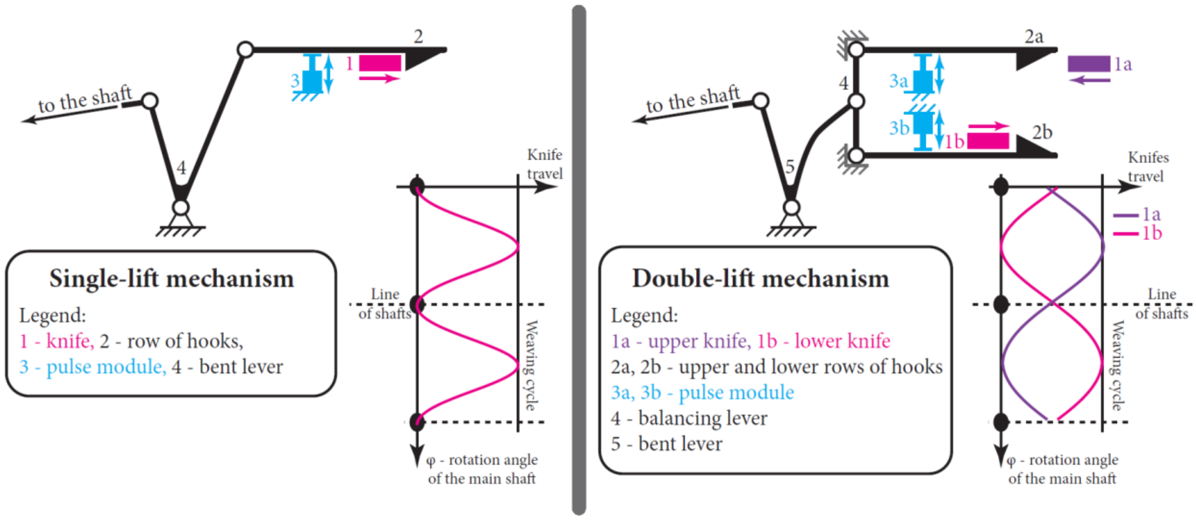


Figure 102: Hattersley single-lift and double-lift dobby mechanism

The **function** of the single-lift and double-lift mechanisms is shown in Figure 103. This figure illustrates schematically the positions of the hooks and knives in their extreme positions during three weaving cycles. The not illustrated shaft is connected to the S-point on the hook through the not illustrated bent lever (for single-lift mechanism) or to the S-point of the balancing lever (for double-lift mechanism). When the S-point is on the left, the shaft is in the bottom position and when the S-point is on the right, the shaft is in the top position. The drawing and description of the function of the mechanisms are based on the situation where the shaft is in the bottom position; in the first and second weaving cycles, it takes the top position and in the third cycle, it is again in the bottom position.

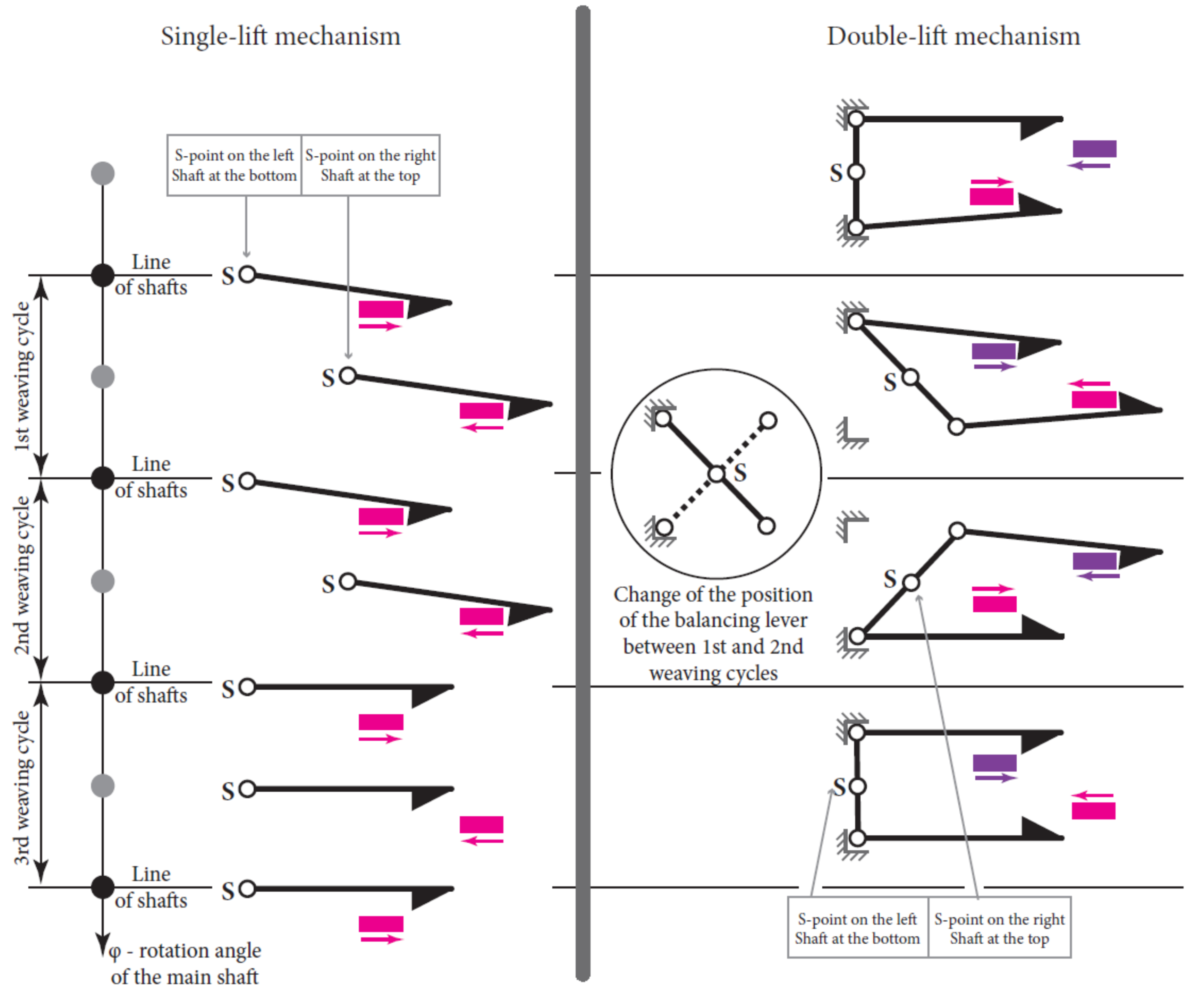


Figure 103: Schematic representation of the extreme positions of the hooks and knives during three weaving cycles

For single-lift mechanism, the hooks are tied in the position of the line of shafts. In the first weaving cycle, the hook in this position is moved towards the knife. The knife moves the hook to the right and the shaft connected through a bent lever to the S-point takes the top position. In this first weaving cycle, the knife then returns to the initial position (left). Therefore, at the beginning of the second cycle (in the position of the line of shafts), the S-point is again on the left and the shaft is in the bottom position. Now, the hook is again moved towards the knife and during the second weaving cycle, the shaft is moved in the same manner to the top and subsequently to the bottom position. At the beginning of the third cycle, the hook is moved away from the knife and in the third weaving cycle, the S-point remains motionless in the left position and the shaft remains in the bottom position. The single-lift shedding mechanism thus changes the position of the shafts (moves to the top position) when the threads threaded through it should create the warp interlacing points and within each weaving cycle, the shafts are moved from the top position back to the bottom position. The shafts, through which the threads forming the weft interlacing points are threaded, remain motionless in the bottom position. Therefore, in the beat-up, all warp threads are always in one plane, regardless of the weave of the fabric to be produced.

For **double-lift mechanism**, tying takes place in the middle of the weaving cycle. This means that, in this case, the bottom hook was moved towards the knife in the middle of the weaving cycle, which precedes the first cycle. During the interval of the weaving cycle, the bottom hook is moved to the right, thus moving also the S-point on the balancing lever to the right. Therefore, in the first weaving cycle, the shaft is in the top position. In the middle of the first cycle, the top hook moves towards the knife. The bottom knife with the hook moves to the left and the top knife moves to the right with the result that they reach their extreme positions during the interval of the weaving cycle. Therefore, in the transition from the first to the second weaving cycle, the balancing lever turns around the S-point but the position of the S-point will not change (the S-point is always on the right). The shaft connected through a bent lever to the S-point therefore remains motionless in its top position even in the second weaving cycle. In the second weaving cycle, the bottom hook moves away from the knife, thus remaining in its left position. The top hook is moved to the left and, in the third weaving cycle, the S-point on the balancing lever changes its position (moves to the left), i.e. in the third weaving cycle, the shaft is in the bottom position. If the top hook is moved away from the knife in the third cycle, the shaft will remain in the bottom position also in the fourth cycle. The shafts in heald of the double-lift mechanism thus remain motionless in their top position until the threads threaded through it shall create the warp interlacing points. Therefore, in the case of some weaves, the beat-up is carried in the open shed, i.e. all warp threads are not in one plane during the beat-up.

Figure 104 shows the dependence of the shaft lifting on the rotation angle of the main shaft during three weaving cycles for the above described model situation using the single-lift and double-lift mechanisms.

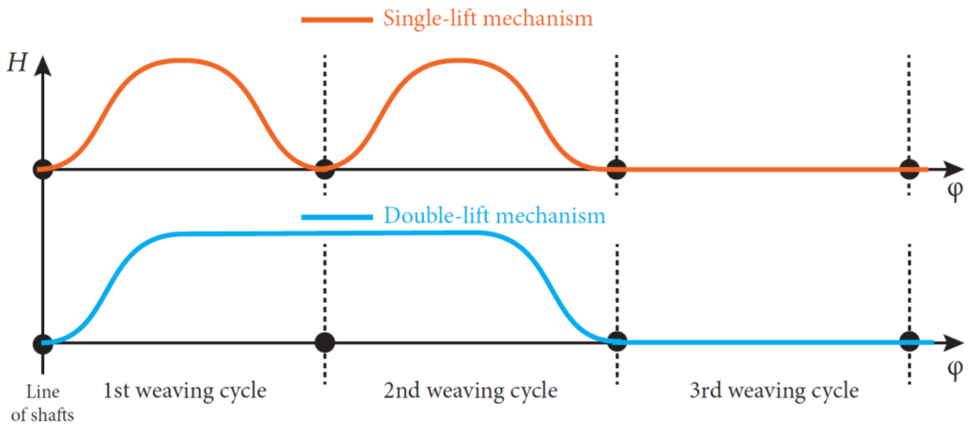


Figure 104: Course of shaft lifting during three weaving cycles, as described above

Double-lift rotary dobby mechanism

Due to the preference given to the possibility of achieving higher weaving frequencies, the rotary dobby shedding devices are always designed as double-lift mechanisms. The main parts of the rotary shedding mechanism are shown in Figure 105. The mechanism is located in the oil housing on the right side of the machine and consists of the tappet shaft, which is driven by the main shaft via the angular velocity modulator. The rotation frequency of the tappet shaft is half size with regard to the weaving frequency. The angular velocity modulator ensures the change in the angular velocity of the tappet shaft within the weaving cycle so as to allow handling of keys using the pulse device (see description of the function of the mechanism). There are the bushings securely mounted (keyed) on the tappet shaft, having grooves on the opposite sides. The tappets float on the bushings, but the keys allow interconnection of the tappet and the bushing. When the tappet is connected with the rotating bushing, the motion is transferred via the tappet sleeve and the bent lever on the shaft. The number of tappets is equal to the number of shafts in the heald, i.e. each tappet controls one shaft.

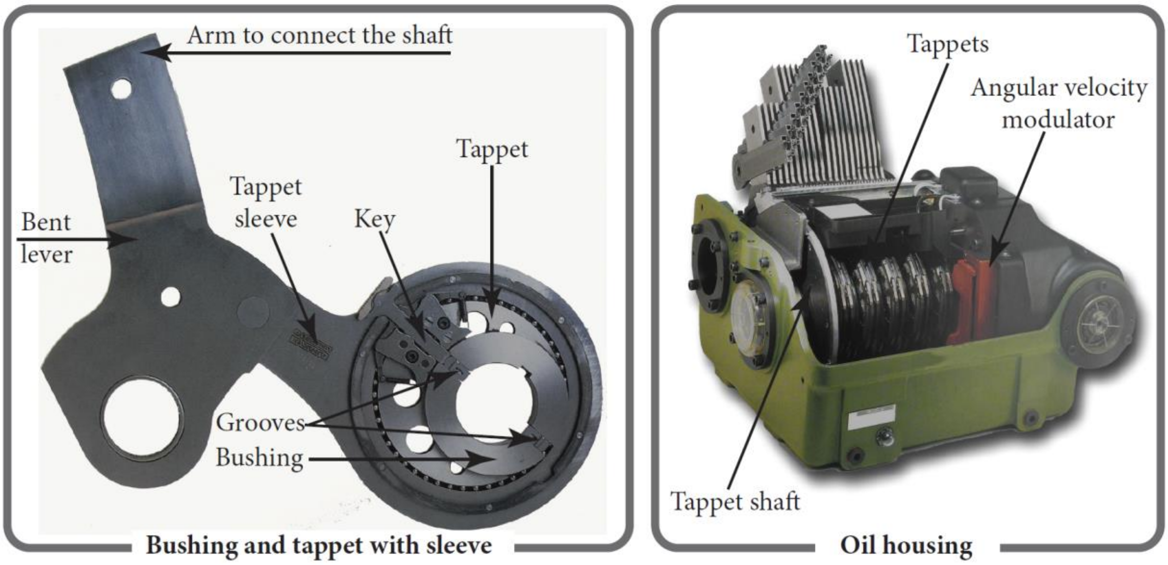


Figure 105: Main parts of the double-lift rotary dobby mechanism (source) [25]

Figure 106 shows a simplified diagram of the double-lift rotary dobby mechanism. The bushing is not drawn and the grooves are indicated directly on the tappet shaft. The diagram is completed by a graph showing the dependence of the angular velocity of the tappet shaft on the rotation angle of the main shaft during two weaving cycles. The key is the only component of pulse module drawn.

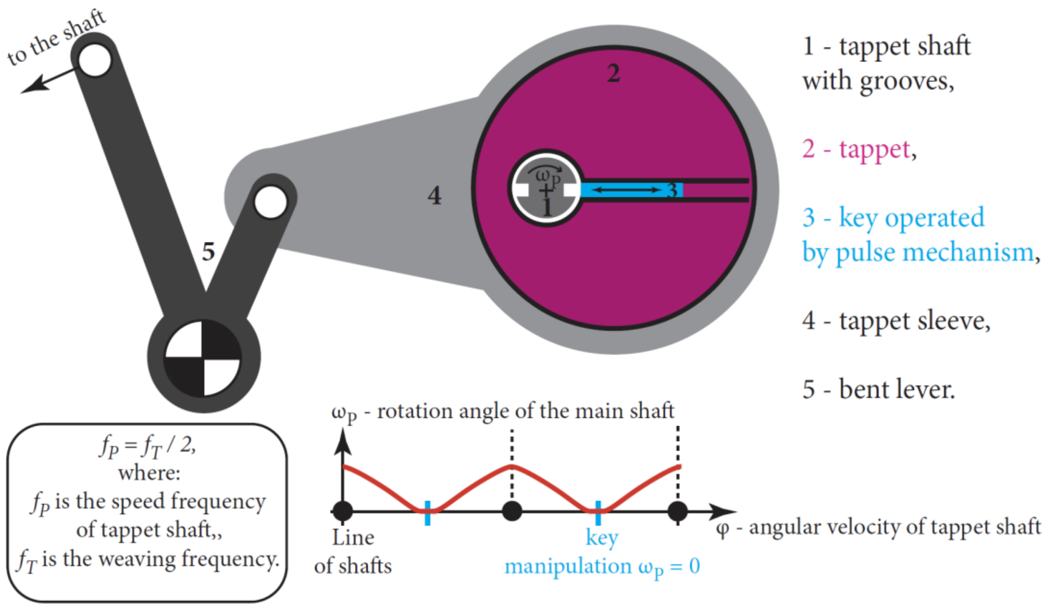


Figure 106: Diagram of the rotary dobby mechanism

During the weaving process, the tappet may take two positions that correspond to the extreme positions of the shaft. When the mechanical elements used to connect the shaft to the bent lever are arranged as shown in Figure 107, the appropriate shaft is in the bottom position upon rotation of the tappet to the right. When the tappet is rotated to the left, the appropriate shaft is in the top position. The diagram shown in Figure 106 thus corresponds to the bottom position of the shaft. In the middle of the interval of the weaving cycle, when the angular velocity of the tappet shaft equals to zero, it is possible to manipulate the key. If the key is not inserted in the groove of the shaft, the tappet will remain rotated to the right and the shaft will remain in the bottom position also in the next weaving cycle. If the key is inserted in the groove of the shedding shaft, the tappet will rotate by 180° during the interval of one weaving cycle, i.e. in the next weaving cycle, it will be rotated to the left and the shaft will take the top position. At this moment, the angular speed of the shedding shaft again equals to zero and the key can be manipulated. If, in this position, the key is pushed out of the groove, the shaft will remain in the top position in the next weaving cycle and if the key remains inserted in the groove, the tappet will be rotated to the right and the shaft will take the bottom position in the next weaving cycle. Moving the key in and out is ensured by the pulse module of the mechanism according to the desired method of interlacing the individual wefts.

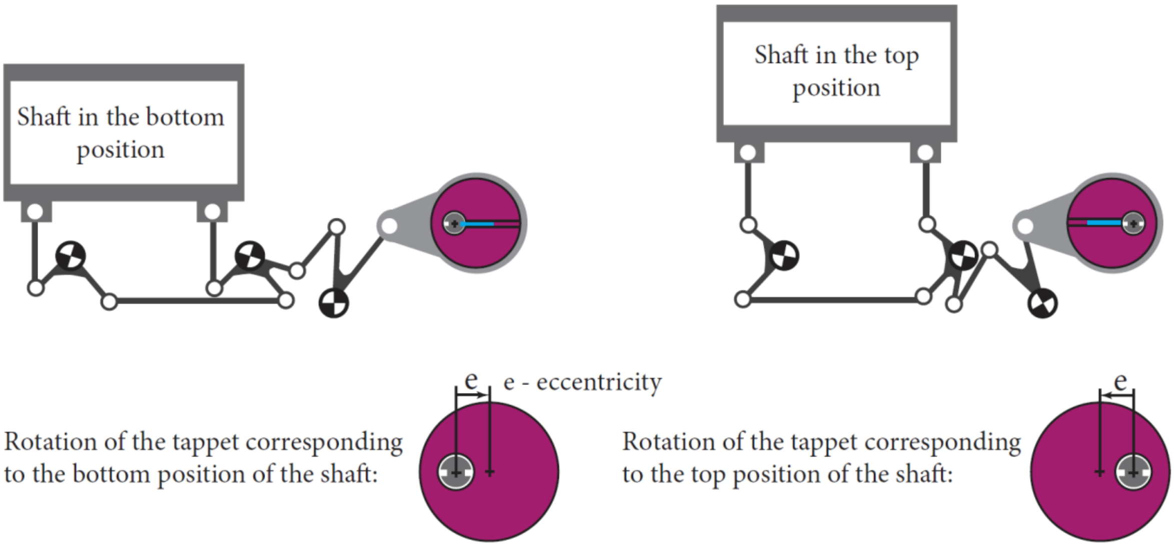


Figure 107: Tappet positions that correspond to the extreme positions of the shaft

The **function of the mechanism** will be described on the example of the same model situation as the function of the Hattersley type mechanism, i.e. in the initial situation, the shaft is connected to the tappet in the bottom position, takes the top position the first and second weaving cycles and takes again the bottom position in the third cycle.

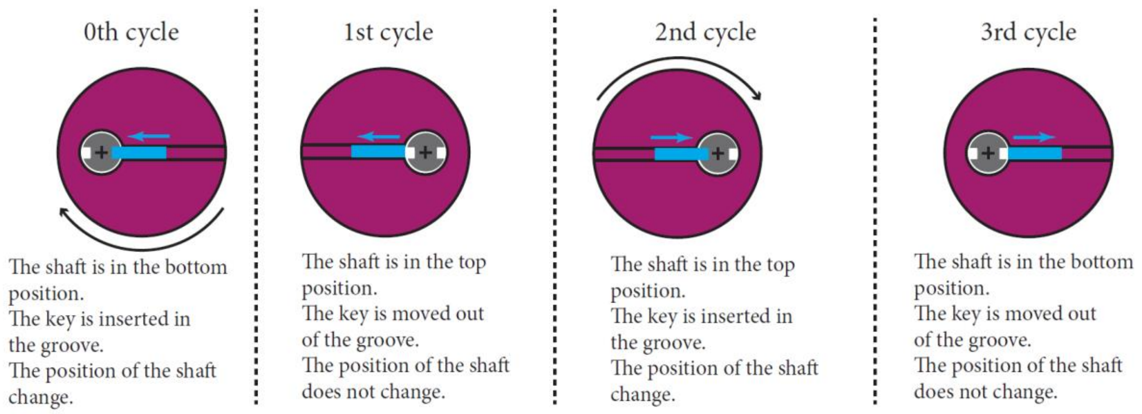


Figure 108: Tappet positions during three weaving cycles for the above described model situation

In the middle of the weaving cycle, which precedes the first cycle, the key is inserted in the groove. During the interval of the weaving cycle, the tappet rotates to the left. Therefore, in the first weaving cycle, the shaft is in the top position. In the middle of the first cycle, the key is moved out of the groove, the tappet remains rotated to the left and the shaft remains in the top position even in the second cycle. In the middle of the second cycle, the key is inserted in the groove and the tappet rotates to the right during the interval of the weaving cycle. Therefore, the shaft is in the bottom position in the third cycle. If the key is moved out of the groove in the middle of the third cycle, the shaft will remain in the bottom position also in the fourth cycle.

Dependence of the shaft lifting on the rotation angle of the main shaft for the above described model situation is shown in Figure 109. The graph is completed by the course of angular velocity of the tappet shaft during three weaving cycles.

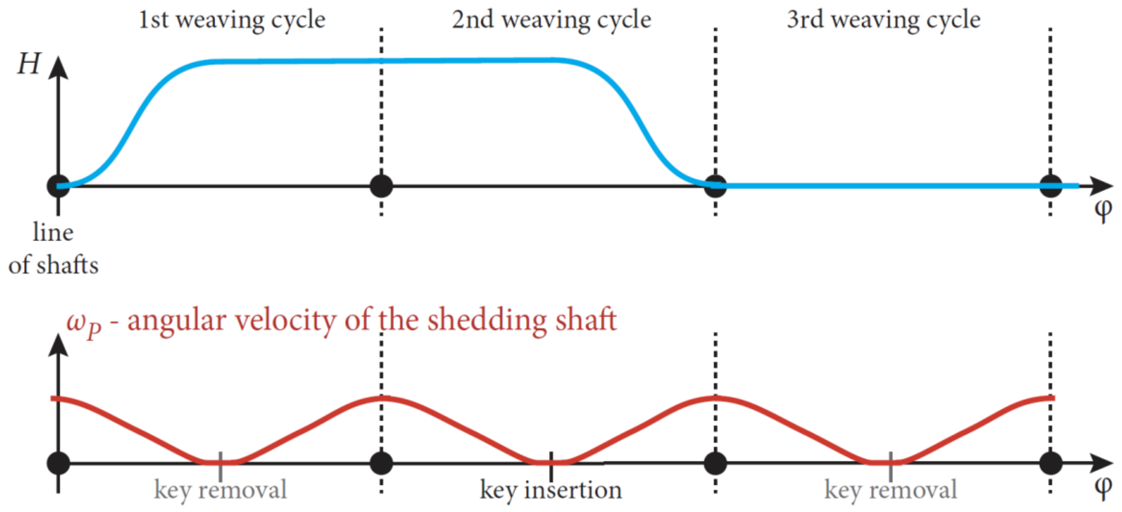


Figure 109: Course of shaft lifting during three weaving cycles for the above described model situation

Pulse module of the dobby mechanism

The pulse module of the dobby mechanism includes a program for creating the desired weave and elements that are able to transmit information on the interlacing method for the weft in question to the power module (needles or electromagnets, keys). **In terms of form of the program, dobby shedding mechanisms can be divided** into two groups: **mechanically and electronically controlled** shedding mechanisms.

In case of **mechanically controlled dobby mechanism**, the program is formed by the so-called “cards”, which are basically punch cards, which carry information on the interlacing method for individual wefts (see Figure 110). The cards are made of stiff cardboard. The method of interlacing the weft is indicated by means of full positions or holes so that the full position in the card represents the weft interlacing point and the hole in the card represents the warp interlacing point. The cards for individual wefts are joined (sewed) in the order that is determined by the order of the individual wefts in fabric. Then, the cards form a continuous chain that is attached to the perforated prism of the dobby mechanism. The pulse module further comprises needles that are pressed against the card by means of springs. Each needle is fixed to the top arm of the triangle lever and its sliding motion deflects these levers. The levers then move the keys in or out of the groove of the tappet shaft.

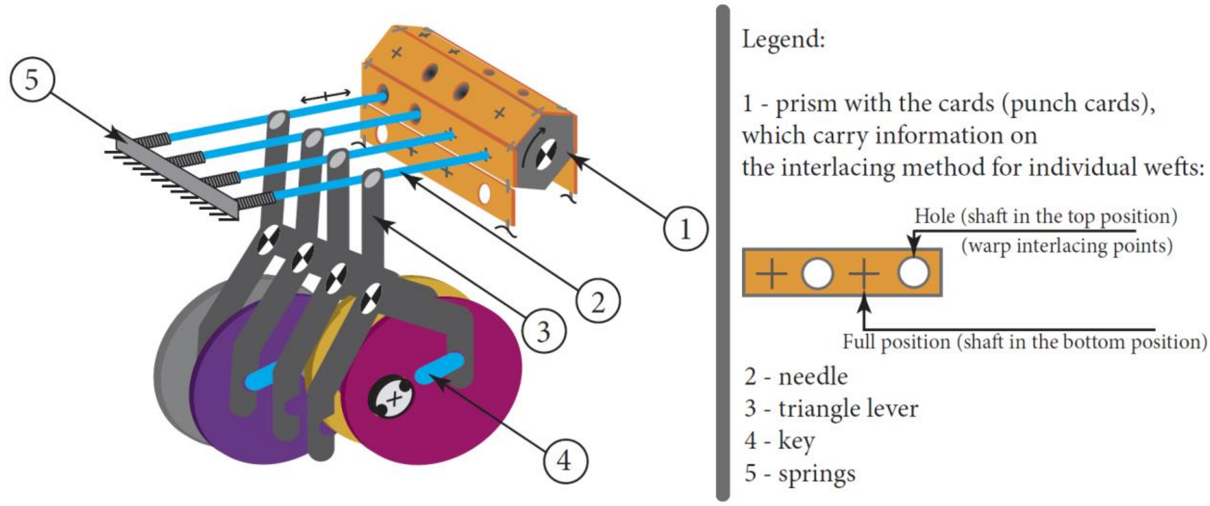


Figure 110: Main components of the pulse module of the mechanically controlled dobby mechanism

Function: After weaving in the weft, the prism is rotated during the interval of the weaving cycle so as to set another card against the needles. If the needle is against the full position (see Figure 111, left diagram), it will be moved to the left and the triangle lever will be deflected in the direction indicated. If the tappet is rotated to the right, the key will be moved out of the groove and the shaft will remain in the bottom position. If the tappet is rotated to the left, the key will be inserted in the groove and the shaft will move from the top position to the bottom position. The full position in the card thus constitutes a signal for creating the weft interlacing points. If the needle is against the hole (see Figure 111, right diagram), it will be moved to the right and the bent lever will be deflected so as to insert the key in the groove upon rotation of the tappet to the right, thus moving the shaft from the bottom position to the top position. Rotating the tappet to the left will move the key out and the shaft will remain in the top position. The hole in the card thus constitutes a signal for creating the warp interlacing points.

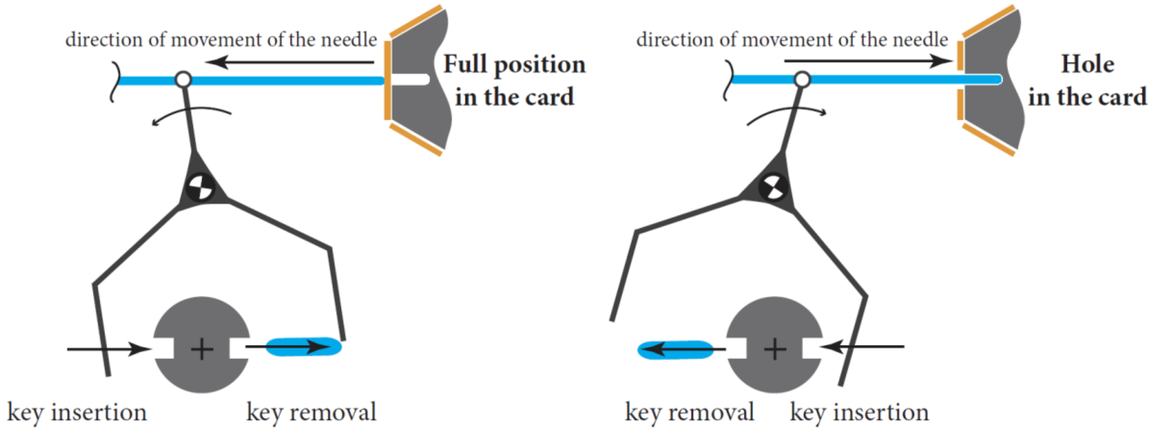


Figure 111: Positions of the triangle lever for the full position in the card and for the hole in the card

In case of **electronically controlled dobby mechanism**, the needles are replaced by electromagnets (electromagnetic relays) and the switching of electromagnets is controlled by a computer, which has stored in its memory information on the method of interlacing the individual wefts, i.e. textile weave (see Figure 112). Therefore, the program for the control of dobby shedding device has an electronic form.

Function: The computer provides information on the method of interlacing the weft in the form of a binary signal to the individual electromagnetic relays (electromagnets). If the appropriate relay is not closed (the electromagnet is not energised), the top arm of the triangle lever will be deflected to the left (see the diagram in Figure 112). If the relay is closed (the electromagnet is energised), the top arm of the triangle lever will be deflected to the right. Manipulation of the keys is then identical to the mechanical control. Open relay thus replaces the full position in the card and constitutes a signal for creating the weft interlacing points. Closed relay replaces the hole in the card and constitutes a signal for creating the warp interlacing points.

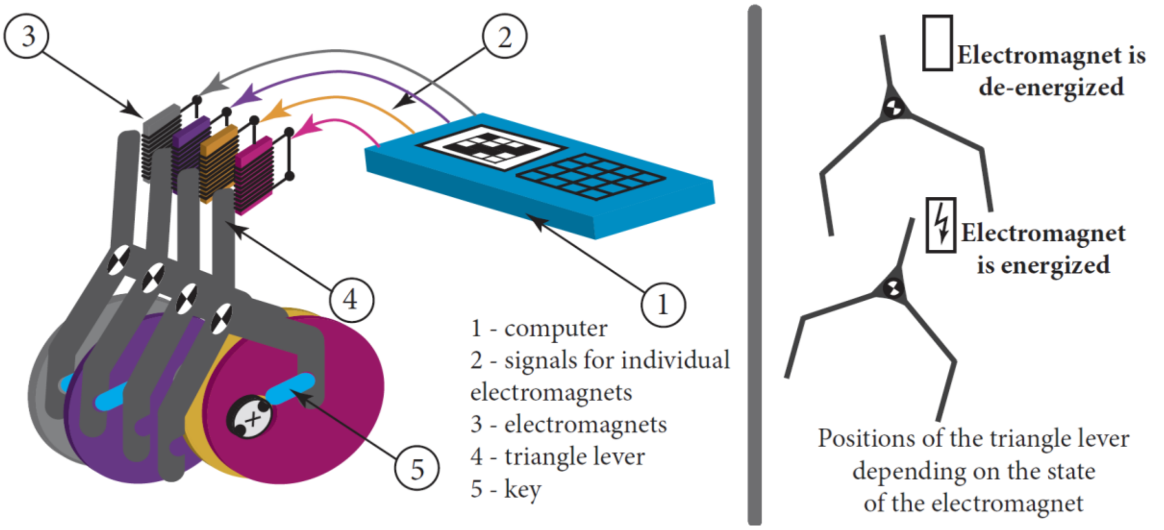


Figure 112: Main components of the pulse module of the electronically controlled dobby mechanism

The **advantages of the electronically controlled dobby mechanisms** are evident. Removing the mechanical elements in the pulse module increases the life of the mechanism and in particular operator comfort in changing the weave of the fabric to be produced. The computer is usually equipped with a simple interface that allows to draw the required weave by means of a keyboard and save it to a computer disk for later use. As a matter of course, the created weaves are copied using portable storage media or via a network to which computers of the weaving machines are connected (see Chapter 4.8). The operator then selects the weave by simply selecting from an existing list of weaves and loading the desired pattern chart in the computer's RAM. Software is also often available for automatically changing the weave, which allows the production of fabrics comprising sections with various weave. With regard to the above advantages, the electronically controlled dobby mechanisms predominate in current technological practice and the mechanical control is described in the textbook for teaching purposes only.

The next part of the chapter defines the term "technical pattern of fabric" and describes the method of drawing this important part of the production specification. The complete technical pattern allows the creation of cards for mechanically controlled dobby mechanisms. The technical pattern is of great importance at present, when the electronically controlled dobby mechanisms are predominantly used. For these mechanisms, it is not necessary to create cards, but the technical pattern provides important information on the method of threading the warp threads in the dobby heald, the number of shafts in the heald and the method of suspending the shafts that must be respected when drawing the required weave in the computer. The above information is also used in preparing the warp, especially in the drafting operation. Therefore, technical pattern usually complements the production specification for fabric.

Technical pattern of fabric

Definition: Technical pattern of fabric is a plan view of fabric on the weaving machine in terms of the method of interlacing the warp and weft threads (weave), the passing of the warp threads through the dents of the reed and heddles of the dobby heald. Furthermore, the technical pattern shows the method of suspending the individual shafts on the shedding mechanism (shaft suspension) and the program for controlling the shedding mechanism (cards). The technical pattern is drawn in the pattern chart paper (see Chapter 3.5.1).

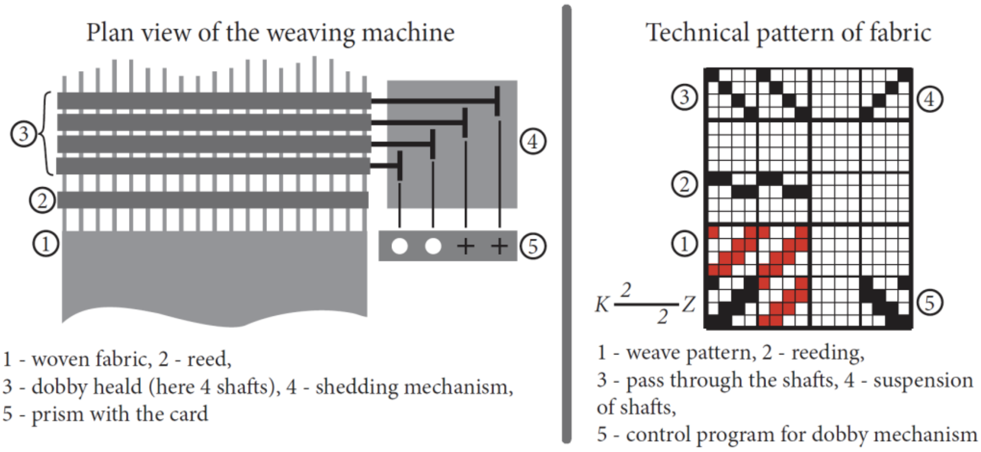


Figure 113: Plan view of the weaving machine and example of the technical pattern of fabric

Figure 113 shows the technical pattern of fabric with stitched 4-harness twill and regular tie in four shafts. The weave pattern is drawn in the lower left corner. Vertical spaces represent the warp threads and horizontal spaces represent the weft threads. Between the face of fabric and the dobby heald, the warp threads are threaded through the dents of the reed. Therefore, the reeding of threads is indicated above the weave pattern. In the top section of the technical pattern (in its left section), the threading of threads in heddles of the dobby heald is drawn and the shafts are represented by individual horizontal spaces. In the upper right section of the technical pattern, the method of suspending the individual shafts on the shedding mechanism (shaft suspension) is indicated and in the lower right section, the program for controlling the shedding mechanism (cards) is schematically indicated. The **procedure for drawing the individual parts of the technical pattern** is described below:

1. *Drawing the weave pattern* (see Chapter 3.5).
2. *Drawing the reeding:* The reeding is always drawn in two horizontal spaces. For clarity, several horizontal spaces (at least two) must be skipped between the two spaces and the last drawn weft in the weave pattern. Indicate threading of the first warp thread in the first dent of the reed with a filled square at the point where the first vertical space intersects the first horizontal space. If the second warp thread is to be threaded through the first dent of the reed, it is necessary to fill the square at the intersection of the second vertical space and the first horizontal space. According to the technical pattern shown in Figure 113, the third warp thread is threaded through the second dent. Therefore, the square at the intersection of the third vertical space and the second horizontal space is filled. The square filled at the intersection of the fourth vertical space and the second horizontal space means that the fourth warp thread will be also threaded through the second dent. Thus, in our case, the threading is indicated for all warp threads from the pattern repeat to the dents of the reed. It is clear that the threading must repeat periodically, i.e. the fifth and sixth warp threads are threaded through the third dent, the seventh and eighth warp threads are threaded through the fourth dent, etc. The reeding shown in Figures 113 and 114 therefore indicates that two warp threads will be threaded through each dent of the reed. In order to increase the clarity, the reeding is indicated up to the last drawn warp thread in the weave pattern.

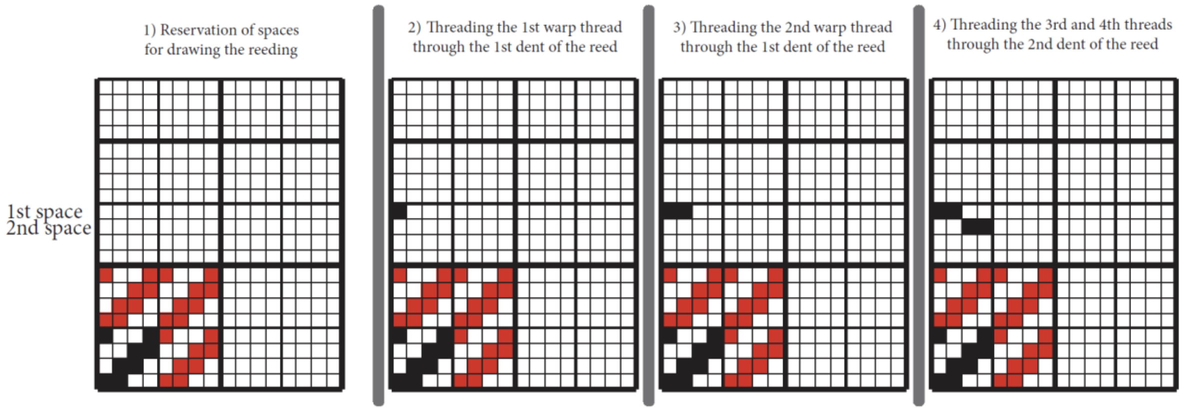


Figure 114: Procedure for drawing the reeding for the above technical pattern

The number of warp threads *n*, threaded through one dent, is generally determined by the proportion of the desired number of weft threads per unit length *Do (threads/10 cm)* and the reed number *Čp* : *n = Do / Čp.* Reed number is generally chosen so that the number of warp threads in one dent does not exceed 5, i.e. there can be ties by one, two, three, four or maximum five threads in one dent of the reed. The specific number of the threads threaded through one dent of the reed also depends on the parameters of warp threads and, to a certain extent, is chosen according to empirical experience and availability of the reeds with different number (see Chapter 4.6). In terms of weave, the reeding is generally solved so as to achieve threading of the warp threads from the pattern repeat in an integral number of dents, i.e. the warp pattern repeat is divisible by the number of threads in one dent of the reed. The number of the threads threaded through the individual dents of the reed may not always be the same. For example, in fabrics with weave of irregular longitudinal ribs, irregular longitudinal ribs may be highlighted by threading identically interlaced warp threads in a common dent of the reed (see first tie-up in Figure 164). The most commonly used is passing two threads through the dent and for warp threads with the highest fineness T_O *(tex)*, there can be the passing of one thread through the dent of the reed. For 5-harness satin of the warp threads with a higher fineness T_O *(tex)*, the passing of three threads through the odd dents and two threads through the even dents is sometimes used. For 5-harness satin of the warp threads with a lower fineness T_O *(tex)*, the passing of five threads through the dent of the reed is generally used.

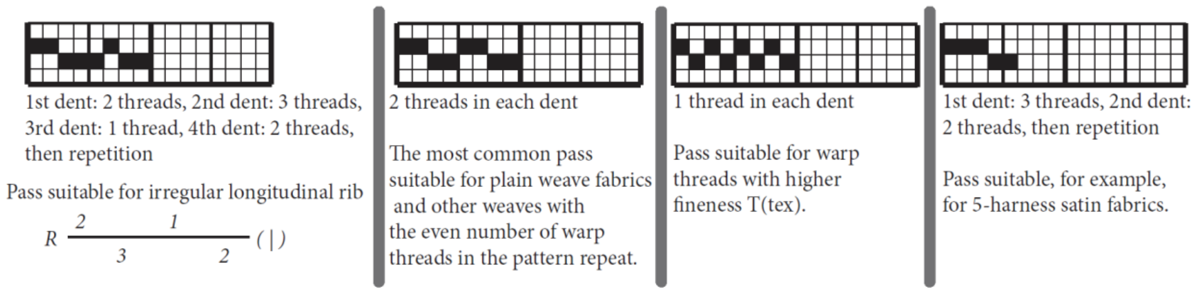


Figure 115: Examples of different ways of passing the warp threads through the dents of the reed

3. *Drawing the pass through the shafts:* Horizontal spaces in the top section of the technical pattern (in its left section) represent the individual heald shafts. Therefore, the number of horizontal spaces, which can be used in drawing the pass through the shafts, is determined by the number of shafts in the heald. Figure 113 shows the heald, which contains four shafts. Therefore, four horizontal spaces will be reserved for drawing the pass through the shafts. The highest horizontal space represents the first shaft, the second space represents the second shaft, the third space represents the third shaft, and the fourth space represents

the fourth shaft. For clarity, it is again advisable to skip several horizontal spaces (at least two) between the space representing the last shaft and the reeding. Indicate the pass of the first warp thread through the eye of the heddle located in the first shaft by filling the square at the intersection of the first vertical space and the top (first) horizontal space. The second warp thread interlaces in a different way than the first thread and, therefore, should not pass through the heddle of the first shaft. In our case, the second warp thread passes through the second shaft, which is indicated by filled square at the intersection of the second vertical space and the second horizontal space. The third warp thread should not pass through the eye of the heddles in the first or second shaft as it interlaces in a different way than the threads threaded through these shafts. In our case, the third warp thread passes through the heddle in the third shaft, which is indicated by filled square at the intersection of the third vertical space and the third horizontal space. The last (fourth) warp thread from the pattern repeat interlaces in a different way than the three previous threads. Therefore, this thread cannot pass through the heddle in the first, second or third shaft, but must be threaded through the heddle in the fourth shaft, i.e. fill the square at the intersection of the fourth vertical space and the fourth horizontal space. This indicates the way of passing all warp threads from the pattern repeat. It is evident that the pass must further repeat regularly, i.e. the fifth warp thread will pass through the first shaft, the sixth thread will pass through the second shaft, etc. In order to increase the clarity, the pass through the shafts is indicated up to the last drawn warp thread in the weave pattern.

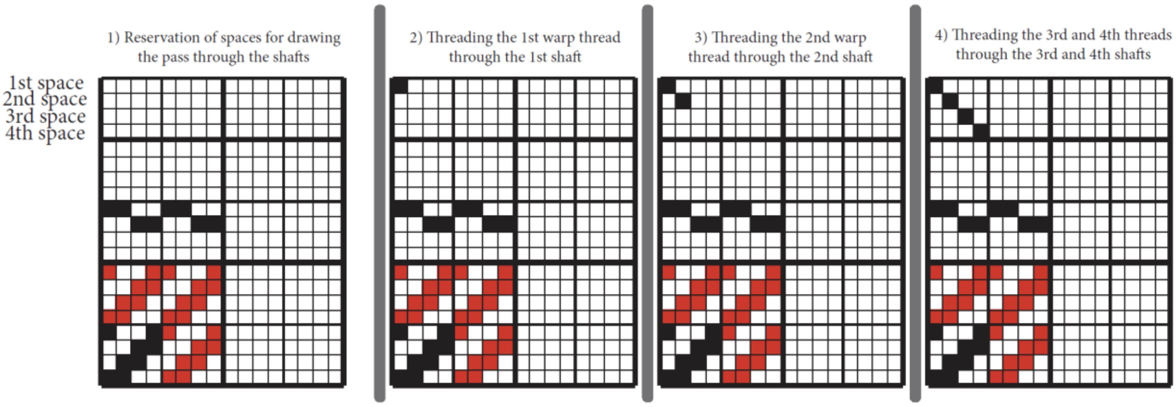


Figure 116: Procedure for drawing the pass through the shafts for the above technical pattern

The indicated pass through the shafts must always respect the already formulated general rule that only identical interlacing warp threads can be threaded through the common shaft. In our case, fabric contains four different interlacing warp threads. Therefore, its production requires using at least four shafts. But this fabric can also be produced with eight, twelve, sixteen, twenty ... shafts. Generally, the number of shafts in the heald must be divisible by the warp pattern repeat. The previously described regular tie is widespread in technological practice, but other ways of passing the warp threads through the dobby heald are occasionally encountered. The so-called “point tie” can be applied to the production of fabrics with a symmetrical pattern repeat, which minimises the number of the shafts used (see Figure 117).

Pass suitable for weaves with a symmetrical pattern repeat along the fifth warp thread:

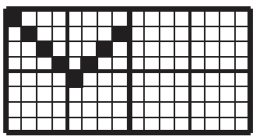


Figure 117: Example of the point tie in five shafts

4. *Drawing the suspension of shafts:* Horizontal spaces between the pass through the shafts and the suspension of shafts represent the lifting rods of individual shafts. In order to align

the warp threads in the shed opening in the top and bottom position, the first shaft must execute the highest lifting (or lowering) and for other shafts, the maximum lifting (or lowering) must be gradually reduced. Therefore, the first shaft is suspended on the shedding mechanism using the longest lifting rod and the lifting rods of the following shafts shall be gradually shortened (see plan view in Figure 113). In the technical pattern, the end of the lifting rod of the shaft, i.e. its suspension on the shedding mechanism, is indicated by the filled square in the upper right section. Therefore, in the technical pattern in Figure 113, the square is filled at the intersection of the maximum horizontal space, which represents the first shaft, and the vertical space, which is the rightmost position in the technical pattern. This point symbolises the suspension of the first shaft on the longest lifting rod. For other shafts, the lifting rods must be gradually shortened. Therefore, in the second horizontal space, the square is filled at the intersection with the second vertical space from the right, in the third horizontal space at the intersection with the third vertical space from the right, and in the fourth horizontal space at the intersection with the fourth vertical space from the right. These points then represent the suspension of four shafts.

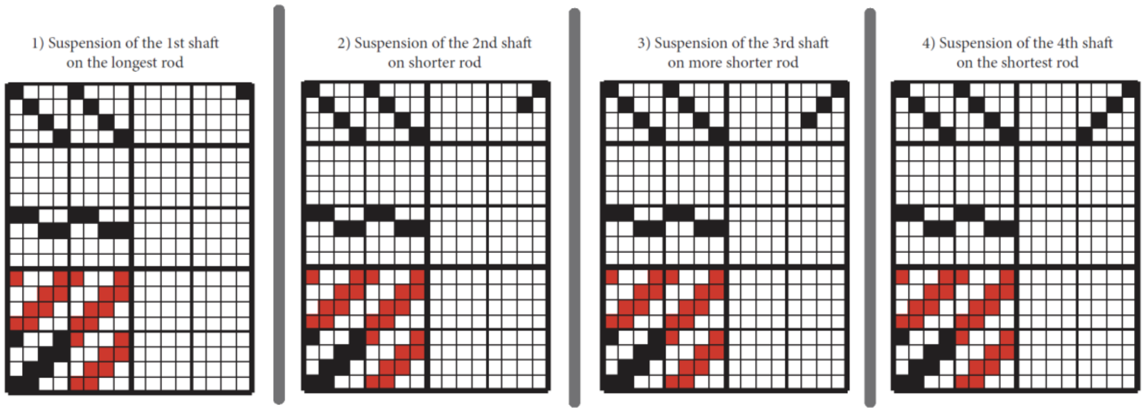


Figure 118: Procedure for drawing the suspension of shafts for the above technical pattern

When drawing the technical pattern, it is always necessary to indicate the suspension for each shaft in the heald. Given that the lifting rods of individual shafts must be shortened in the above described manner, the suspension of shafts is mostly shown in the form of the diagonal, pointed from right to left at an angle of 45°. This indicates that each shaft uses a separate suspension on the shedding mechanism, which is currently common in technological practice. However, if identical interlacing warp threads pass through the adjacent shafts, these shafts can be joined together and suspended on one suspension of the shedding mechanism. Joining the shafts together is shown in the technical pattern by filling several squares in one vertical space (see Figure 119).

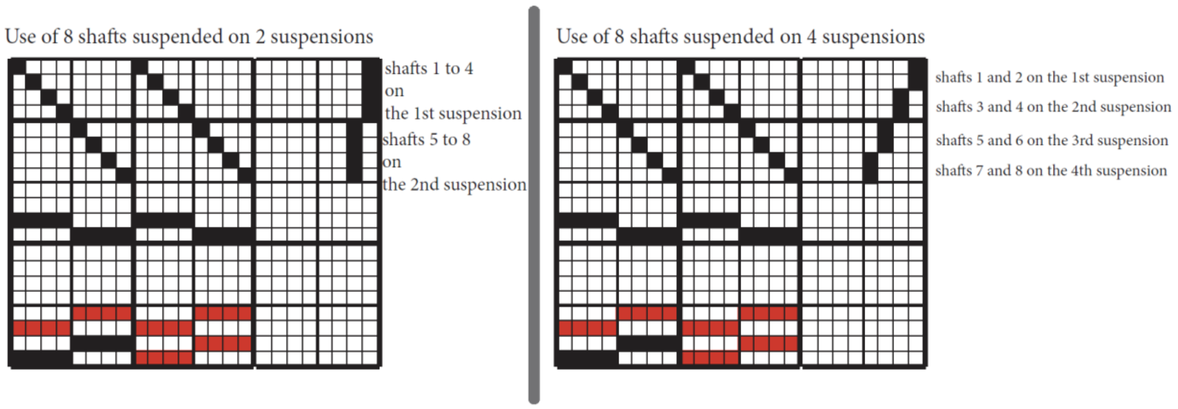


Figure 119: Examples of the suspension of shafts in technical patterns for longitudinal rib

5. *Drawing the control program for dobby mechanism (cards):* Now finish the technical pattern shown in Figure 113 by depicting the cards, which are the carriers of information on the method of interlacing the individual wefts in the case of mechanically driven dobby mechanisms. The cards are always drawn to the width of the suspension of shafts and to the height of the pattern repeat after the weft. This means that the number of used suspensions of shafts is determined by the number of working positions on each card. The number of cards to be drawn is determined by the pattern repeat in the weft. The individual cards are always drawn opposite to the appropriate weft and are represented by individual horizontal spaces. The filled square represents the hole in the card and thus the lifting of the relevant shaft (or shafts) suspended on the given suspension. The blank square represents the full position in the card, i.e. the respective shaft (or shafts) suspended on the given suspension will move to the bottom position. According to the method of interlacing the first weft, in our case, the first and second shafts must be moved to the top position in the first weaving cycle (the threads threaded through it form the warp interlacing points). Therefore, in the first horizontal space, fill the square opposite to the suspension of the first and second shafts. The squares opposite to the suspension of the third and fourth shafts must remain blank (the threads threaded through the third and fourth shafts form the weft points). The card for the first weft is thus completed. Draw the card for the second weft in the second horizontal space by filling the squares opposite to the suspension of the second and third shafts (the threads threaded through them form the warp interlacing points). Then continue drawing the third card in the third horizontal space. It is necessary to fill the square opposite to the suspension of the third and fourth shafts. Finish the technical pattern by drawing the fourth card, filling the square opposite to the suspension of the first and fourth shafts.

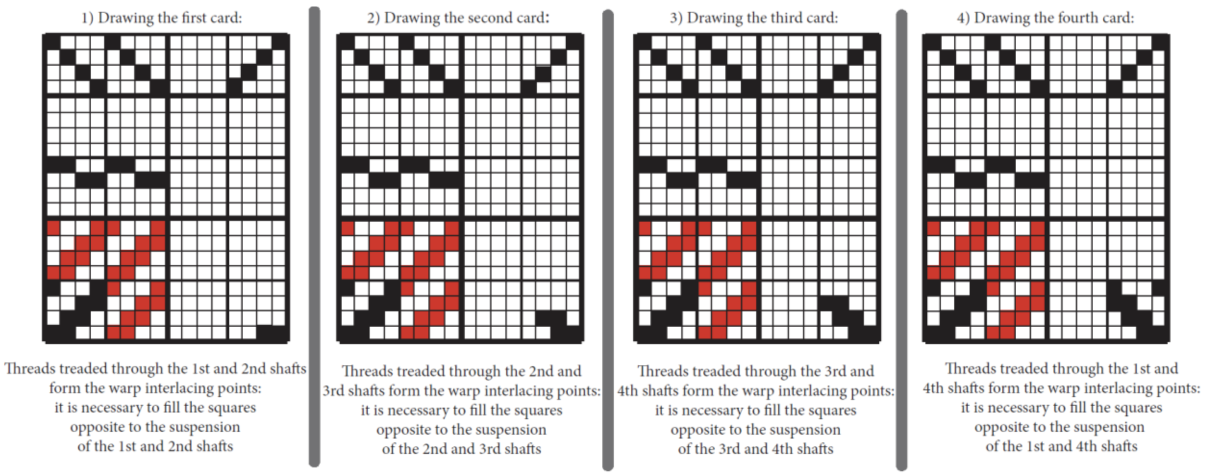


Figure 120: Procedure for drawing the cards for the above technical pattern

Drawing the control program allows the creation (punching) of cards for mechanically controlled dobby mechanisms. The filled square represents the hole in the card and the blank square represents the full position.

The following figures show the **technical patterns for basic weaves and some derived weaves**.

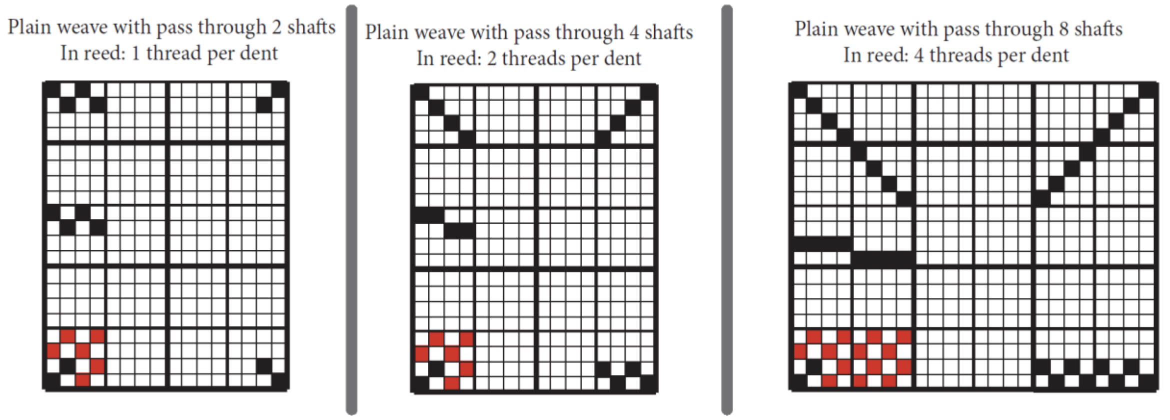


Figure 121: Technical patterns for plain weave with regular tie in different number of shafts

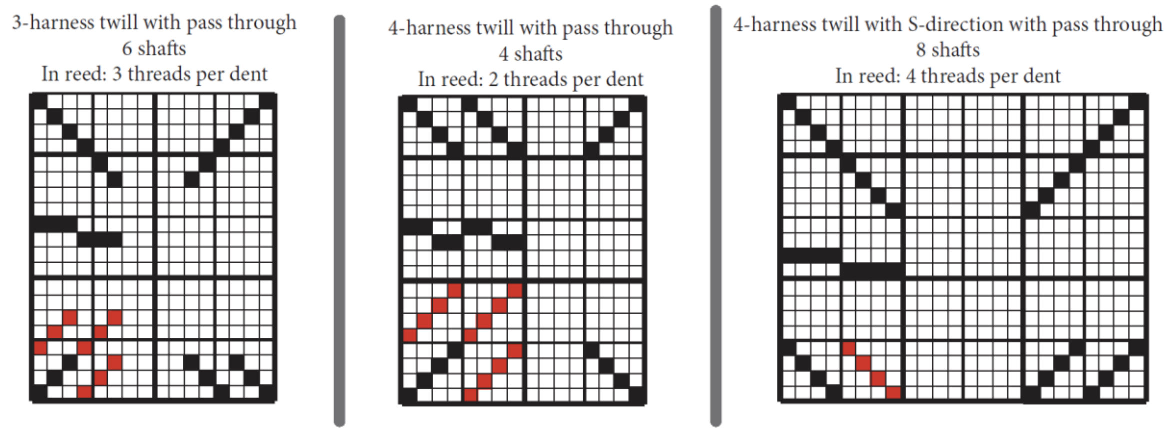


Figure 122: Technical patterns for different ground twills

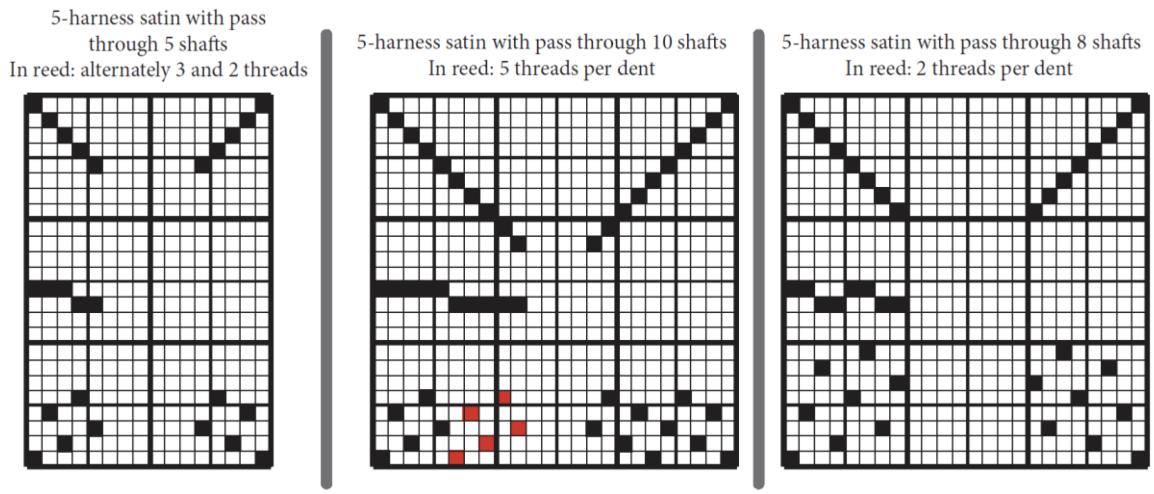


Figure 123: Technical patterns for different ground satins

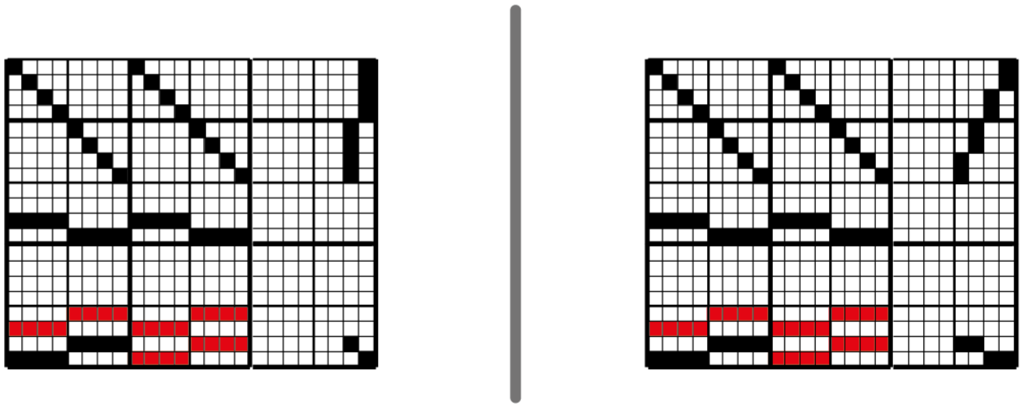


Figure 124: Completing the technical patterns for the longitudinal rib shown in Figure 119 by drawing cards

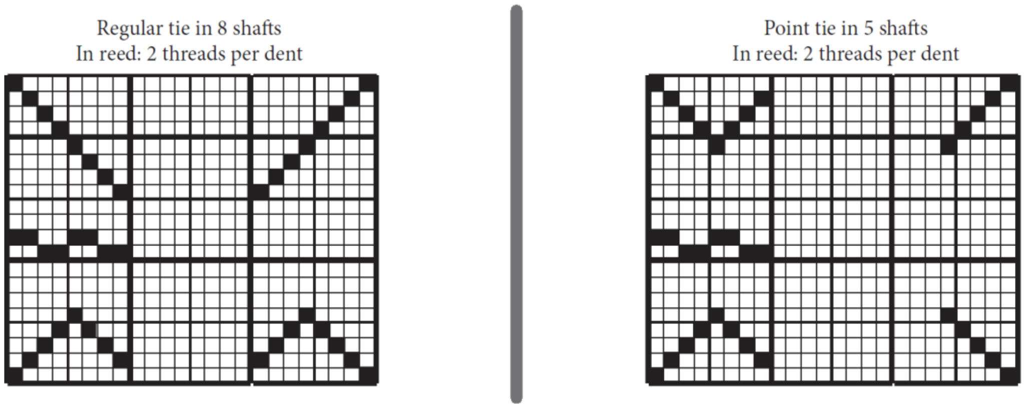


Figure 125: Technical patterns for longitudinal point twill

Recapitulation and procedure for drawing the technical pattern: For reeding, respect the rule that the warp pattern repeat passes through the integral number of dents. For making the weave on the weaving machine, the number of shafts in the heald is crucial. The heald must contain at least as many shafts as different interlacing threads in fabric. The number of different interlacing threads in fabric can be determined from the warp pattern repeat. For most weaves, the warp pattern repeat directly determines the number of different interlacing threads in fabric, but some weaves contain identical interlacing threads in the pattern repeat (e.g. the above mentioned longitudinal point twill). When the number of shafts in the heald is greater than the number of different interlacing threads, it is generally necessary to respect the rule that the number of shafts in the heald is divisible by the pattern repeat. If possible, the regular tie in the dobby heald is preferable, which is the most feasible method for the operator. Each shaft in the heald must be suspended and when drawing the suspension of shafts, the suspension of each shaft on a separate suspension is preferable. The cards are always drawn to the width determined by the number of suspensions and to the height of the pattern repeat after the weft.

Important findings of the chapter:

1) We know the main parts of the dobby mechanisms.
2) We can explain the difference between the single-lift and double-lift dobby mechanisms.
3) We can draw a diagram of the rotary dobby mechanism and explain its function.
4) We know the differences between the mechanically and electronically controlled dobby mechanisms.
5) We can draw technical patterns for a variety of textile weaves and we know relevance to technological practice.

4.4.3 Jacquard shedding mechanisms

The housing of the Jacquard shedding mechanism is mounted on a special structure above the weaving machine. Hooks or modules are arranged in the housing, which allow individual control of individual warp threads or, in the case of repeating patterns, control the warp threads by certain groups.

In general, the **Jacquard mechanisms can be divided into** identical **type groups** as the dobby mechanisms. In terms of function, the Jacquard shedding mechanisms are divided into single-lift and double-lift mechanisms with the result that their properties are identical with the appropriate type of dobby mechanism. This means that on the weaving machine with the single-lift Jacquard mechanism, the beat-up is always carried out in closed shed (during beat-up, all warp threads are in one plane) and on the weaving machine with the double-lift Jacquard mechanism, the beat-up is carried out in open shed. Also, in terms of form of the program for controlling the Jacquard mechanism, the Jacquard mechanisms can be divided into mechanically (program in the form of cards - punch cards) and electronically controlled (program stored in computer memory) mechanisms. In current technological practice, the double-lift Jacquard mechanisms with electronic control clearly predominate. The double-lift capacity of these mechanisms ensures their ability to operate at high weaving frequencies thanks to the minimisation of the dynamic forces acting in the hook, harness cord, heddle and spring system (see note in Chapter 4.4.2). The electronic control ensures a high operator comfort when changing the pattern of the fabric to be produced.

The **interlacing capacity**, i.e. the maximum number of different interlacing warp threads, which may comprise the fabric, **is determined by the number of hooks of the Jacquard mechanism**. The Jacquard mechanisms are constructed with different number of hooks. For older, mechanically controlled Jacquard mechanisms, the number of hooks is determined by the pitch of holes in the card and the number of parts of the mechanism (for more information see reference [10]). For example, for cards with the highest pitch (6.8 mm, the so-called “Vienna coarse pitch”), split devices were constructed with the number of hooks from 104 to 612. For cards with the smallest pitch (3 mm, the so-called “Verdol pitch”), devices were constructed, which contained multiples of 336 or 448 hooks. In the first case, there were devices equipped with the maximum of 1008 hooks and in the second case, there were devices equipped with the maximum of 1792 hooks. Currently available are the electronically controlled Jacquard mechanisms with significantly variable number of hooks or modules, which replace classical hooks (see description of the Jacquard mechanisms hereinafter). The modules are arranged in blocks in the form of panels, which can be placed in the housing of the mechanism in a different number. As an example, the numbers of the hooks of Jacquard mechanisms are stated, which are offered by leading manufacturers at the time of creation of the textbook, i.e. Bonas and Stäubli companies.

Number of hooks of the Bonas Jacquard shedding mechanisms (source [26]):

Type	**Number of hooks** (modules)						
ZJ	1,344	2,688					
LJ	2,688	4,032	5,376	6,336	8,448	10,560	12,672
Si	from 7,680 to 18,432						

Number of hooks of the Stäubli Jacquard shedding mechanisms (source [27]):

Type	**Number of hooks** (modules)					
LX 1602	3,072	4,096	5,120			
LX 3202	6,144	8,192	10,240	12,288	14,336	18,432

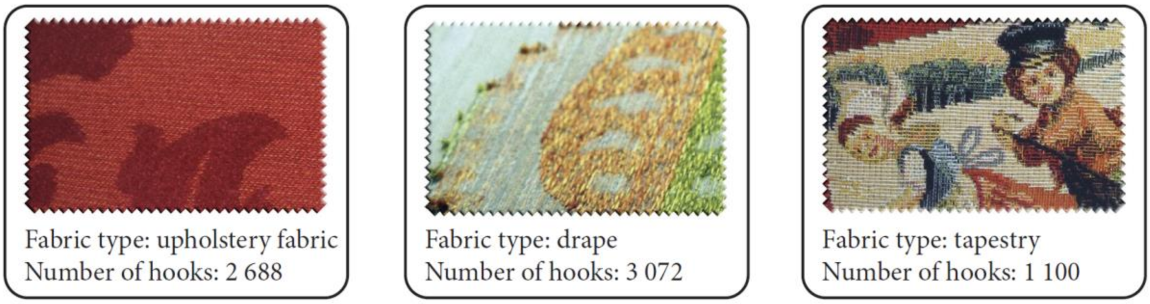


Figure 126: Examples of the fabrics produced with a certain number of hooks (source [26])

Jacquard shedding mechanisms

As in the case of the dobby mechanisms, the Jacquard mechanisms consist of **two basic parts: pulse and power modules**. In case of mechanically controlled Jacquard mechanisms, the pulse module includes the program in the form of cards (punch cards) and needles. The power module consists of hooks and knives, which are driven by the main shaft and perform sliding oscillating motion in the vertical direction. In case of mechanisms with electronic control, the program is in the computer's RAM and needles are replaced by electromagnets (solenoids). In the power module, the hook is replaced with a pair of plates, which are interconnected by cable. The cable runs through a pulley to which the harness cords are attached. The power module of the electronically controlled mechanism includes knives with sliding oscillating motion in the vertical direction.

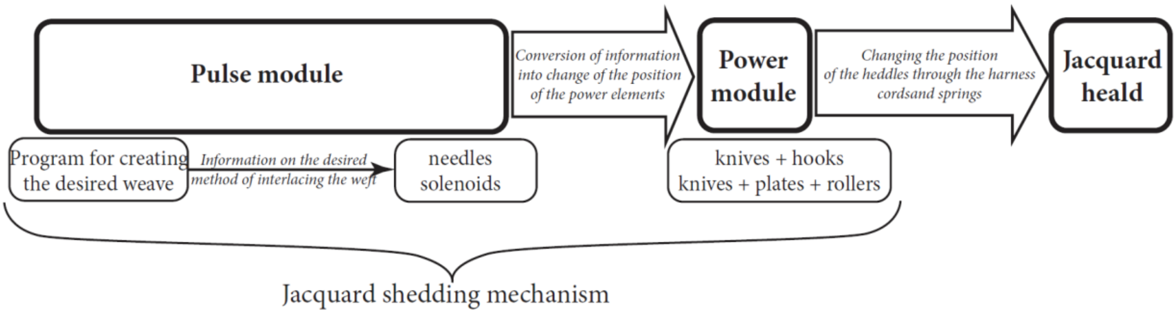
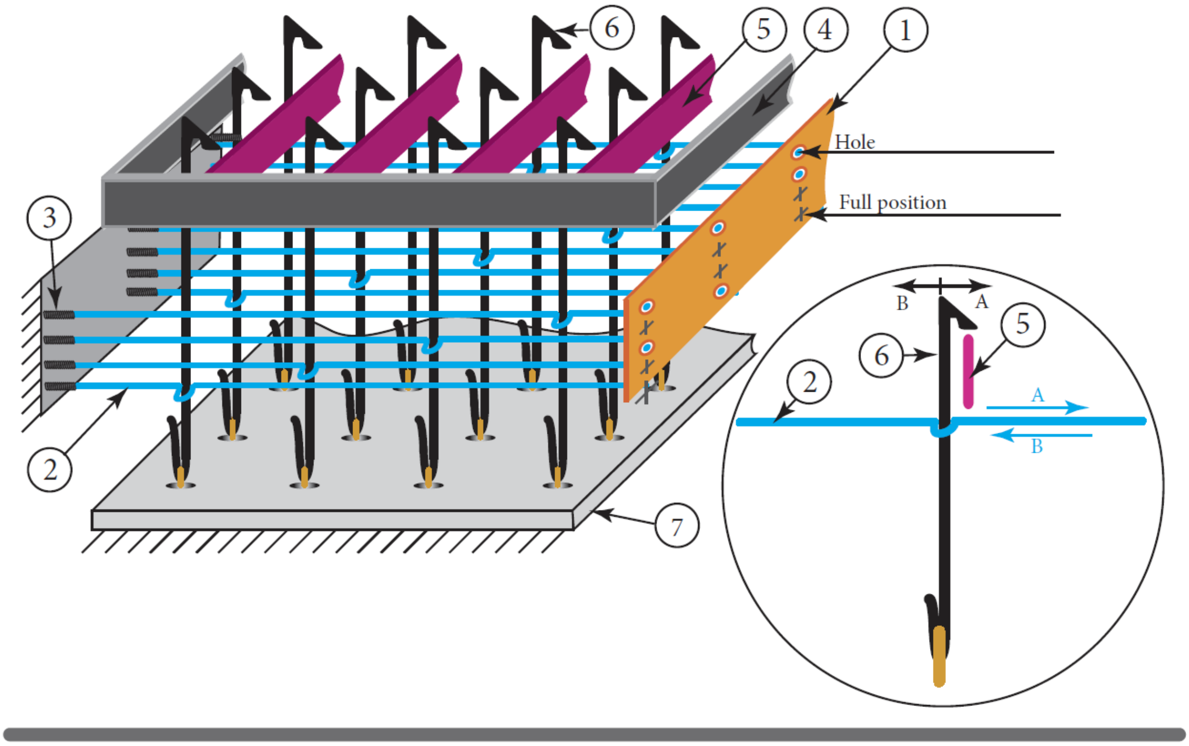


Figure 127: Block diagram of the main parts of Jacquard shedding mechanisms

As mentioned above, double-lift Jacquard mechanisms with electronic control are predominantly used in current technological practice. For teaching purposes, the textbook includes the description of single-lift and double-lift Jacquard shedding devices with mechanical control.

Single-lift Jacquard device with mechanical control

Figure 128 shows 3D diagram of the mechanically controlled single-lift Jacquard shedding device. The program is made up of rigid cardboard cards and each card determines the method of interlacing a particular weft of the weft pattern repeat. The hole in the card is the signal for creating the warp interlacing point and the full position is the signal for creating the weft point. The cards are sewed in a continuous chain and the chain is fitted on a prism, which is rotated by one edge during the weaving cycle. Other components of the pulse module are the needles with butts, made of steel wire of circular cross-section. The needles are guided in the sliding guide, not shown, and have the force coupling with the prism formed by means of springs. The needle butt fits into a particular hook, which is also made of steel wire of circular cross-section and is provided with a beard in its top part. A bundle of harness cords is attached by means of a cable to the bottom part of the hook. Because the hooks are arranged in several rows (for example, four rows - see Figure 128), the mechanism always includes several knives (the number of knives is equal to the number of rows of the hooks), which are arranged in the griffe block. The griffe block is driven by the main shaft by mechanical means and performs sliding oscillating motion in the vertical direction with a period of one weaving cycle.



Pulse module: 1 - card on the prism not shown
2 - needle with the butt guided in the sliding guide not shown
3 - springs

Power module: 4 - griffe block
5 - knife
6 - hook

7 - hook board (part of special structure for fixing the Jacquard mechanism)

Figure 128: 3D diagram of the single-lift Jacquard device with mechanical control

The **function** of the mechanism is shown in Figure 129. This figure shows the extreme positions of the knife and hook during three weaving cycles with the result that the heddles mounted on the hook in the initial situation are in the bottom position, shall take the top position in the first and second weaving cycles, and shall again take the bottom position in the third cycle. The figure is completed by a graph showing the dependence of the heddle lifting on the rotation angle of the main shaft during three weaving cycles.

The hooks are tied in the position of the heddles in line. In the first weaving cycle, the needle is opposite to the hole. Therefore, the needle moves to the right. This moves the hook towards the knife. In the motion of the knife upwards, the hook is caught and lifted from the hook board. This motion is transferred by cable to the bundle of harness cords, which is fixed at the S-point. The heddles thus move to the top position. Then, in the first weaving cycle, the knife moves back to the bottom position, the hook returns to the hook board and the S-point moves to the bottom position. Therefore, the heddles are in the bottom position at the end of the first cycle. In the second weaving cycle, the needle is again opposite to the hole and thus the situation is repeated: in the second cycle, the S-point moves to the top position and then to the bottom position. In the third cycle, the hole is not against the needle. Therefore, the needle moves to the left and deflects the hook away from the knife. In the third cycle, the hook is not caught. Thus, the S-point and the heddles mounted thereon do not change their position during the third cycle and remain in the bottom position. The single-lift mechanism thus changes the position of heddles (moves to the top position) in the event that the threads threaded through it should create warp interlacing points. In each weaving cycle, the heddles move from the top position back to the bottom position. The heddles, through which the threads forming the weft interlacing points are threaded, remain motionless in the bottom position. Therefore, all warp threads are always in one plane during beat-up.

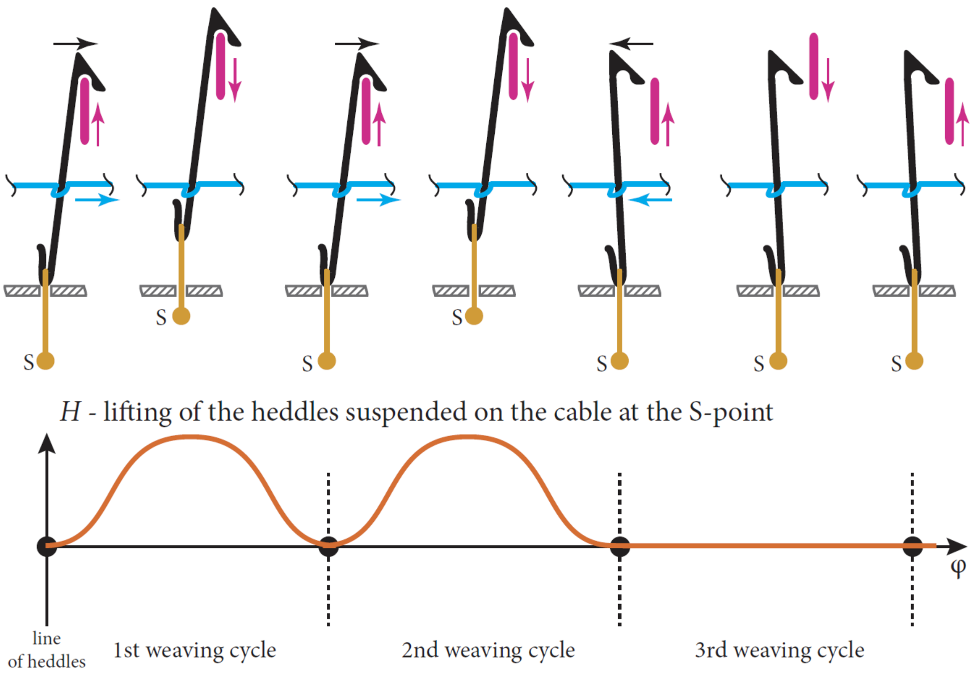


Figure 129: Positions of the hook and knife of the single-lift mechanism during three weaving cycles as described above

Double-lift Jacquard device with mechanical control

The hook of the double-lift mechanism is a U-shaped wire, which has two beards in its upper part and a protrusion in the lower right part (see Figure 130). The needle is provided with two beards, which fit into the left and right parts of the hook. The mechanism is equipped with two griffe blocks that perform opposing sliding oscillating motion with a period of two weaving cycles. Along each row of hooks, there is a stationary (locking) knife.

The **function** of the double-lift mechanism will be explained again on the same model situation as the function of the single-lift mechanism. In the initial situation, the heddles are mounted on the hook at the S-point in the bottom position. The hooks are tied in the middle of the weaving cycle. In the middle of the weaving cycle, which precedes the first cycle, the needle moves to the right (there is a hole in the card) and thus deflects both parts of the hook towards the knives. In the motion upwards, the right knife catches the hook and during the interval of the weaving cycle, moves it to the top position. Therefore, in the first weaving cycle, the heddles, mounted on this hook, are in the top position. At the same time, the hook gets caught through its protrusion on the fixed locking knife. In the middle of the first weaving cycle, the hooks are tied again. In our case, the needle is opposite to the hole. The needle is thus moved to the right and the hook is moved towards the knives. Therefore, the protrusion of the hook remains on the fixed locking knife and the S-point remains in the top position even in the second weaving cycle. During tying in the middle of the second cycle, there is a full position in the card. The needle moves to the left, thus deflecting the hook away from the knives. The protrusion of the hook is not in contact with the fixed locking knife and the hook moves, during the interval of the weaving cycle, along with the left knife to the bottom position. Therefore, the S-point is in the bottom position in the third cycle. If, during tying in the middle of the third cycle, there is a full position in the card, the two parts of the hook will be deflected away from the knives (see Figure 130) and the S-point will remain in the bottom position even in the fourth cycle.

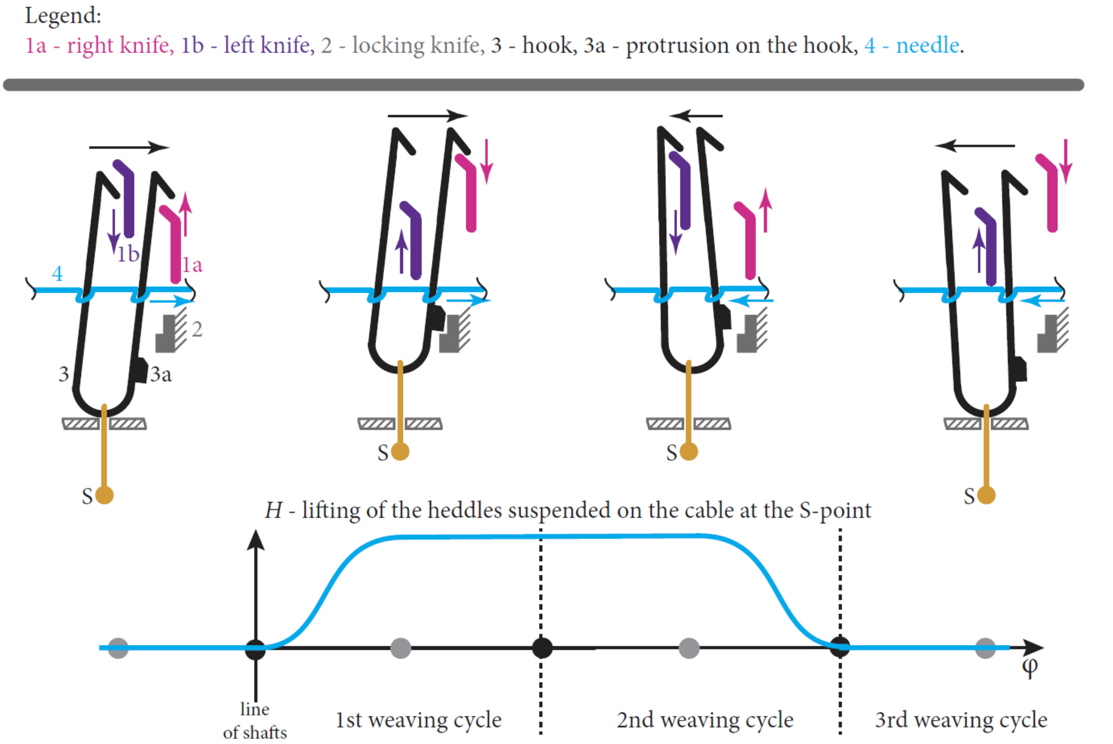


Figure 130: Positions of the hook and knives of the double-lift mechanism during three weaving cycles as described above

The **disadvantages of the mechanically controlled Jacquard mechanisms** again results from the tying clearances between the knives and the hooks. These clearances give rise to impact forces during operation of the machine. Furthermore, friction forces are generated between the needles and the hooks, which leads to wear of these mechanical parts and reduction of the service life of the mechanism. The electronically controlled Jacquard mechanisms eliminate the above deficiencies and also significantly increase operator comfort when changing the pattern of the fabric to be produced.

Double-lift electronically controlled Jacquard mechanism (Stäubli)

The principle and function of the electronically controlled double-lift Jacquard mechanism will be described on the example of the particular configuration used currently by the Stäubli company on its mechanism. The main parts of the mechanism are shown in Figure 131. The program for creating the desired pattern is in the computer’s RAM and the binary signal is transmitted therefrom to the electromagnets, which are part of the individual modules.

The pulse module includes two spring-loaded catches, which are placed on the opposite sides of the electromagnet and are controlled by the electromagnet.

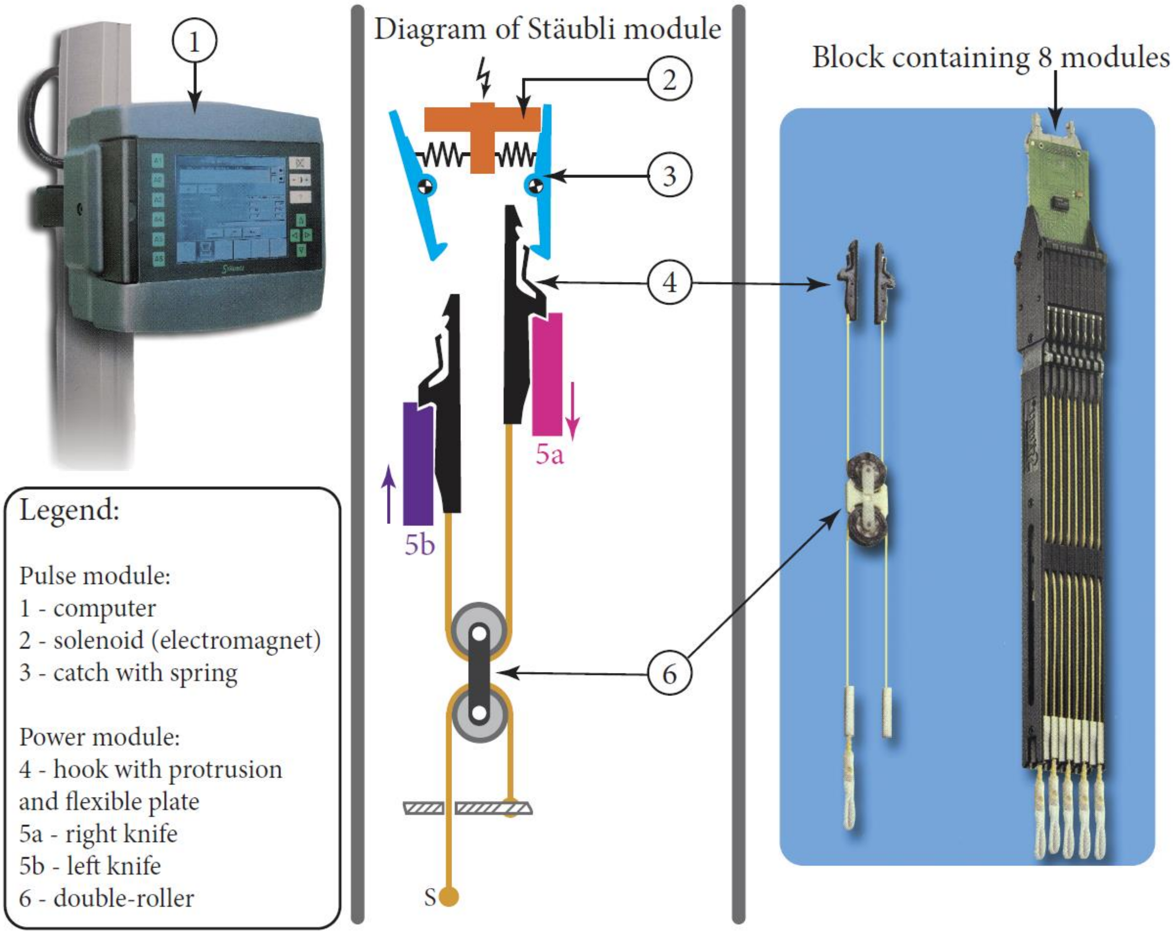


Figure 131: Main parts of the Stäubli Jacquard mechanism (source [27])

The power module consists of the pair of hooks with the protrusions. The protrusions ensure contact between the hook and the knife. A flexible plate is above the protrusion of the hook, which generates force coupling between the catch and the hook in its top position, i.e. during tying (see description of the function of the mechanism). In the upper part of the hook is a recess, which allows insertion of the catch in the hook. A pair of hooks is interconnected by cable that runs through the upper part of the double-roller. The cable runs through the lower part of the double-roller, which is connected at the S-point to the bundle of harness cords. The mechanism is equipped with two griffe blocks that perform opposing sliding oscillating motion with a period of two weaving cycles. The modules are grouped into blocks and the blocks are arranged in the housing of the Jacquard mechanism, which is mounted above the weaving machine.

The **function** of the mechanism will be described on the same model situation as in the previous cases. Figure 132 again shows the positions of knives and hooks during three weaving cycles. In the initial situation, the heddles are attached to the cable at the S-point in the bottom position.

In the middle of the weaving cycle, which precedes the first cycle, the electromagnet is de-energised. Therefore, when the protrusion of the right catch leaves the flexible plate of the hook, it fits into its recess, thus fixing the hook in the top position. During the interval of the weaving cycle, the left knife moves together with the hook to the top position, thus moving the double-roller upwards. Therefore, the S-point and the heddles mounted thereon are in the top position in the first weaving cycle. In the middle of the first weaving cycle, the electromagnet is de-energised, thus pushing the catch in the left hook. Therefore, the double-roller and the S-point remain in the top position even in the second weaving cycle. In the middle of the second weaving cycle, the electromagnet is energised. This will deflect the right catch and release the hook. Then, the right knife together with the hook move to the bottom position during the interval of the weaving cycle and the respective heddles are in the bottom position in the third cycle. If, in the middle of the third cycle, the electromagnet is again energised, the catch will be deflected and the left hook released. Then, the S-point remains in the bottom position even in the fourth cycle.

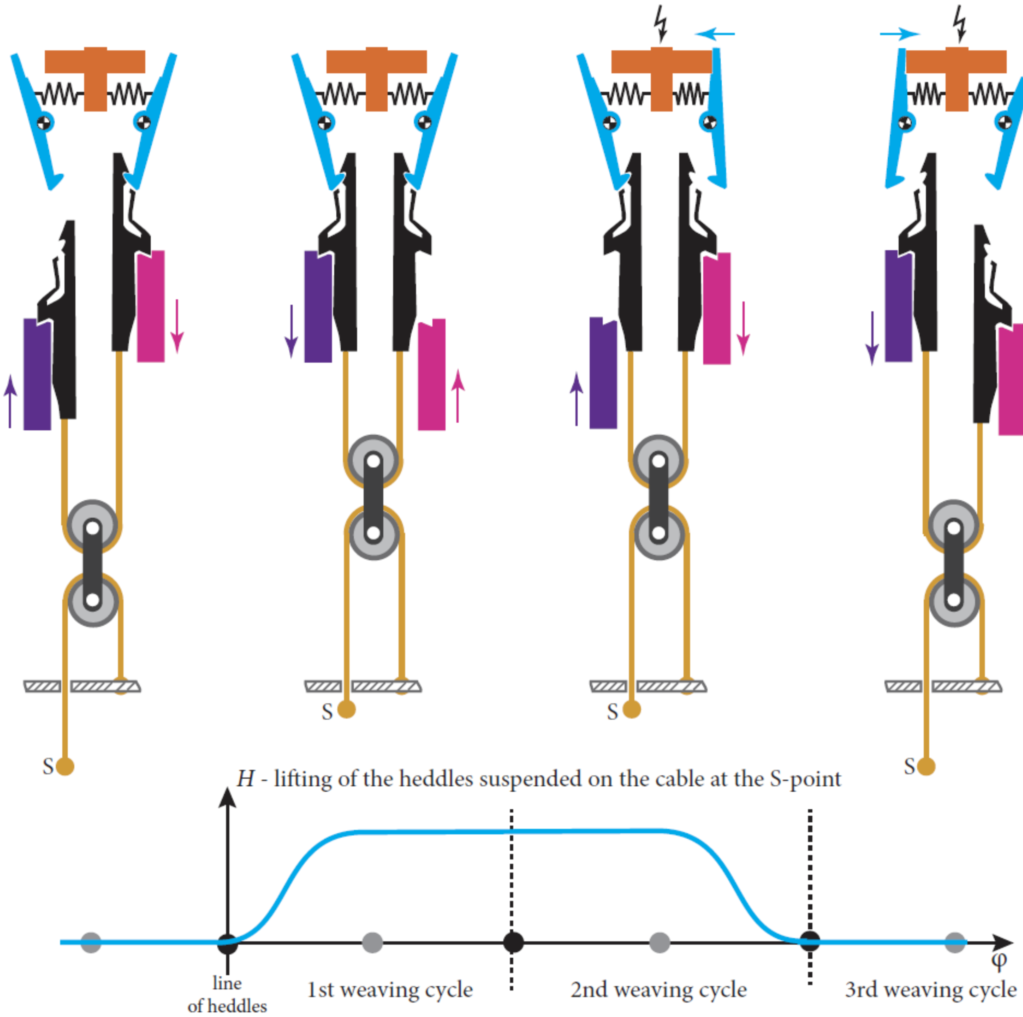


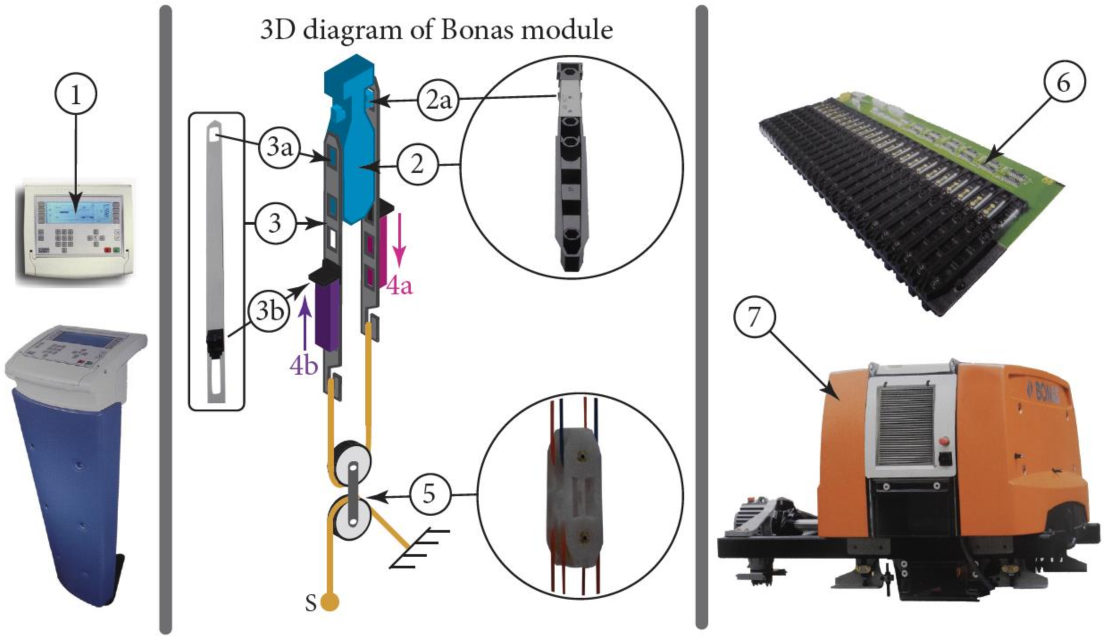
Figure 132: Positions of the hooks and knives of the Stäubli Jacquard mechanism during three weaving cycles as described above

The bottom position of the S-point thus corresponds to the situation, in which both knives are in contact with the protrusions on both right and left hooks. The top position of the S-point corresponds to the situation, in which one of the knives is not in contact with the protrusion on the hook.

Double-lift electronically controlled Jacquard mechanism (Bonas)

The main parts of the Bonas Jacquard mechanism are shown in Figure 133. The program for creating the desired pattern is in the computer's RAM and the binary signal is transmitted therefrom to the individual solenoids (electromagnets), which are part of the individual modules. Two hooks are placed on opposite sides in the upper part of the solenoid.

The power module consists of a pair of plates having a hole in their upper part and a protrusion in central part. The protrusion serves to generate a mutual contact between the knife and the plate. In the bottom part, the pair of plates is interconnected by cable that runs through the upper part of the double-roller. The cable runs through the lower part of the double-roller, which is connected at the S-point to the bundle of harness cords. The mechanism is equipped with two griffe blocks that perform opposing sliding oscillating motion with a period of two weaving cycles. The modules are grouped into the panel and individual panels are arranged in the housing mounted above the weaving machine.



Legend:

Pulse module: 1 - computer,
2 - solenoid (electromagnet),
2a - hook in the upper part of the solenoid.

Power module: 3 - hook,
3a - hole in the upper part of the hook,
3b - protrusion on the hook,
4a, 4b - knives,
5 - double-roller.

6 - module panel, 7 - Jacquard mechanism housing.

Figure 133: Main parts of the Bonas Jacquard mechanism (source [26])

Function: Figure 134 shows the positions of the knives and plates during three weaving cycles for the same model situation as in the description of the Stäubli double-lift Jacquard mechanism.

In the initial situation, the heddles are attached to the S-point in the bottom position. In the middle of the weaving cycle, which precedes the first cycle, the electromagnet is energised. The right upper plate is deflected towards the electromagnet, thus inserting the hook into the plate hole. During the interval of the weaving cycle, the left knife moves together with the left plate to the top position, thus moving the double-roller upwards. Therefore, the S-point and the heddles mounted thereon are in the top position in the first weaving cycle. In the middle of the first weaving cycle, the electromagnet is again energised and the left upper plate is also deflected towards the electromagnet. This will insert the hook into the hole of this plate. Therefore, the double-roller and the S-point remain in the top position even in the second weaving cycle. In the middle of the second weaving cycle, the electromagnet is de-energised and the right knife moving upwards released the plate from the hook. Therefore, the double-roller and the S-point move to the bottom position during the interval of the weaving cycle and the respective heddles are in the bottom position in the third cycle. If, in the middle of the third cycle, the electromagnet is de-energised (see Figure 134), the left knife will also release the left plate and the S-point will remain in the bottom position even in the fourth cycle. The bottom position of the S-point thus corresponds to the situation, in which both knives are in contact with the protrusions on the plates and the top position of the S-point corresponds to the situation, in which one of the knives is not in contact with the protrusion on the plate.

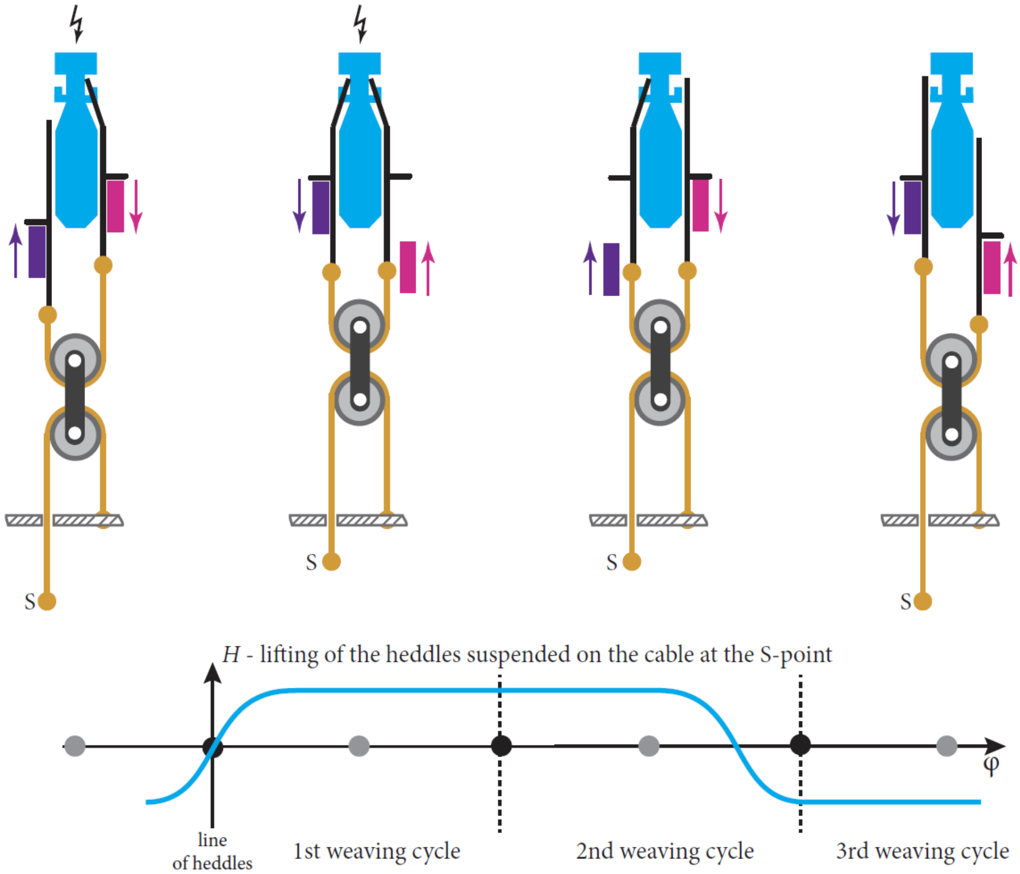


Figure 134: Positions of the plates and knives of the Bonas Jacquard mechanism during three weaving cycles

Differences between the Bonas and Stäubli mechanisms

The description of function of the two mechanisms shows that the basic principle of shed formation is the same for both mechanisms. Because these are the double-lift mechanisms, voltage is applied to certain electromagnets in a pulse manner always in the middle of the weaving cycle based on the value of the binary signal from the computer (for example: 1 – on, i.e. the electromagnet is energised, 0 – off, i.e. the electromagnet is de-energised). In Bonas mechanism, switching on the certain electromagnet will cause the respective heddles to move to the top position from the bottom position and switching off the electromagnet will cause the heddles to move to the bottom position from the top position. In Stäubli mechanism, switching on or off the electromagnet will result in opposite effects, i.e. switching off the electromagnet moves the respective heddles to the top position from the bottom position and switching on the electromagnet moves the respective heddles to the bottom position from the top position. In case of the Bonas mechanism, the pulse module (electromagnet) is able to lock one or both plates in the top position. Locking one of the plates causes the respective heddles to change their position, locking both plates causes the heddles to remain in the top position and when the plates move together with the knives, the heddles are in the bottom position. In Stäubli mechanism, the pulse module (electromagnet and catches) ensures locking of hooks and change of the position of heddles in the same manner.

Griffe block drive

In double-lift Jacquard mechanisms, two griffe blocks are used, which perform linear oscillating motion in opposite direction with a period of two weaving cycles. The extreme dead centres are reached in the middle of the weaving cycle (see Figure 135).

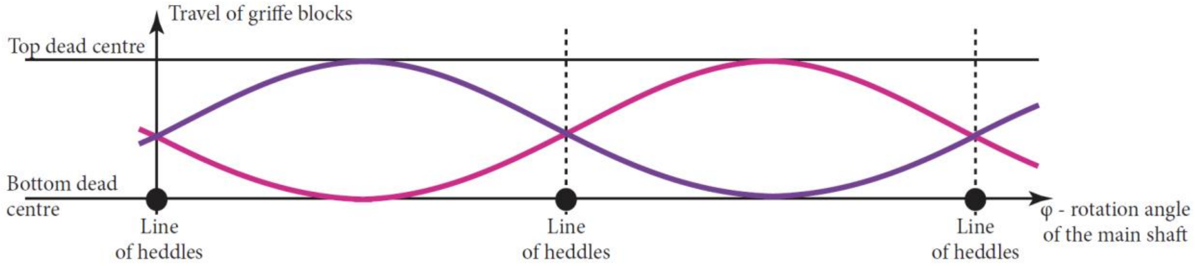


Figure 135: Lifting dependence of the griffe blocks of the double-lift Jacquard mechanism

In practice, the griffe blocks are driven by the main shaft of the weaving machine by mechanical means (vertically mounted shafts, etc.). Opposing linear oscillating motion of the griffe blocks is formed, for example, by means of tappets and fourbar mechanisms (see Figure 136). The Stäubli company also offers the possibility of driving the Jacquard mechanisms using an independent motor. The Jacquard device then has no mechanical connection with the weaving machine and the mutual synchronisation is solely ensured by electronic means. At the time of creation of the textbook, the Jacquard mechanisms with independent drive are not widely applied in practice, but in the next few years, they are a prerequisite for the further development of weaving machines with individual drive of the main mechanisms (see Chapter 4.2.1 - drive type D).

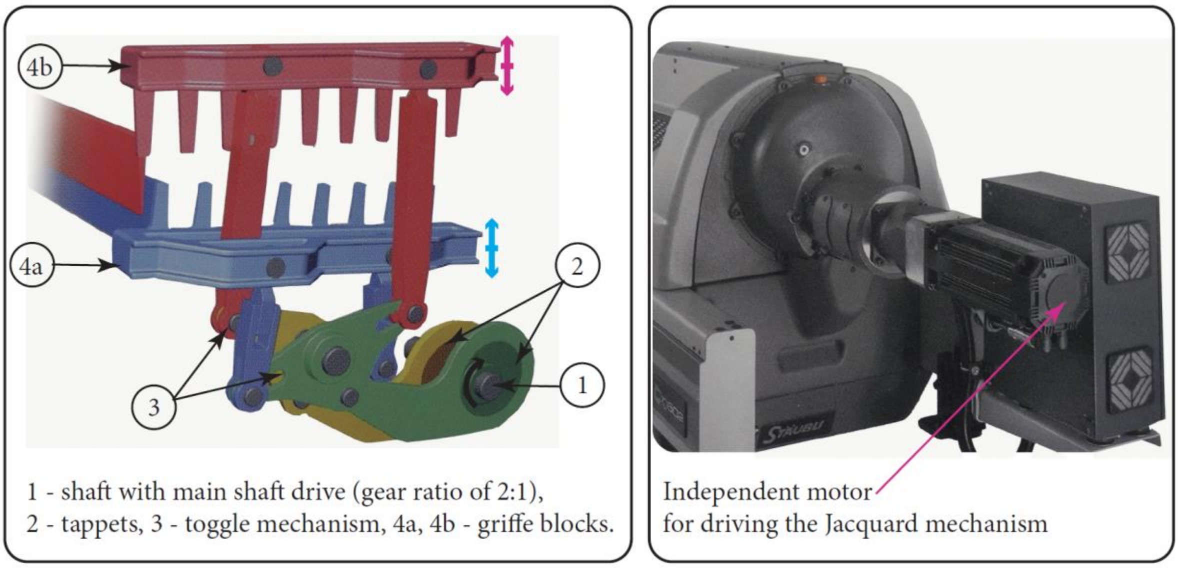


Figure 136: Jacquard device driving mechanism and independent drive (source [27])

Important findings of the chapter:

1) We know the main parts of the Jacquard mechanisms.
2) We can explain the difference between the single-lift and double-lift mechanisms.
3) We can draw a diagram of the electronic Jacquard mechanism and explain its function.
4) We know the method of driving the griffe blocks of the Jacquard mechanisms.

4.4.4 Individual drive for single shafts or heddles

The interface between the pulse and power modules is removed in the mechanisms for individual drive of single shafts or heddles. Synchronisation between the weaving machine and the shedding mechanism is solely implemented by electronic means. Figure 137 represents the **general diagram of the drive of shaft or heddle**. Information on the method of tying the wefts is again stored in the computer's memory. The signal from the computer is applied to the converter via the bus, which controls the angular velocity of the servomotor for driving the shaft or heddle.

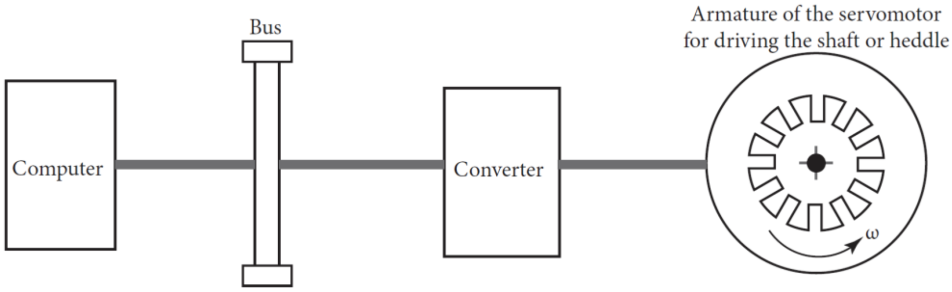


Figure 137: Diagram of the individual drive of shaft or heddle

The **examples of specific shedding devices of this type** may include the mechanisms of Japanese manufacturers (Tsudakoma and Toyota companies), which are briefly mentioned in Chapter 4.2.2. As already mentioned, **independent servomotors are used for driving the individual shafts in the heald**, operating in the electronic cam mode. Therefore, these devices are hereinafter referred to as the shedding mechanisms with electronic cams. The Tsudakoma company presents the appropriate mechanism under the trade name **"ECM"**, i.e. Electronic Cam Motion) and the Toyota company under the trade name **"E-shed"**, i.e. Electronic Shedding Motion. The mechanisms of both companies allows the suspension of sixteen shafts.

In addition, this chapter describes the **Jacquard mechanism type Unival 100**, which is included in the production programme of the Stäubli company. The mechanism uses a standard Jacquard heald. The actuators (small servomotors) are arranged in the mechanism housing, which control the harness cords via a roller. Each actuator controls one heddle by means of the harness cord. Therefore, the device is hereinafter referred to as the Jacquard mechanism with actuators. At the time of creation of the textbook, these shedding mechanisms are not widely applied in technological practice and are rather presented in various exhibitions of textile machines [17]. But given the trend of derive individualisation of the main parts of the weaving machine and the benefits that brings this trend (see Chapter 4.2), their concept seems to be very beneficial in the future.

Shedding mechanism with electronic cams

The main parts of the shedding mechanism with electronic cams are shown in Figure 138. The signal from the computer is applied to the converter via the bus, which controls the angular velocity of each servomotor. The tappet with the sleeve is mounted on the shaft of the servomotor. The sleeve is connected with the bent lever.

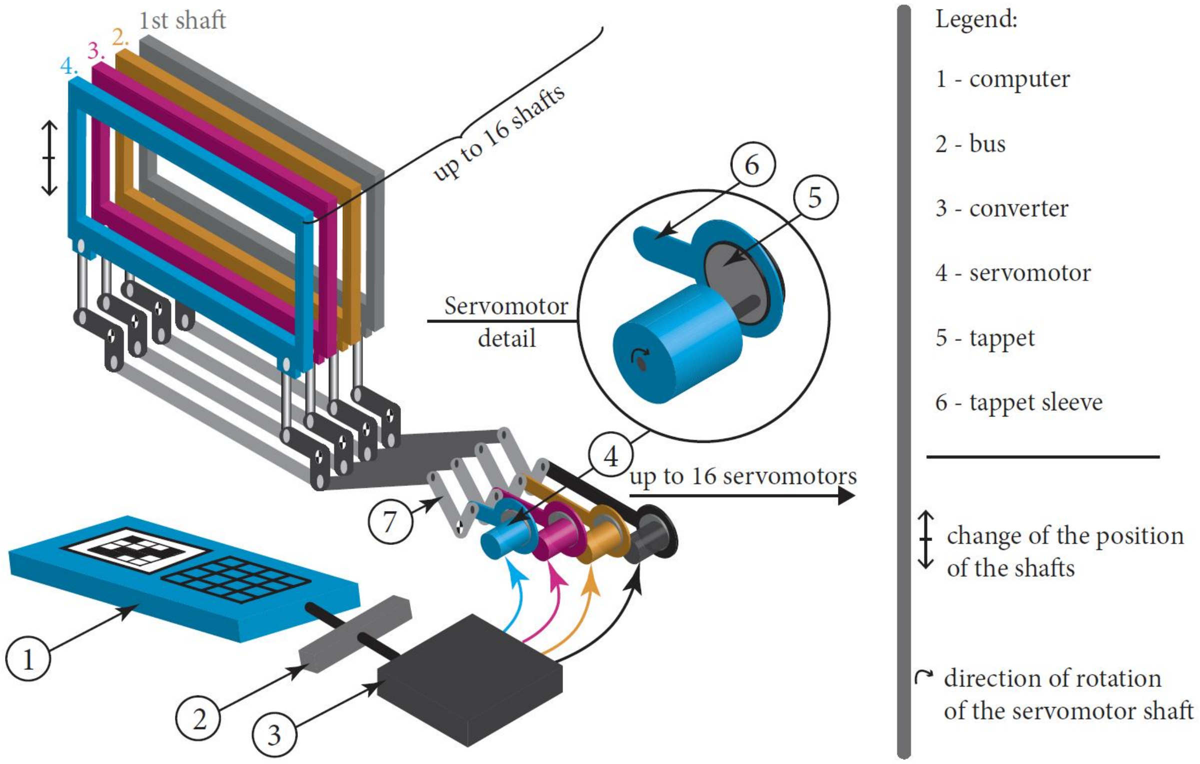


Figure 138: Main parts of the shedding mechanism with electronic cams

Function: The position of the shaft is changed by rotating the tappet of the servomotor. This motion is transferred via the tappet sleeve to the bent lever and respective shaft. Rotation of the shaft of individual servomotors is controlled according to the desired method of interlacing the weft. The course of angular velocity of the shaft of the servomotor within the weaving cycle, which is programmable, determines the lifting function of the shaft. This feature is applicable to the flexible modification of the static angle (see Figure 139). The period of the course of angular velocity may consist of several weaving cycles. Using this feature may provide a simple choice between the beat-up in the open or closed shed.

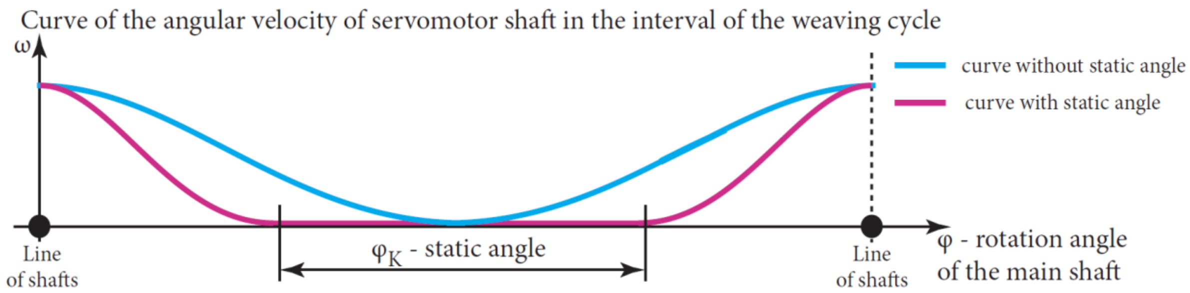


Figure 139: Example of the course of angular velocity of the servomotor in the interval of the weaving cycle

Jacquard mechanism with actuators

The main parts of the Jacquard shedding mechanism with actuators are shown in Figure 140. The module consists of the actuator with the roller, on which the harness cord is mounted. The actuators are grouped into blocks. These blocks are arranged in the housing of the mechanism, which is mounted above the weaving machine. At the time of creation of the textbook, the Stäubli company offers mechanisms that contain from 512 to 15,360 actuators.

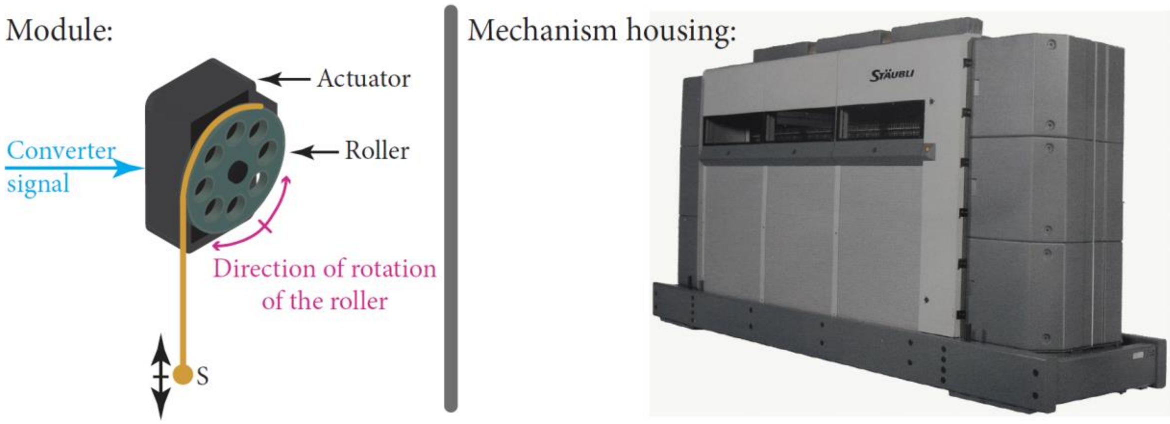


Figure 140: Main parts of the Jacquard mechanism with actuators (source [27])

Function: The operation of the individual actuators is controlled by signal from the converter according to the desired pattern. The heddle is moved to the top position by winding the harness cord onto the roller and is moved to the bottom position by unwinding the cord from the roller. The shafts of the individual actuators thus change the direction of rotation depending on the method of interlacing the given weft and the course of angular velocity determines the lifting function of the heddles.

The **advantages of the individual drives of shafts or heddles** are evident. An easy change of the lifting functions of the shafts or independent heddles may be applied to the construction of weaving machines. In technological practice, these mechanisms can ensure a high operator comfort when changing the weave or pattern of the fabric to be produced, thus reducing the maintenance requirements of the mechanism. In terms of practice, a flexible choice between the beat-up in the open or closed shed according to the current technological requirements also appears to be interesting. Due to the minimum number of mechanical elements, a relatively high life durability with prolonged operation of these mechanisms may be expected as well as ability to operate at high weaving frequencies.

4.4.5 Stress on warp threads due to creation of the shed

During the weaving process, it is necessary to apply stress to the threads solely in the area of elastic deformations so as to prevent permanent deformations or even breaks. This chapter describes the influence of the number of shafts in heald on the maximum elongation of the warp threads in the formation of the shed.

Figure 141 shows the warp thread threaded through the heddle. The symbol H is the distance of the heddle eye from the weaving plane (heddle lifting), the symbol A represents the length of the front shed (distance of the heddle in the last heald shaft from the beat-up bar) and the symbol B represents the length of the whole shed (front and rear parts), which is considered as the distance between the back rest and the beat-up bar. It is further assumed that there is no slippage between the thread and the back rest, and between the thread and the beat-up bar (the warp thread is woven on the back rest and in the beat-up bar). Then, use the Pythagorean theorem to express the dependence between the elongation of the thread ΔL and the heddle lifting H using the non-linear function:

$$\Delta L(H) = \left[\sqrt{(B-A)^2 + H^2} + \sqrt{A^2 + H^2}\right] - B,$$

where ΔL is the elongation of the warp thread, H is the lifting or lowering of the heddle, A is the length of the front shed and B is the length of the whole shed.

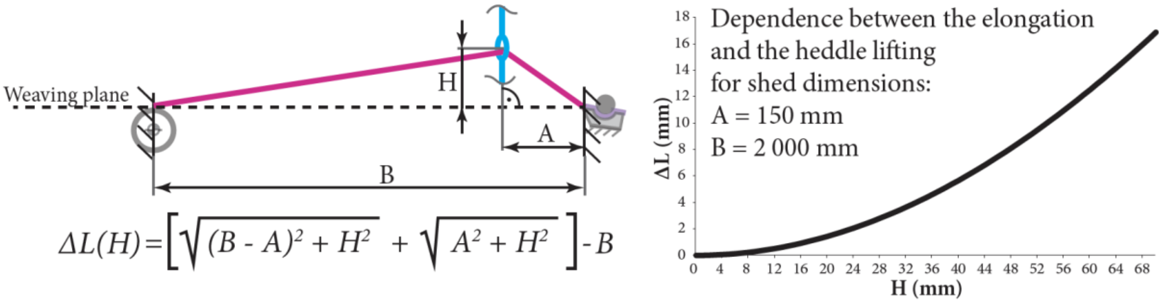


Figure 141: Diagram of the warp thread with the heddle and thread elongation-heddle lifting chart

Note: We assume that lifting of the heddle (distance of the heddle eye in the top shed position from the weaving plane) is the same as its lowering (distance of the heddle eye in the bottom shed position from the weaving plane). Therefore, the elongation of the warp thread is the same in its position in the top and bottom shed positions.

During the weaving process, it is necessary to create a shed with dimensions that allow smooth weft insertion (see Chapter 4.1.1). This requirement determines the maximum lifts of the heddles $H[i]_{MAX}$, which are required in the formation of the shed. As already mentioned in Chapter 4.4.2 (in the section dealing with technical pattern of fabric), the maximum lift of the first shaft in the heald $H[1]_{MAX}$ is the greatest and is gradually reduced for next shafts, i.e.: $H[1]_{MAX} > H[2]_{MAX} > \dots > H[i]_{MAX} > \dots > H[n]_{MAX}$. This ensures that during opening of the shed, the warp threads in the top and bottom position are in alignment and together with the reed form a wedge-shaped space for weft insertion. The dimensions of this wedge-shaped space must match the dimensions of the carrier and enable seamless weft insertion. The geometry in Figure 189 shows that with the length of the front of the shed A, pitch (distance) of heald shafts R and the required maximum lifting of the last heald shaft $H[n]_{MAX}$, each preceding heald shaft must create maximum lifting given by the relation:

$$H[i]_{MAX} = \frac{H[n]_{MAX}}{A}.[A + (n - i).R],$$

where $H[i]_{MAX}$ is the maximum shaft lifting, i is the move number of the shaft, $H[n]_{MAX}$ is the maximum lifting of the last shaft, n is the total number of shafts, A is the length of the front shed and R is the pitch of shafts.

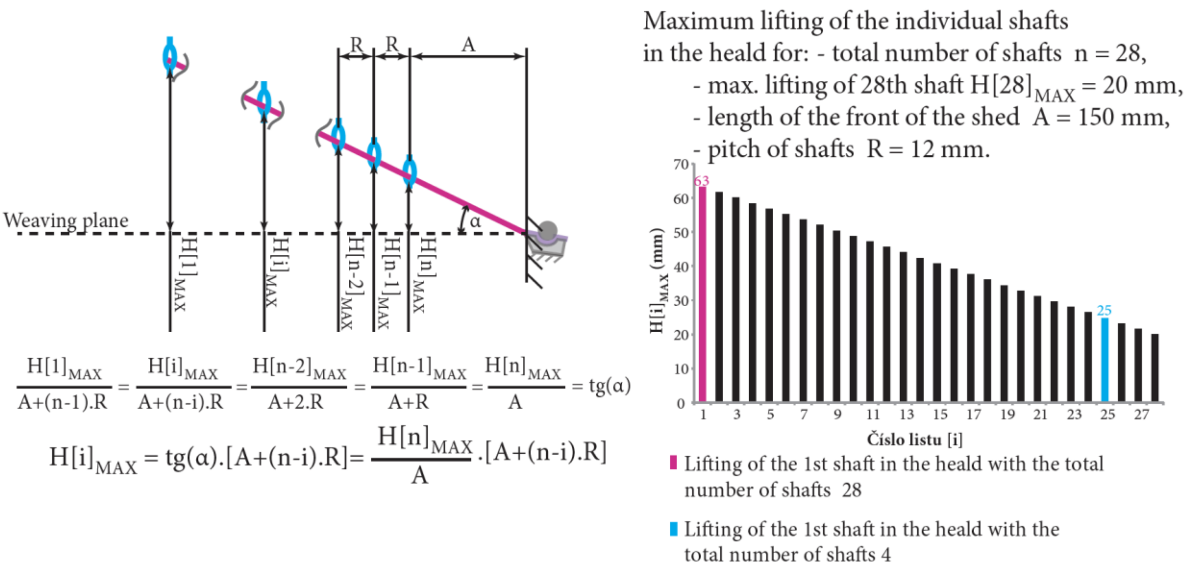


Figure 142: Maximum lifting of the individual shafts in the heald

Creating the shed applies the most stress to the warp threads threaded through the first shaft (this shaft has the maximum lift). The graph in Figure 143 indicates the maximum elongation of the warp threads for the heald that contains four shafts and for the heald that contains 28 shafts. It is obvious that the maximum elongation of warp threads increases with the number of shafts in heald in a progressive manner. Therefore, the heald with a large number of shafts can be used in the processing of warp threads having high elasticity, i.e. the ability to return to its original shape even at a relatively large elongation. Processing of the warp threads with low elasticity requires using the heald with a smaller number of shafts.

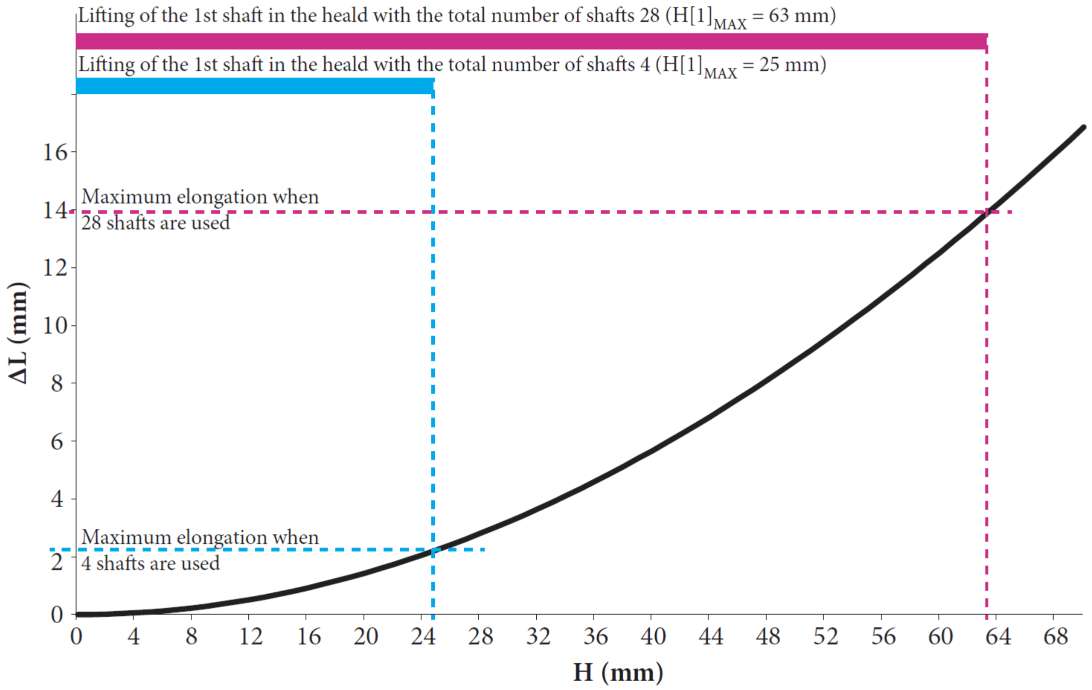


Figure 143: Maximum elongation for the heald with 4 and 28 shafts

Important findings of the chapters:

1) We can draw and explain a diagram of the individual drive of shaft or heddle.
2) We know what are the benefits of individual drive of shafts or heddles in design and technological areas.
3) We can express the relationship between elongation of the warp thread and lift of the shaft.
4) We know the influence of the number of shafts in heald on the maximum elongation of the warp threads.

4.5 Weft insertion

With sufficient opening of the shed, the weft insertion phase is started. **The function of the picking mechanism is to insert the weft thread in the shed across the reed width of fabric.** It is a discontinuous process that is repeated cyclically with a period of one weaving cycle.

The package of weft thread is wound onto the pirn and before the phase of weft insertion, the thread has zero velocity. In the insertion of the weft, the picking mechanism unwinds the thread from the pirn with the velocity waveform, which depends on the type of picking mechanism. The thread is inserted in the shed with a certain tensile stress, which prevents the thread from buckling. After weft insertion across the reed width, thread unwinding by the picking mechanism is completed, i.e. the weft velocity is again equal to zero. **The process of weft insertion is carried out in three stages:**

1. Giving velocity to the weft thread (acceleration stage).
2. Inserting the weft thread in the shed with a certain velocity waveform and tensile stress (picking stage).
3. Stopping, i.e. reducing the velocity of weft thread to zero (braking stage).

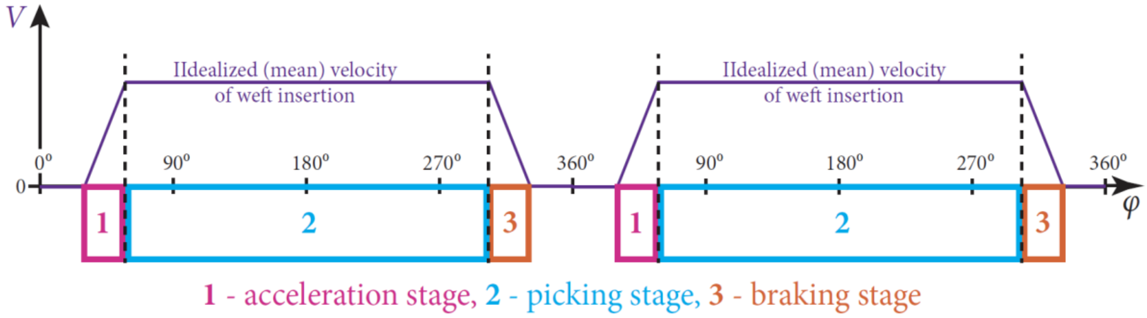


Figure 144: Weft insertion stages depending on the rotation angle of the main shaft

Division of picking mechanisms by the carrier:

1. *Ballistic type mechanisms with fixed carrier* (shuttle, gripper) use the principle of projectile. In the acceleration stage, the carrier is given the velocity. In the picking stage, the carrier with the weft thread moves through the shed due to inertia. The velocity of the carrier is decreasing due to drag forces. After the weft insertion across the weaving width (picking path), the carrier is braked, thus stopping the weft thread.
2. *Kinematic type mechanisms with fixed carrier* (rapier)*:* The carrier (rapier) is part of the kinematic chain of the picking mechanism, i.e. its velocity waveform through the weaving cycle is determined by kinematic parameters of the picking mechanism. Before the start of the acceleration stage, the force coupling is generated between the weft thread and the rapier. Then, there is an increase in velocity and, in the picking stage, the carrier with the weft moves through the shed with the velocity waveform, which is determined by kinematic parameters of the mechanism. After the weft insertion across the weaving width, the velocity decreases to zero, thus implementing the weft stopping stage. The weft is usually inserted by a pair of rapiers.

- *Jet mechanisms with carrier in the form of medium* (water, air) use the principle of momentum transfer of the flowing medium to the weft thread. A condition of the transfer is the difference between the medium and weft velocities. Therefore, the medium velocity is higher than the weft velocity in all picking stages. The jet of fluid (water or air) is directed into the shed by means of a nozzle, through which passes the weft thread. At the moment, at which medium begins to flow into the shed, its momentum is transferred to the weft thread, which starts to move with a certain velocity (acceleration stage). In the picking stage, the velocity waveform of both medium and weft is decreasing as a result of the action of drag forces. Weft stop cannot be implemented by means of the carrier and, therefore, external means are employed.

Gripper, rapier, jet (water and air) mechanisms are generally referred to as the **shuttleless picking mechanisms**.

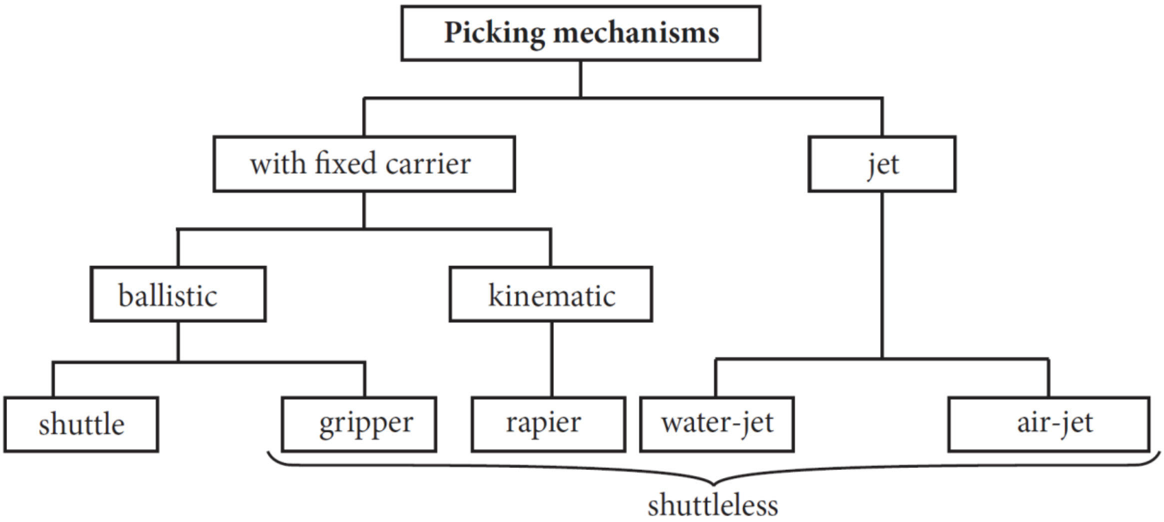


Figure 145: Division of picking mechanisms

As already stated in Chapter 2.2.5, the second half of the 20th century is characterised by the development of various picking mechanisms. Therefore, in this period, the type of picking mechanism is used as the most important criterion for the division of weaving machines (principles, systems). The above **diagram of picking mechanisms** thus simultaneously **represents the division of weaving machines** as usually defined in the previously published literature (for example [1], [2] and [3]).

The **development of different picking mechanisms was primarily driven by the requirement for improving the performance of weaving machines** (for definition of the performance parameters of weaving machines see Chapter 5). Machines with the shuttle picking mechanism, which are the predominant means for the production of fabrics until the early 1950s, are unable to meet this requirement. In shuttle weaving machines, weft package (weft pirn) moves together with the carrier (shuttle). Therefore, the shuttle is characterised by relatively large dimensions and mass. In shuttleless picking mechanisms, weft package is mounted on the creel in a stationary manner. This arrangement allows size reduction and mass reduction of the carrier. The following table (source [28]) shows the approximate mass of carriers of the individual picking mechanisms m_Z and the corresponding top (maximum) weft performance U (see Chapter 5), achieved by the individual weaving systems in the past. The above values show that in the system with the lowest mass of the carrier (air-jet weaving machines), the weft performance was successfully increased five times relative to the shuttle weaving machines.

Carrier	Mass m_Z (kg)	Performance U (m/min)
shuttle	0.300	600
needle	0.200	1500
gripper	0.040	1500
water jet	0.005	2500
air jet	0.001	3000

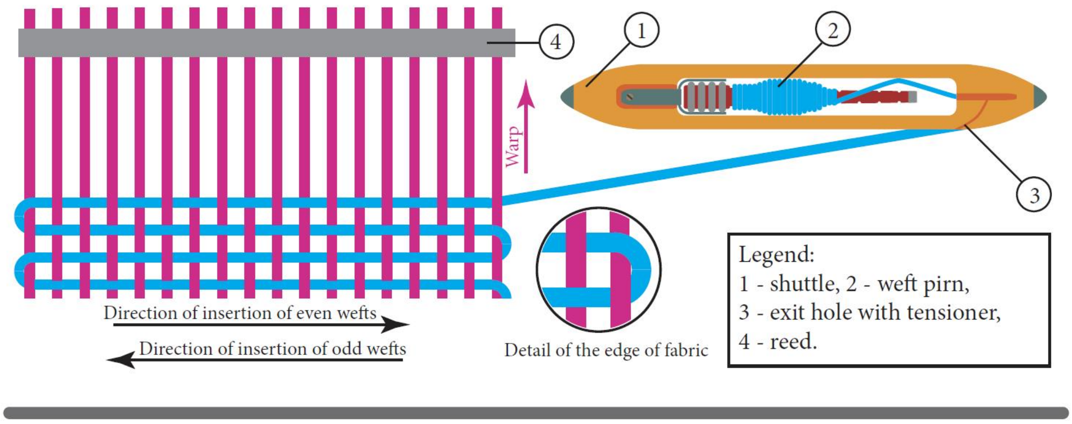
Note: Using advanced methods of mechanics, equations of motion for the carrier in the form of differential equations can be compiled for the individual picking mechanisms (excluding rapier mechanism). Solution of the appropriate equations determines the velocity waveform as a function, in which mass and variables characterising drag forces figure in the form of parameters. It is then possible to analyse in the exact manner the effect of the mass of the carrier on the performance parameters of individual weaving systems. Given the need to use advanced methods of mechanics, this issue is addressed in the context of the theory of weaving.

Description of the individual picking mechanisms

Industrial production of fabrics is currently implemented predominantly on air-jet and rapier weaving machines. The picking mechanisms of these machines are described in detail in separate chapters. Other methods of weft insertion (using the shuttle, gripper, water jet) are described hereinafter only briefly with respect to the explanation of reasons for their current minority representation in industrial practice. More detailed information about these minority picking mechanisms can be found in previously published literature, especially in [1] and [3].

Weft insertion using a shuttle

Figure 146 shows a plan view that illustrates the production of fabric on the shuttle weaving machine. The weft pirn is placed inside the shuttle. In the picking stage, the shuttle moves through the shed, the thread unwinds from the weft pirn, passes through the exit hole and is inserted in the shed. Tensile stress in the weft thread during insertion in the shed is determined by the thread tensioner positioned within the exit hole of the shuttle. The direction of weft insertion in the odd and even weaving cycles changes, i.e. when the shuttle moves in the odd weaving cycle from right to left, it must move in the opposite direction (from left to right) in the even weaving cycle. Therefore, the individual wefts in fabric consist of a single continuous thread and fabric has the so-called “selvedge”. Movement of the shuttle, i.e. its acceleration at the start of the pick (acceleration stage) and stopping after completion of the pick (braking stage), is ensured by non-illustrated picking mechanism, which is described for example in [3].



Photograph of the shuttle with weft pirn:

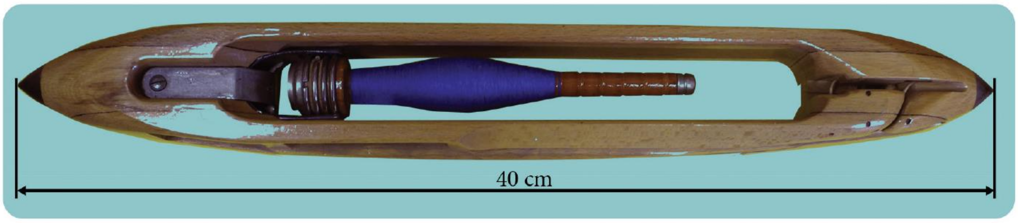
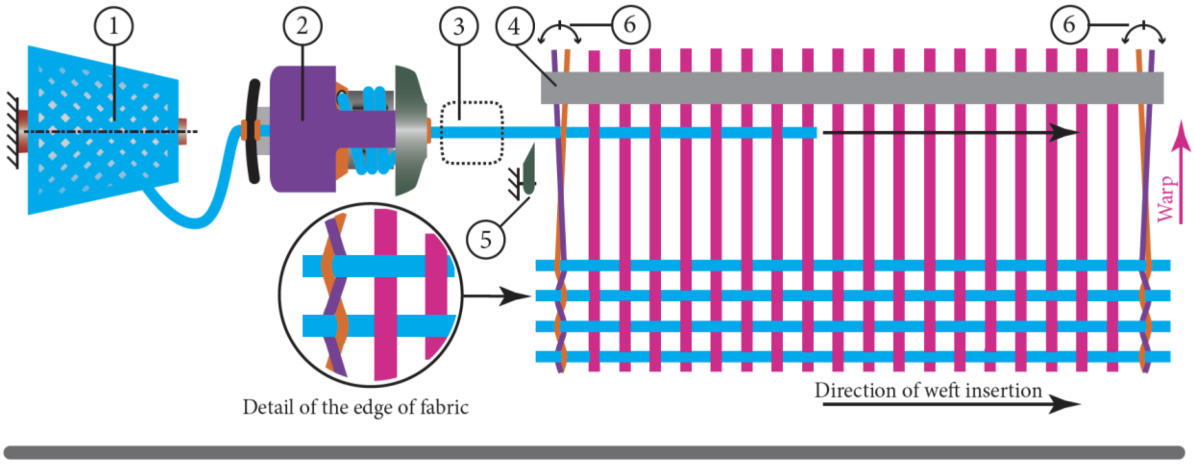


Figure 146: Plan view showing the weft insertion using a shuttle

At the time of creation of the textbook, shuttle machines are not used for industrial production of fabrics. The disadvantage of low performance has already been mentioned. Given the size of the shuttle, a relatively large maximum lifting or lowering of the heddles is required in the creation of the shed, which results in increased stress on the warp threads (see Chapter 4.4.4). Using the shuttle machines is also complicated by the technological process of preparing the weft as it is necessary to rewind the weft thread from the cone onto the pirn.

Weft insertion on shuttleless weaving machines

Figure 147 illustrates a general plan view showing the weft insertion on shuttleless weaving machines. Weft package is, in the form of the cone, placed on a creel. The thread is unwound from the cone by unwinder on the gripper and rapier weaving machines or by feeder on the jet machines (for more information see Chapters 4.5.1 and 4.5.2). The end of the weft thread is guided to the picking mechanism, which is located on the left side of the machine. In the acceleration stage, the end of the weft is caught by fixed carrier (gripper, rapier) or drifted by medium (water, air), thus giving the weft thread the velocity. In the picking stage, the end of the weft thread (face of the weft) moves from left to right, while for the picking mechanisms with fixed carrier, the tensile stress in the weft is provided by thread tensioner, which is usually part of the unwinder. In jet picking mechanisms, the tensile stress in the weft generates the difference between the velocity of medium and the velocity of the face of the weft (for more information see Chapter 4.5.2). Stopping of weft thread after the picking is implemented by braking the gripper on gripper machines and by reducing the rapier velocity to zero on rapier machines. On jet weaving machines, stopping of weft by carrier (jet of medium) cannot be ensured. Therefore, it is implemented by external means, which are usually part of the feeder (for more information see again Chapter 4.5.2). After tying the inserted weft, the weft thread at the left edge of fabric has to be cut off, thus creating the end (face) of the weft for subsequent pick.



Legend:
1 - weft pirn, 2 - weft unwinder or feeder, 3 - location of the picking mechanism, 4 - reed,
5 - shearing device (shears), 6 - mechanism for reinforcing the edges of fabric by leno weave.

Figure 147: Plain view of weft insertion on shuttleless weaving machines

The comparison of Figures 146 and 147 shows the differences in the principle of producing fabric on shuttle and shuttleless weaving machines. On shuttleless weaving machines, weft package is positioned in a stationary manner on the left side of the machine and the face of the weft is transported from left to right in each weaving cycle. After weaving in the weft, it will be cut off on the left side. Therefore, wefts in the fabric are not formed by a single continuous thread as in the fabric produced on a shuttle machine. The wefts are comprised of individual threads, whose length is determined by reed width of fabric and weft contraction. Therefore, on shuttleless weaving machines, selvedges are not created automatically, but their reinforcement must be ensured by means of special mechanisms. Figure 147 shows reinforcement of the edge of fabric by means of leno weave. The different ways of reinforcing the edges of fabric on shuttleless weaving machines are addressed in more detail in Chapter 4.5.3.

The so-called “catch edge” is often created on the left and right sides on shuttleless weaving machines (see Figure 148). The warp threads for catch edges are usually wound on separate bobbins and threaded through the heddles of the heald and reed so as to make a gap for shears between the edge of fabric and the catch edge. Wefts are then cut off at these points on the left and right sides of fabric, thus ensuring the aesthetic appearance of the edges (the projecting weft ends are also cut down to the same length). Catch edges are then removed as waste.

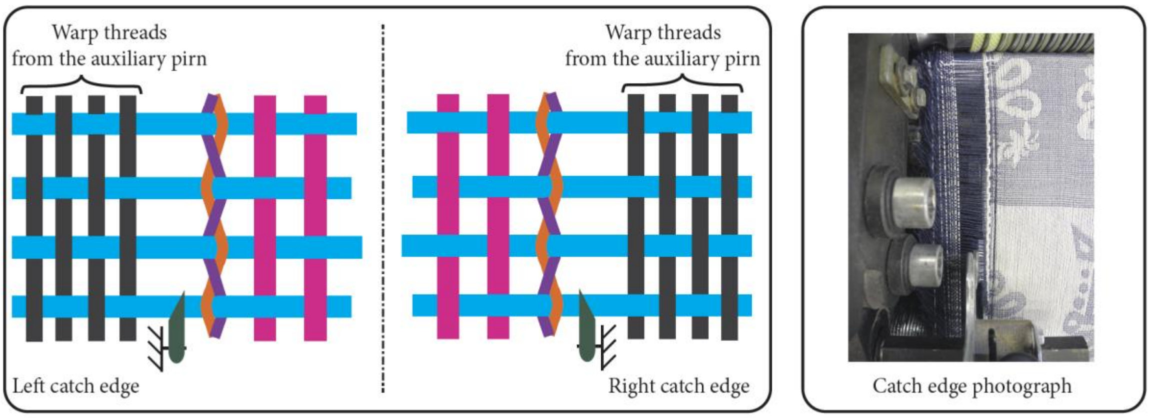


Figure 148: Catch edge of fabric on shuttleless machines

The foregoing description of the essential characteristics of shuttleless picking mechanisms shows that the shuttleless weaving machines have some disadvantages compared with the shuttle weaving machines. Reinforcement of the edges of fabric must be addressed by a special mechanism and catch edges increase the amount of waste material. But these disadvantages were successfully solved in a relatively efficient way in the past. There are currently reliable mechanisms available for reinforcing the edges of fabric (for more information see Chapter 4.5.3). For most conventional textile materials, waste from the catch edges can be easily recycled or used in other products. If this is not possible, cheaper material can be used for the warp threads of the catch edges. The advantages of shuttleless weaving machines, with the ability to achieve high performance being the most important advantage, clearly predominate. Therefore, the industrial production of fabrics is currently implemented solely on shuttleless weaving machines. The shuttle picking mechanisms are only applied in the case of weaving machines designed for artistic or small batch production.

Weft insertion using a gripper

The weft thread is usually unwound from the cone by means of the unwinder (see Figure 147) and is further guided to the weft feeder (see Figure 149). Before the acceleration stage, the end of the weft thread must be caught by gripper collets. Opener hook is inserted into the hole in the gripper. This opens its collets and the feeder positions the weft end between the gripper collets. Removing the opener hook will grip the weft end by gripper collets. Then the collets of weft feeder open and the gripper is thus ready for the acceleration stage of the picking process.

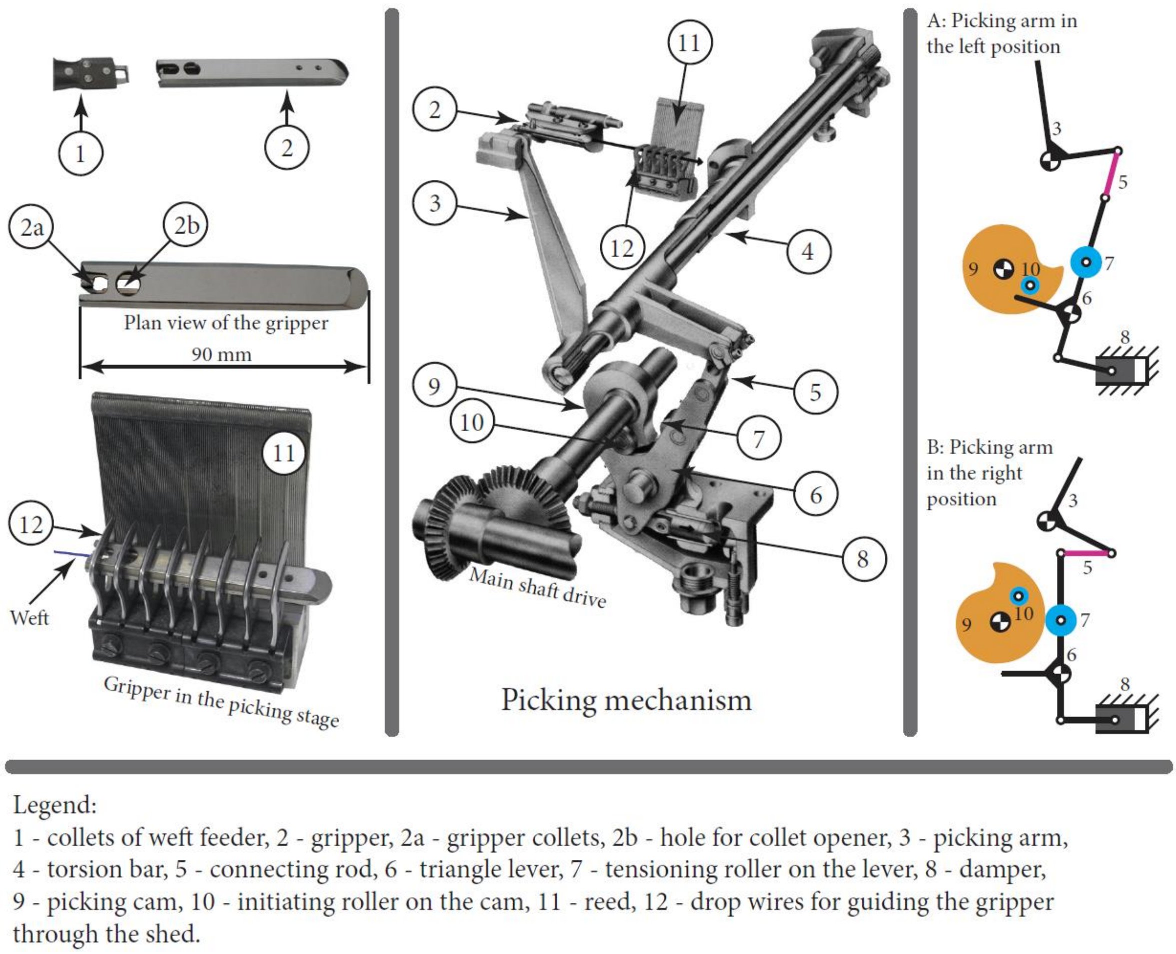


Figure 149: Picking mechanism of the gripper machine (source [14])

The velocity is given to the gripper by picking mechanism (see Figure 149). This mechanism consists of the picking arm, torsion bar, connecting rod, triangle lever with a tensioning roller, damper and picking cam with an initiating roller. The shaft of the picking cam is driven by the main shaft of the weaving machine and has a constant angular velocity. The tensioning roller of the triangle lever follows the shape of the cam, thus changing the position of the lever. The triangle lever deforms (twists) through the connecting rod the torsion bar, with one end being fixed into the frame. The picking arm is fixed on the other side of the torsion bar. The deformation of the torsion bar occurs until the mechanism reaches a self-locking position (see Figure 149-A), i.e. a positive locking torque is generated on the triangle lever (for more information see [1]). Upon further rotation of the picking cam, the initiating roller hits the left arm of the triangle lever, exceeds the locking torque by its action of force, thus releasing the torsion bar. Subsequently, the picking arm is deflected to the right (see Figure 149-B) and gives velocity to the gripper.

In the shed, the gripper is guided by means of drop wires, which are fastened to the reed. Tensile stress in the weft thread is generated by means the thread tensioner located on the left side of the machine (usually in the unwinder). After completion of the picking stage, the gripper is braked in the gripper box, thus implementing the weft stopping stage.

The inserted weft is then gripped on the right and left sides of fabric by retainers. At the same time, the weft is caught by feeder clamps and cut off on the left side of fabric. The gripper collets open in the gripper box, thus releasing the weft end on the right side of fabric. The gripper is then moved to a chain conveyor that passes under the fabric and delivers the gripper to the left side of the machine. There are several grippers in circulation, which are gradually picked from left to right.

The previously published literature [1], [3] describes various gripper mechanisms but only the Sulzer gripper weaving machines with the above described picking mechanism are widely applied in industrial practice. At the time of creation of the textbook, the gripper machines are included in the production program of the Itema company, which is the successor company of the Sulzer company (see Chapter 7).

In the 1970s and 1980s, the gripper weaving machines have a significant share in the industrial production of fabrics. In 1975, about 40,000 Sulzer gripper machines were in operation and in 1980, more than 80,000 of these machines are installed (source [1] and [29]). At the turn of the Millennium, representation of the machines with gripper picking mechanism is substantially reduced. The gripper machines are replaced in various areas of production by other systems, in particular rapier and air-jet weaving machines. The likely reason is achieving performance limits of the gripper machines. The dimensions of the torsion bar and its mechanical properties do not further allow to increase the velocity of the gripper. There is currently only one company (Itema) engaged in the production of the gripper picking mechanisms. Therefore, the share of gripper machines in the industrial production of fabrics is likely to decrease in the coming years.

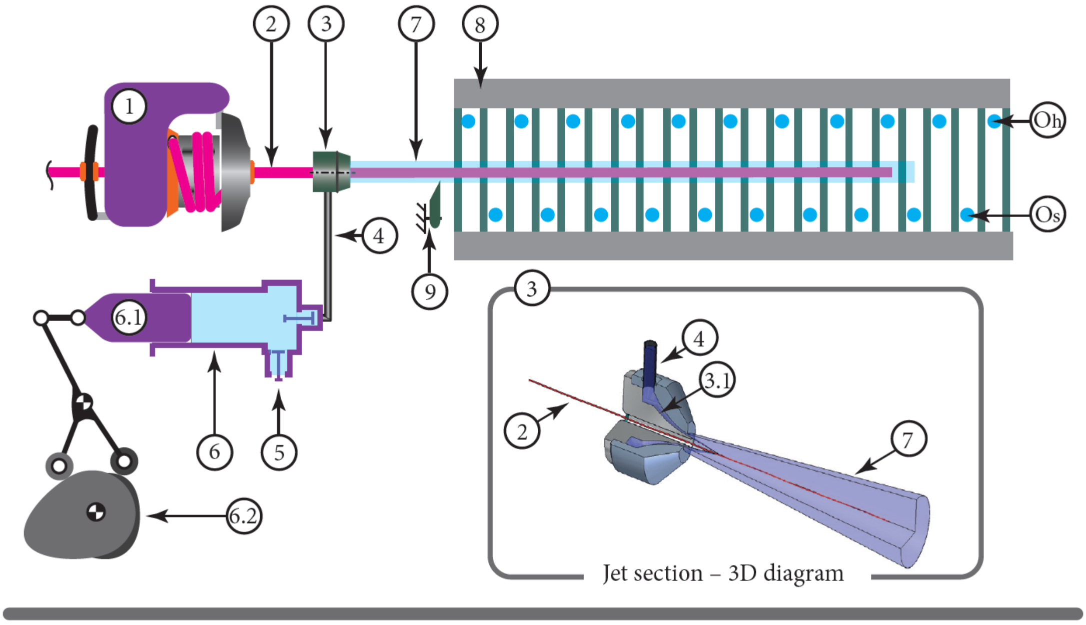
Weft insertion using a water jet

The picking mechanism of water-jet (hydraulic) weaving machines is shown schematically in Figure 150. The weft thread is unwound from the cone by means of the feeder, which prepares the weft length required for one pick before the start of acceleration stage. The weft end is guided into the nozzle. The nozzle is mounted on the machine frame and the water supply to the nozzle at a desired pressure is provided by a pump. The piston stroke of the pump is determined by the shape of the picking cam, which is driven by the main shaft at constant angular velocity. Water is supplied to the pump through a standard water supply pipe. Before the acceleration stage, the piston is on the left and the pump cylinder is filled with water.

In the acceleration stage, the piston moves to the right and displaces water out of the pump cylinder to the pipe, which connects the pump and the nozzle. The water jet in the nozzle transfers momentum to the weft thread, thus giving it velocity. The nozzle has a tapered rotating channel shape and the outlet water flow rate can be derived from piston speed using the continuity equation.

In the picking stage, the face of the weft moves from left to right and the tensile stress in the thread is determined by difference between the water flow rate and the weft velocity. The velocity profile can be defined in the cross section of the water jet. Individual parts of the jet (nozzle) have different velocity and pressure. The maximum velocity and minimum pressure of the nozzle are in the axis of the jet. The weft thread moves through the shed in the axis of the jet. However, the water jet breaks up with increasing distance from the nozzle due to drag forces of the external environment and internal turbulences. Therefore, the reed width of fabric is limited. At the time of creation of the textbook, the maximum values range from 2 m to 3.5 m.

The weft braking (stopping) stage is implemented through the pin, not shown, which is usually integrated in the feeder (for more information see Chapter 4.5.2).



Legend:
1 - weft feeder, 2 - weft, 3 - jet, 3.1 - jet channel, 4 - water supply to the jet, 5 - water supply to the pump, 6 - pump, 6.1 - pump piston, 6.2 - complementary cam for piston drive, 7 - water jet, 8 - reed, 9 - shears, Oh - warp thread in the top shed position, Os - warp thread in the bottom shed position

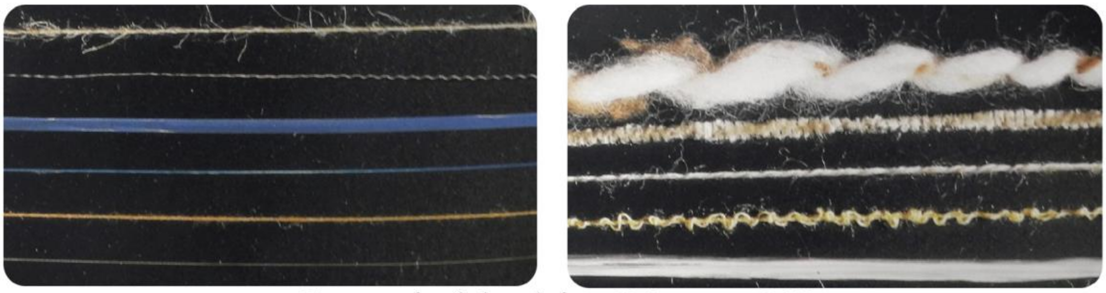
Figure 150: Diagram of the picking mechanism of the water-jet weaving machine

The positive properties of water-jet weaving machines include the ability to achieve high weft performance (2,500 to 3,000 m/min) at a relatively low energy consumption.

The disadvantages of water-jet weaving machines result primarily from contact between the textile materials and the insertion medium, i.e. water jet. The textile material (in particular warp) must be sufficiently water resistant and shall not absorb water. Therefore, a relatively limited range of synthetic materials may be processed on the water-jet weaving machines, which meet the stated requirements. It is further necessary to remove water from the fabric produced. Fabric is partially dewatered directly on the weaving machine by squeezing or suction, but additional final drying on drum drying machines is usually needed. The final drying of fabric complicates the technological procedure and increases its energy requirements. Another disadvantage is the limited capacity in creating the picked pattern. The water-jet machines are usually not equipped with a colour change mechanism (see Chapters 4.5.1 and 4.5.2) or provide a colour change for a very small number of colours (at the time of creation of the textbook, maximum of three colours). Therefore, the machines with water-jet picking mechanism are applied in the production of the relatively narrow range of mostly industrial fabrics. In the coming years, their significant expansion into other areas of production cannot be expected.

4.5.1 Rapier picking mechanism

On rapier weaving machines, the kinematic variables of the weft in the course of insertion are determined solely by kinematic parameters of the picking mechanism and are thus independent of the drag forces and the mass of the carrier. The rapier picking mechanisms are able to weave in wefts of different parameters (for example, different fineness), while placing relatively low demands on the operator in the adjustment. The minimal demands on the operator to change the parameters of the weft are the most important advantages of the rapier weaving machines and the main reason for their significant share in the industrial production of fabrics.



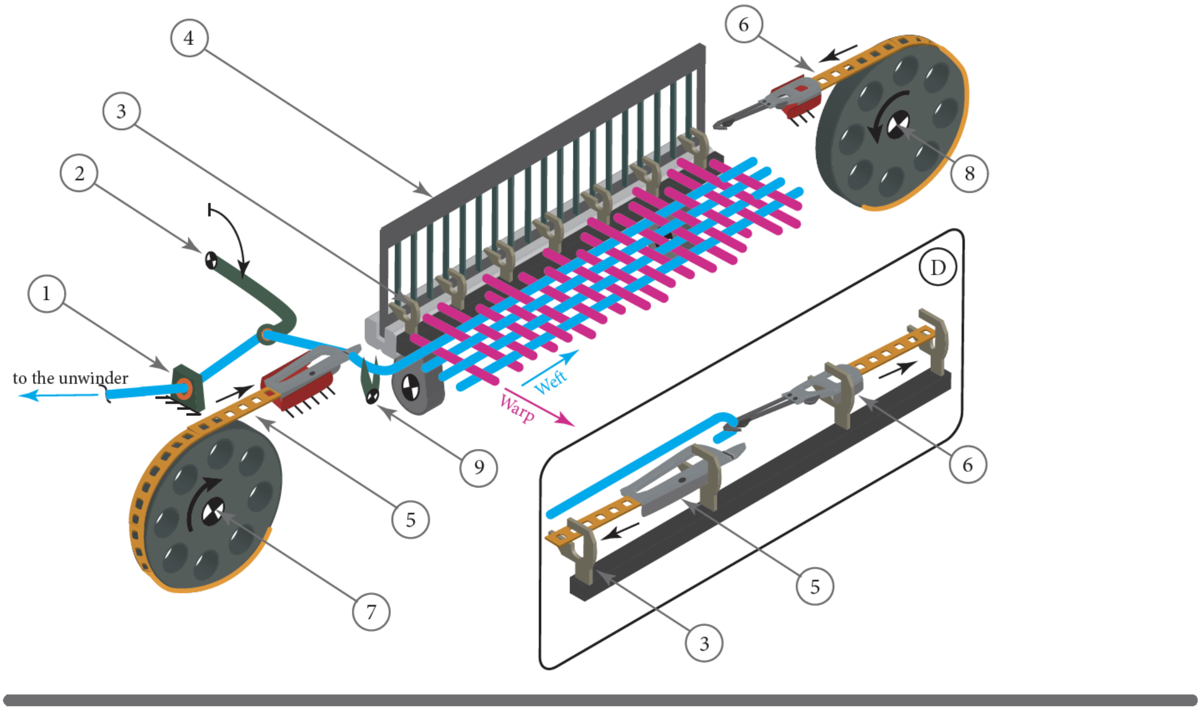
Fineness of weft threads from 0.77 tex up to 3 333 tex

Figure 151: Examples of wefts, which can be woven on the Dornier rapier machines (source [30])

In the previously published literature [1] and [3], **various principles of weft insertion on the rapier machines** are described. The *Iwer* system uses one rapier, which is inserted into the shed first from right to left. On the left side, it catches the end of the weft thread and during the reverse motion, inserts the weft into the shed. The *Gabler* system uses two rapiers, while the left (transfer) rapier makes a loop of the weft thread up to the half of the picking path and the right (receiving) rapier then expands the loop over the entire reed width. The *Dewas* system also uses two rapiers. The left (transfer) rapier transports the weft ends to the half of the picking path. Here, the end of the weft is transferred to the right (receiving) rapier, which completes the weft insertion over the total reed width. The *Iwer* and *Gabler* picking mechanisms limit the weaving frequency (compared to the *Dewas* system). Therefore, **rapier weaving machines with the Dewas systems are exclusively applied in industrial practice at the turn of the Millennium**. At the time of creation of the textbook, flexible rapiers are used by most manufacturers. Rigid rapiers are used only on the Dornier weaving machines.

Weft insertion using flexible rapiers

The picking mechanism with flexible rapiers is shown in Figure 152. In general, the weft thread is unwound from the cone using the unwinder and further threaded through the guide eye of the weft stop motion. Between the stop motion and the left edge of fabric, the weft thread passes through the guide eye of the feeder and then continues to the fabric as the last woven weft. The rapiers form flat stripes, which are made of flexible composite materials and metal heads are fixed at their ends. The rapiers are guided outside the shed by sliding guide on the machine frame and in the shed, the rapiers are guided by means of metal drop wires that are mounted at regular distances on the bottom reed. The rapier drive (moving the rapiers in and out of the shed) is ensured by driving wheels that have rotary connection to the frame. After catching the weft, the transfer (left) rapier cuts off the weft thread at the left edge of fabric using a shearing device (shears).



Legend:
1 - weft stop motion, 2 - weft feeder, 3 - drop wires for guiding the rapiers through the shed, 4 - reed, 5 - transfer rapier, 6 - receiving rapier, 7 - driving wheel of the transfer rapier, 8 - driving wheel of the receiving rapier, 9 - shearing device (shears), D - detail of rapier heads after transfer of the weft end in the middle of the picking path.

Figure 152: 3D diagram of the main parts of the rapier picking mechanism with flexible rapiers

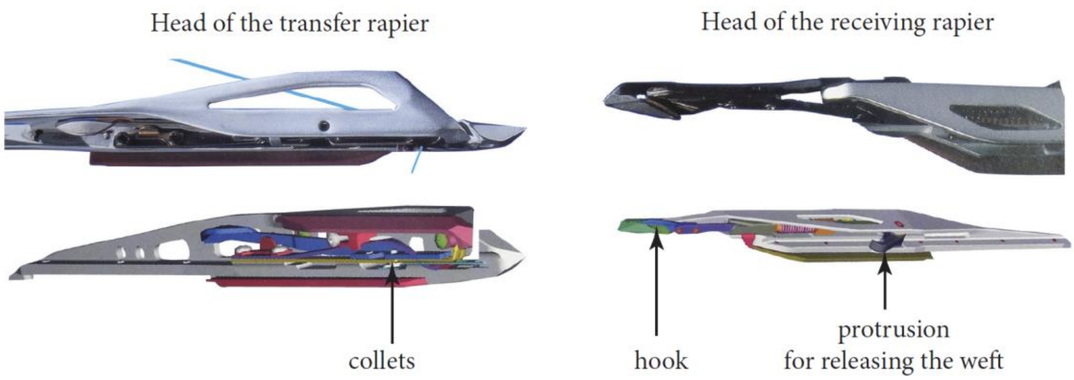


Figure 153: Rapier head of the Somet machines (source [15])

Function: Before starting the weft insertion phase, the most parts of rapiers are wound onto the driving wheels. The picking mechanism starts its operation by rotating the driving wheels towards the fabric. Both rapiers are unwound from the driving wheels and their heads move towards the edges of fabric. Simultaneously, the weft feeder is deflected to the bottom position and thus setting the weft thread in the path of the transfer rapier. The transfer rapier grips the weft in its collets. Subsequently, the weft is cut off at the left edge of fabric. In the first part of the picking stage, the two rapiers move in the shed. The transfer rapier transports the weft end to the half of the picking path, where it meets the receiving rapier. Both rapiers stop so that their heads are inserted into one another and the weft thread passes through the hook of the receiving rapier. In the second part of the picking stage, the driving wheels of the two rapiers rotate away from the fabric. This starts the process of moving the rapiers out of the shed. The receiving rapier releases the end of the weft thread from the collets of the transfer rapier while clamping it in the hook. After moving both rapiers out of the shed and interlacing the weft, the protrusion of the receiving rapier hits the sliding guide. This will release the weft end.

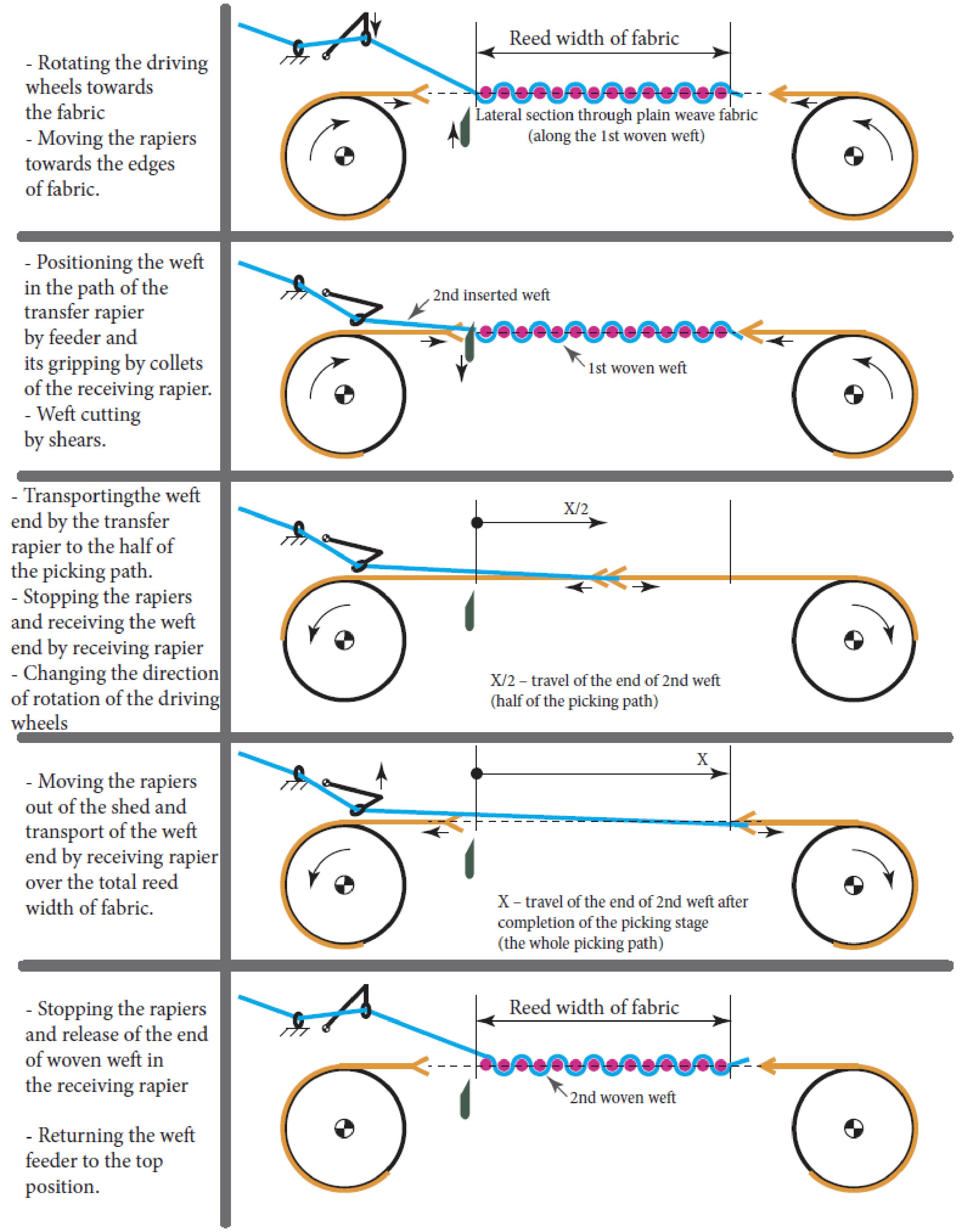
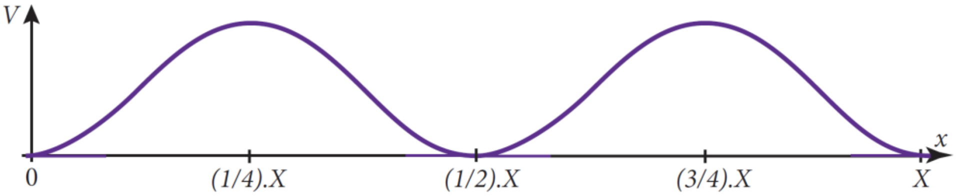


Figure 154: Simplified diagram of the weft insertion by means of two flexible rapiers

The shape of the desired velocity of the rapiers, which in the picking stage determines the velocity of the weft, results from the above-described weft insertion system. After catching the weft by the transfer rapier and cutting it off, the weft thread is given the velocity, which increases until the first quarter of the picking path. The weft velocity then decreases and equals to zero in the middle of the picking path (where the weft end is transferred to the receiving rapier). In the second part of the picking stage (when moving the rapiers out of the shed), the weft velocity first increases to a maximum that is reached in the ¾ of the picking path. Then the velocity decreases and after the weft insertion over the total reed width of fabric, is again equal to zero (see Figure 155). The manufacturers use various mechanisms to ensure the desired velocity of the rapiers (see below).



V - weft velocity, x - picking path, X - reed width of fabric

Figure 155: Dependence of the weft velocity on the picking path in the Dewas system

Weft insertion using rigid rapiers

The rapier picking mechanism with rigid rapiers will be described on the example of the particular configuration, which are used by the Dornier company on its rapier machines. The rapiers are of a metallic hollow section of rectangular cross-section. The profile is open at the bottom and toothed bars are integrated in its internal part. To toothed bars engage the gears, which drive the rapiers. The weft is unwound from the cone by means of the unwinder, further passes through the guide eye of the weft stop motion and feeder, and at the left edge of fabric, there is a shearing device (as in the picking mechanisms with flexible rapiers). Handling of collets in the transfer of the weft is ensured by stops that are controlled by cams. Rigid rapiers do not require guide drop wires in the shed.

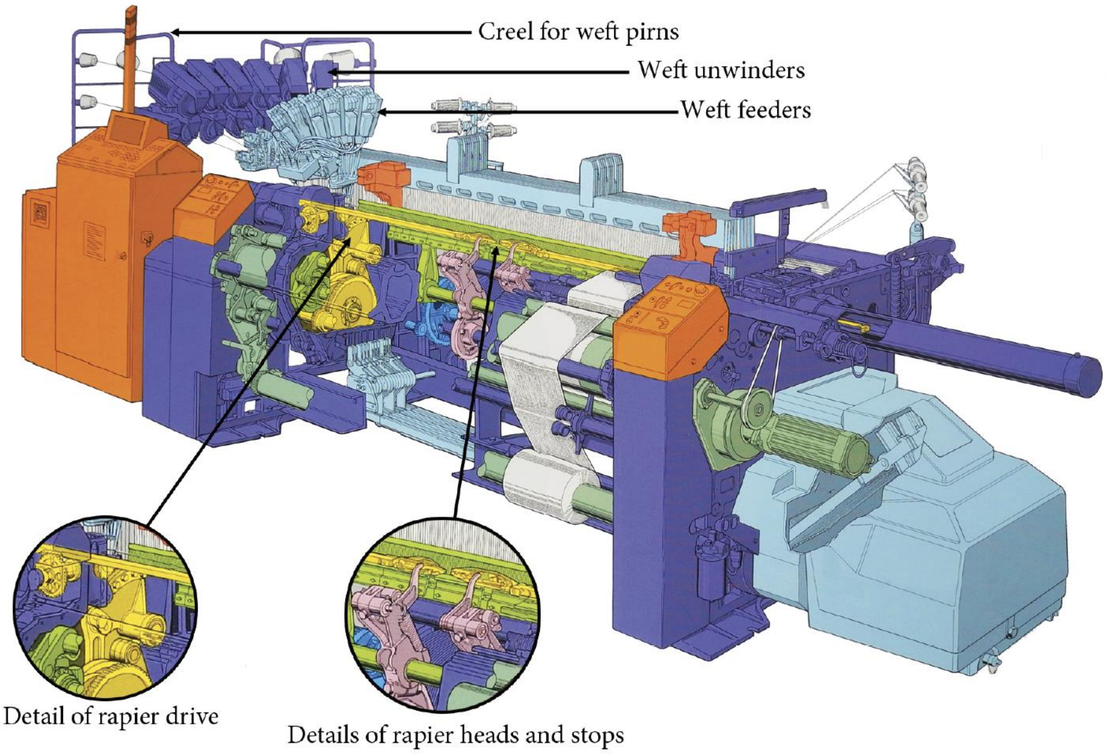


Figure 156: Dornier rapier weaving machine with rigid rapiers (source [30])

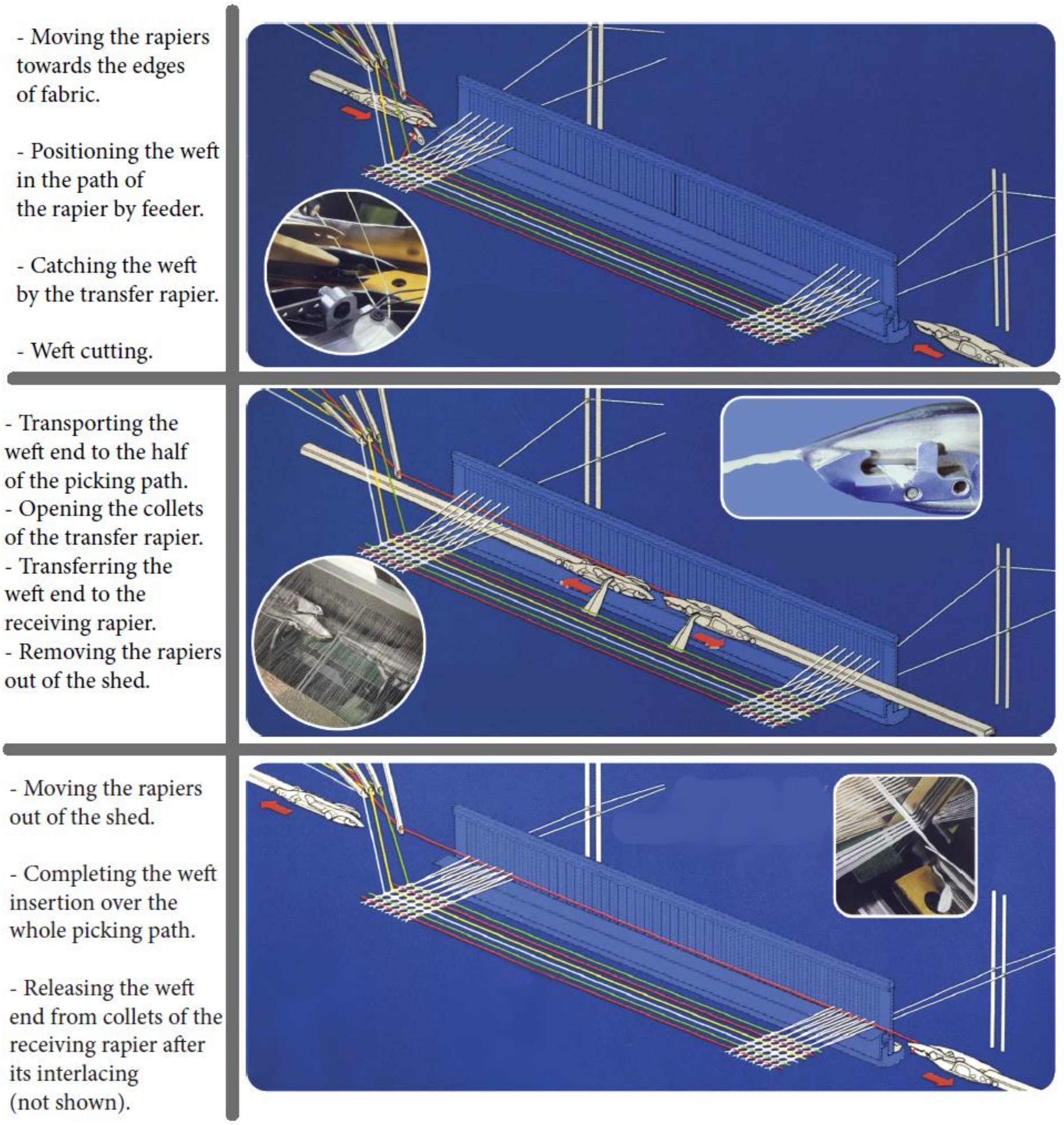
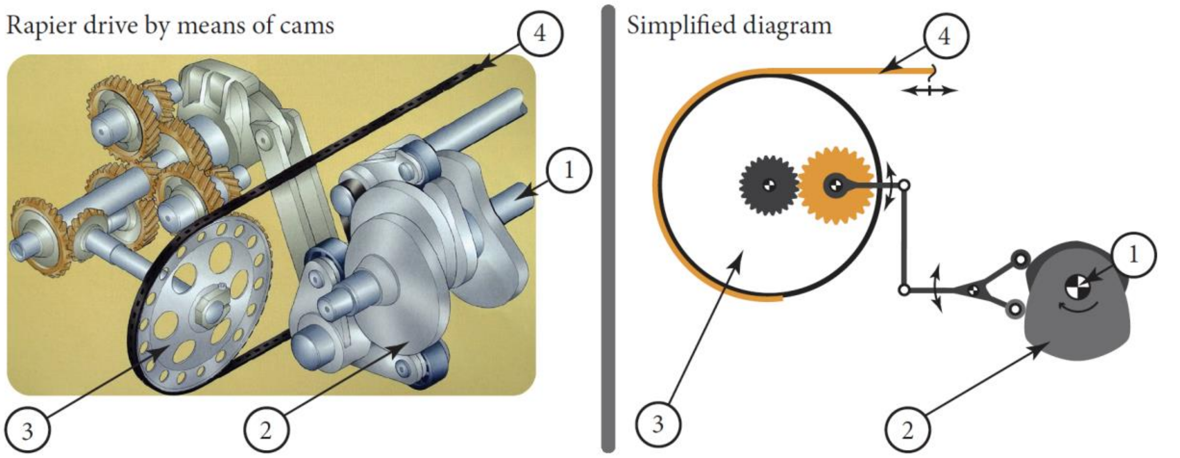


Figure 157: Diagram of the weft insertion by means of two rigid rapiers (source [30])

Function: Before starting the weft insertion phase, the rapiers are inserted in the tubes, which are mounted on the side parts of the frame. The picking mechanism starts its operation by rotating the driving gear wheels of rapiers towards the fabric. Therefore, the heads of both rapiers move towards the edges of fabric. Simultaneously, the weft feeder is deflected to the bottom position and thus setting the weft thread in the path of the left (transfer) rapier. The transfer rapier catches the weft in its collets so that the thread is transversely threaded through the transfer head. Subsequently, the weft is cut off at the left edge of fabric. In the first part of the picking stage, the two rapiers move in the shed. The transfer rapier transports the weft end to the half of the picking path, where it meets the right (receiving) rapier. The stop opens the collets of the receiving rapier and in further motion, the weft end is inserted between the collets of the receiving rapier. Then the rapiers stop and change the direction of rotation of the gears of the drive of the rapiers, i.e. rapiers begin to move out of the shed. The right stop closes the collets of the receiving rapier, which grip the weft end, and the left stop opens the collets of the transfer rapier. After moving both rapiers out of the shed and interlacing the weft, the end of the weft thread is released from the collets of the receiving rapier by the stop located at the right edge of fabric. The course of weft velocity is equal to the velocity course of the picking mechanisms with flexible rapiers (see Figure 155).

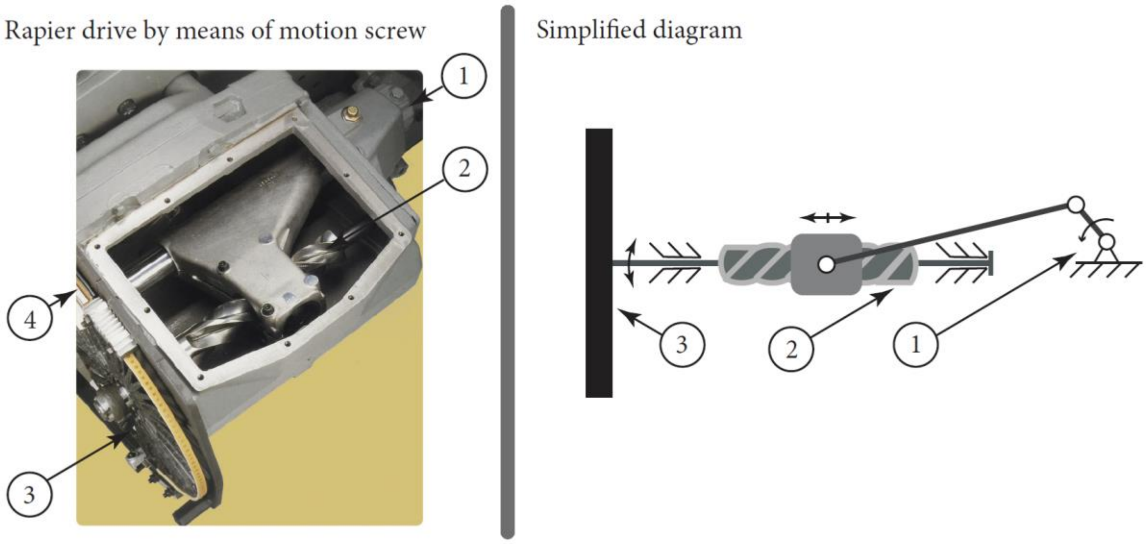
Drive mechanisms for rapiers

The rapier picking mechanisms are driven by the main shaft of the weaving machine. Rotary motion with constant angular velocity is transformed into translational reciprocating motion of the rapiers by various means. Most manufacturers use complementary cams to drive the rapiers (see Figure 158). Other, less applied method of driving the rapiers include mechanisms with the so-called "motion screw" (see Figure 159) or spatial fourbar mechanism (see Figure 160).



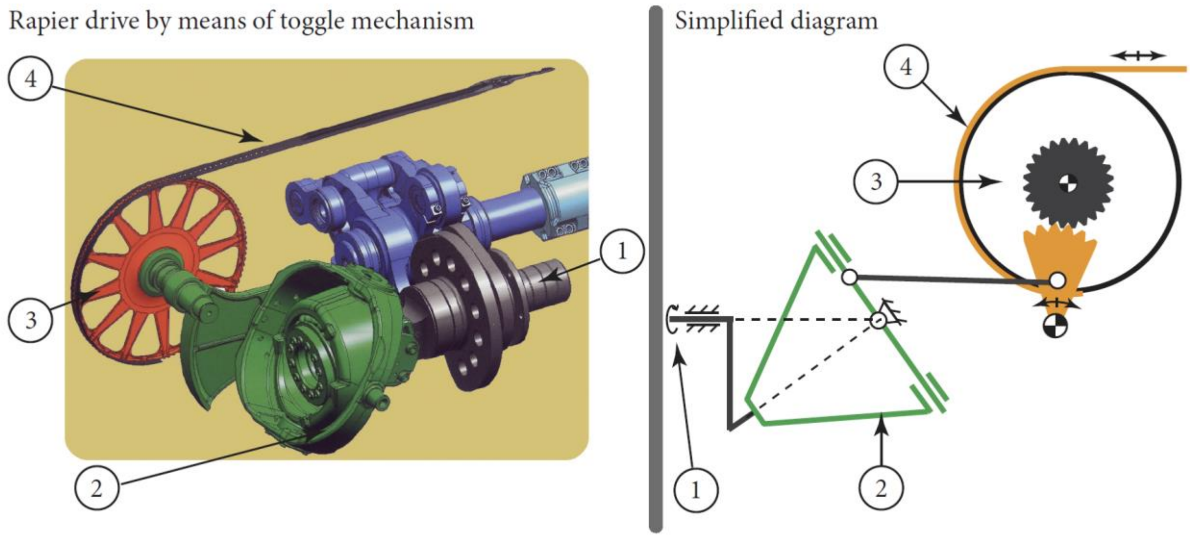
1 - main shaft drive, 2 - cams, 3 - driving wheel of the rapier, 4 - rapier

Figure 158: Rapier drive by means of complementary cams on the Somet machines (source [15])



1 - main shaft drive, 2 - motion screw, 3 - driving wheel of the rapier, 4 - rapier

Figure 159: Rapier drive by means of motion screw on the Vamatex machines (source [31])

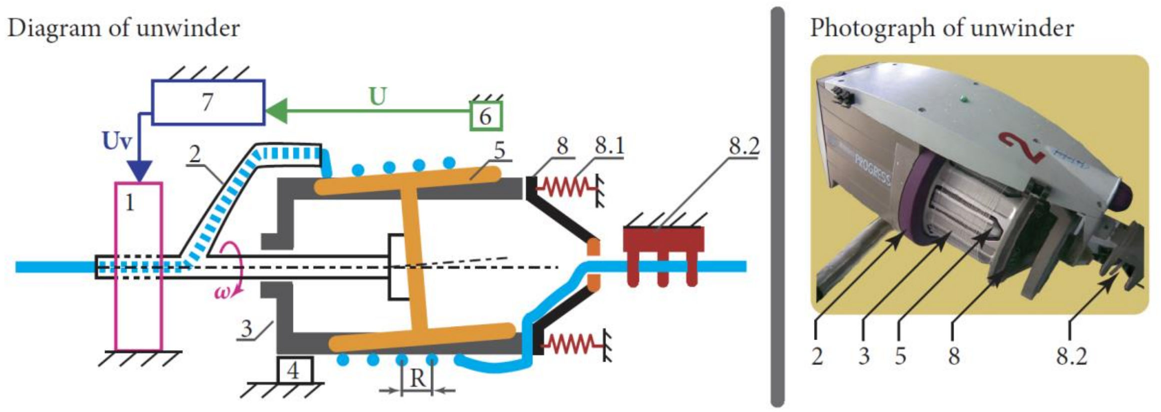


1 - main shaft drive, 2 - spatial toggle mechanism, 3 - driving wheel of the rapier, 4 - rapier

Figure 160: Rapier drive by spatial fourbar mechanism on the Smit Textile machines (source [18])

Weft unwinder

On rapier weaving machines, the weft thread is usually unwound from the cone using the unwinder. This subsystem is equipped with autonomous control, independent motor, mechanism for separating the windings and the means which allow to set the mean value of the internal tensile stress in the weft during its insertion in the shed (thread tensioner). The unwinder is able to reduce the stress applied on the weft thread in the insertion in the shed, reduce the variations in tensile stress and ensure more uniform unwinding speed of thread from the cone, i.e. the unwinder generally stabilises the conditions during weft insertion.



1 - motor, 2 - lapping tube (wing), 3 - drum, 4 - permanent magnet, 5 - oscillating fins, 6 - device for checking the number of windings, 7 - block of autonomous control with microprocessor, 8 - ring of the main thread tensioner, 8.1 - springs of the main thread tensioner, 8.2 - pins of the auxiliary thread tensioner, R - pitch of the individual windings on unwinder drum, U - signal from the device for checking the number of unwindings, Uv - output signal from the block of autonomous control, ω - angular velocity of the motor or wing,

Figure 161: Diagram and photograph of weft unwinder

The weft thread passes through the hollow shaft to the lapping tube (wing) and its rotary motion is provided by the motor. The rotation of the wing results in the individual windings formed on the stationary drum, which is immobilised by a permanent magnet. Oscillating fins are mounted on the rotating shaft so that they extend above the contour of the drum at the point of weft lapping and are below the contour of the drum on the opposite side. At each revolution, the fins move each newly created winding by rate *R* (winding pitch), thus separating the individual windings from each other. The unwinder includes a device for checking the number of windings, which comprises a mechanical or optoelectronic sensor. The sensor signal *U* is processed by a microprocessor, which is located in the autonomous control block. The output signal *Uv* then controls the angular velocity of the motor so as to ensure more uniform speed of thread unwinding off the cone.

In the picking stage, the weft thread is unwound from the drum. Further it passes through the slot between the drum and the ring of the thread tensioner, which has the form of an annular brush (for yarns) or a conical plate (for mono-filaments or multi-filaments). In the slot, the friction force acts on the weft, which can be used to adjust the internal tensile stress in the thread. The main thread tensioner uses the principle of sliding friction (see Figure 162). The ring of the thread tensioner is mounted on springs. The force N, which acts in the slot perpendicular to the weft thread, can be adjusted by deforming these springs. The friction force T, which acts between the weft thread and the ring, is then determined by the product of force N and the coefficient of friction f. The output force after the thread tensioner F_2, which determines the internal tensile stress in the weft, is the sum of the tensile force before the tensioner F_1 and the friction force T . In some cases, an auxiliary thread tensioner is also integrated in the unwinder, which generally uses the principle of belt friction. The correlation between the input and output forces is determined by the Euler's equation. The thread passes through the three pins and the tensile stress is adjustable by the angle of wrapping on the central pin. The auxiliary tensioner is used for finer adjustment of the desired tensile stress in the weft.

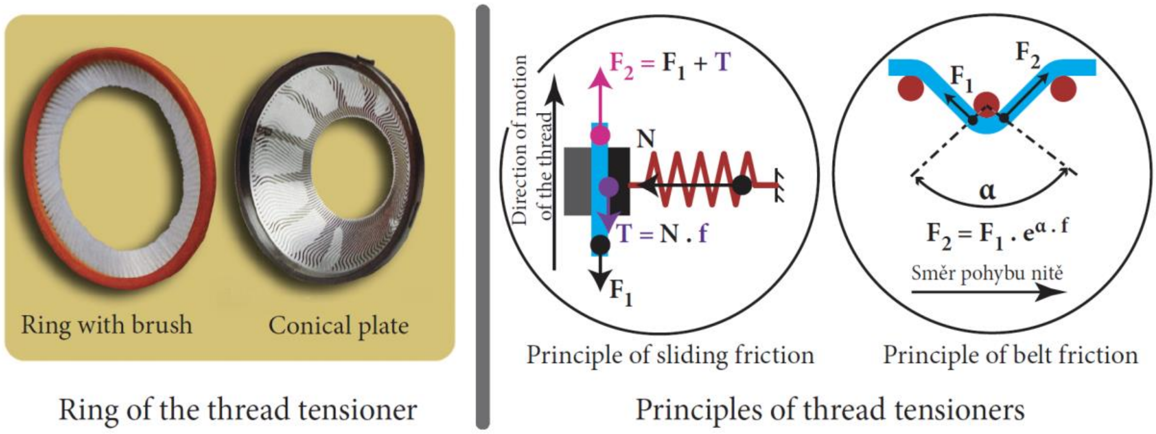


Figure 162: Rings of the thread tensioners and diagram of the principles of their functions

In addition to adjustment of the desired tensile stress in the weft, the unwinders allow selecting the direction of rotation of the wing. In order to prevent untwisting of the weft, it is advisable to select the direction of rotation of the wing identical with the twist of thread. It is usually possible to set the pitch of windings in a limited period, thus adapting the unwinder to various finenesses of the weft threads.

Weft stop motion

In case of break or any other defect of the weft thread, the weaving machine is required to react by stopping and reversing to the position with open shed. The stop signal is generated by the weft stop motion. On rapier machines, the weft stop motion comprises a strain gauge, which is installed between the unwinder and the feeder. The strain gauge is positioned in the guide eye. If break or any other defect of the weft thread occurs, no force will be applied to the strain gauge and no signal will be sent to stop the machine.

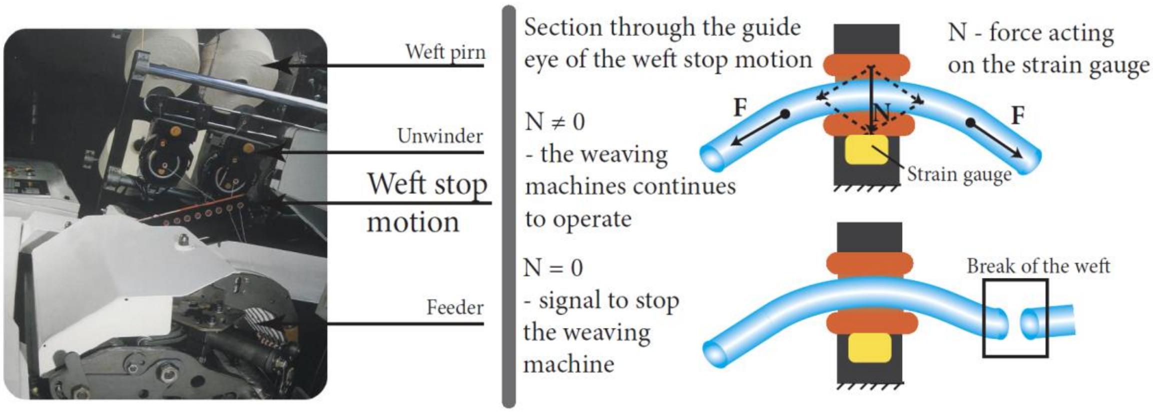


Figure 163: Weft stop motion on the Panter rapier machine (source [32]) and the principle of its function

Colour change

The colour change is a programmable mechanism that allows to weave on the weaving machine wefts of different colours or parameters in the required order, i.e. create the picked pattern. The weaving machines with rapier picking mechanism provide a relatively wide range of options in this aspect. At the time of creation of the textbook, there are rapier machines, which are able to produce fabrics containing up to 16 different colours in the weft, i.e. they are equipped with the so-called "sixteen-colour change". By default, the rapier machines are equipped with four-colour, six-colour, eight-colour and twelve-colour change.

Colour change configuration: Four weft pirns of different colours are mounted on the creel. The thread is unwound from each pirn by means of a separate unwinder and is further guided through a separate guide eye of the weft stop motion. The picking mechanism is equipped with four feeders and each weft thread passes through the eye of the relevant feeder. The operation of feeders is program-controlled according to the desired picked pattern, i.e. the weft of desired colour is given to the rapier in each weaving cycle.

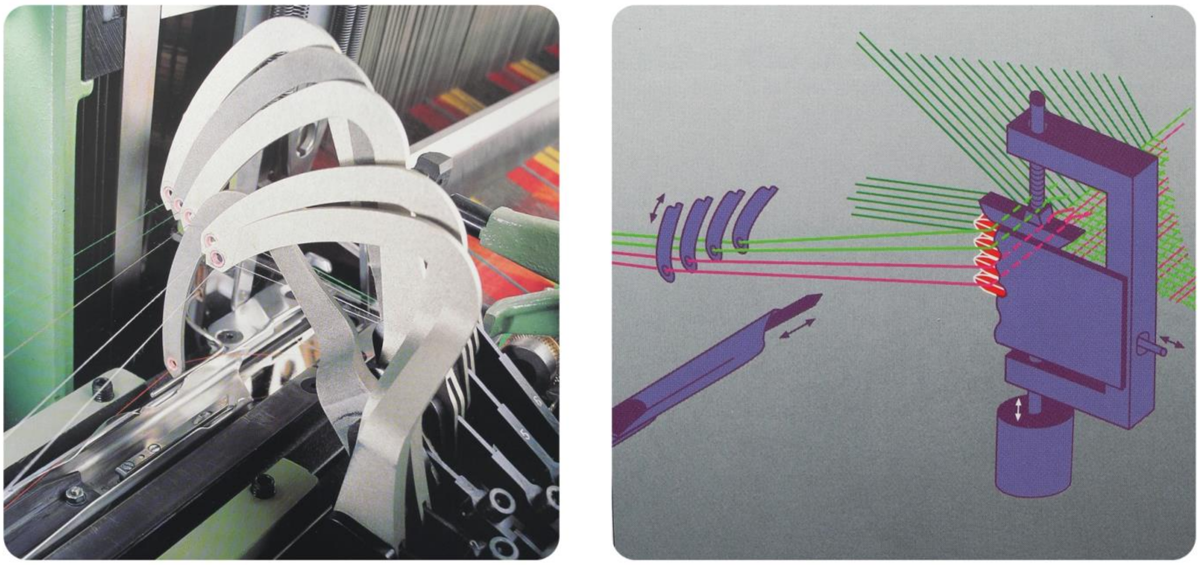


Figure 164: Photographs of the colour change feeders and diagram of four-colour change (source [14])

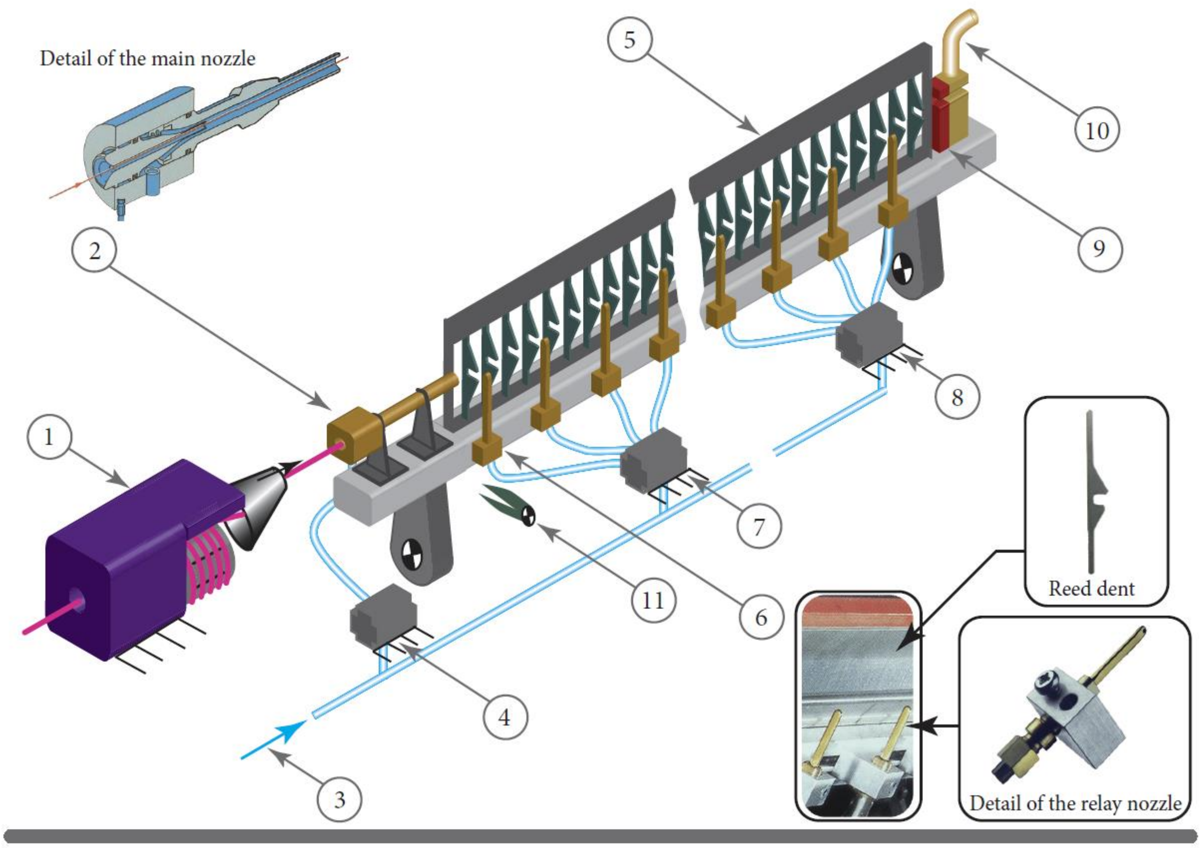
4.5.2 Air-jet picking mechanism

The picking mechanism of air-jet (pneumatic) machines is a separate subsystem that is synchronised with the weaving machine by electronic means. The source of pressure air consists of a central compressor, which provides air distribution to individual weaving machines. Air pressure energy is then transferred in the channel of the nozzle into kinetic energy. The positive properties of air-jet weaving machines include the ability to achieve high performance (at the time of creation of the textbook, up to 3,000 metres of woven weft per minute). However, in comparison with rapier weaving machines, it is necessary to take into account higher demands on the operator while adjusting mechanism the picking mechanism for the weft threads of different parameters. The range of parameters of textile materials (warp and weft threads), which can be processed on air-jet machines, is currently very wide, but the weft threads with a smooth surface (in particular, various strips made of synthetic materials) are difficult to weave using the air-jet picking mechanism.

Description of the air-jet picking mechanism

The air-jet picking mechanism is schematically illustrated in Figure 165. The weft thread is unwound from the cone, not illustrated, by means of the feeder and is further guided to the main nozzle. The air supply to the main nozzle is controlled by an electromagnetic valve. The spreading of air jet in the shed is limited by profile reed. Weft insertion at greater distance is allowed by relay nozzles that are mounted at regular distances on the bottom reed. A certain number of relay nozzles (2, 3, 4 to 5) is connected to one valve that controls the air supply to the nozzles. The group of relay nozzles connected to the common valve is referred to as a section. The weft stop motion works on the optoelectronic principle and is located on the right side of the reed. The tensioning nozzle is also on the right side of the reed, which generates tensile force in the weft after its insertion over the total reed width. After tying, the weft is cut off by the shearing device (shears) at the left edge of fabric.

Note to the reed width of the air-jet weaving machines: The air jet breaks up at a shorter distance than the water jet. Therefore, it is possible to insert the weft with one main nozzle at very short distances. The first industrially-manufactured air-jet weaving machine (type P45) had the reed width of only 45 cm. Later, the reed width of the air-jet machines was increased (approximately to 160 cm) using the so-called “confuser”. Confuser is a lamella channel, which restricts in the shed the air jet dispersion in the environment. The air-jet picking mechanism with confuser is described in detail in previously published literature, in particular [1] and [3]. Although the confuser allows a limited increase in the reed width, is also a source of various textile-technological problems. Friction forces are generated between the warp threads and the confuser lamellas during the creation of the shed. It is difficult to process warps with high number of threads per unit length on the weaving machines with confuser. Therefore, the air-jet weaving machines with relay nozzles are solely applied at the turn of the Millennium. In addition to the removal of textile-technological problems, this concept allows further increase in reed width. At the time of creation of the textbook, the maximum reed width of the air-jet machines with relay nozzles ranges from 4 m to 5 m. The air-jet picking mechanisms are currently applied not only on the weaving machines for the production of standard fabrics (for example, for clothing purposes), but also on the weaving machines for the production of industrial or special fabrics (for example, leno weaves - see Chapter 6).



Legend:
1 - unwinder, 2 - main nozzle, 3 - supply of compressed air from the compressor, 4 - valve of the main nozzle, 5 - profile reed, 6 - relay nozzle, 7 - valve of the first section of relay nozzles, 8 - – valve of the n-th section of relay nozzles, 9 - weft stop motion, 10 - tensioning nozzle, 11 - shearing device (shears).

Figure 165: 3D diagram of the main parts of air-jet picking mechanism

Feeder

The feeder stabilises the conditions in weft insertion and is moreover able to winding (prepare) the exact length of the weft required for one pick in each weaving cycle.

The same means as in the unwinder are used to create the winding on the drum of the feeder. The difference involves the possibility of adjusting the wound length, which is determined by the circumference (diameter) of the drum and the number of turns. The construction of the feeder allows the adjustment of the drum diameter D and the number of turns n, i.e. winding length $L = \pi. D. N$, which is created in each weaving cycle. Therefore, the length of winding on the feeder can be adapted to different reed widths of fabric.

On air-jet weaving machines, the tensile stress in the weft in the insertion in the shed generates the difference between the air flow velocity and the velocity of the face of the weft. Therefore, the feeders are not equipped with thread tensioners. An anti-ballooning cover is used to restrict the so-called “balloon”, which is generated in thread unwinding from the drum. After completion of the picking stage, it is necessary to stop the weft thread. Therefore, a mechanical element (pin) is usually integrated in the feeder, which is able to provide this function.

Note: The balloon is the result of centrifugal forces, which act on the thread during its unwinding from the drum of the feeder. The anti-ballooning cover defines the maximum radius for the rotation of the thread element (i.e. balloon radius).

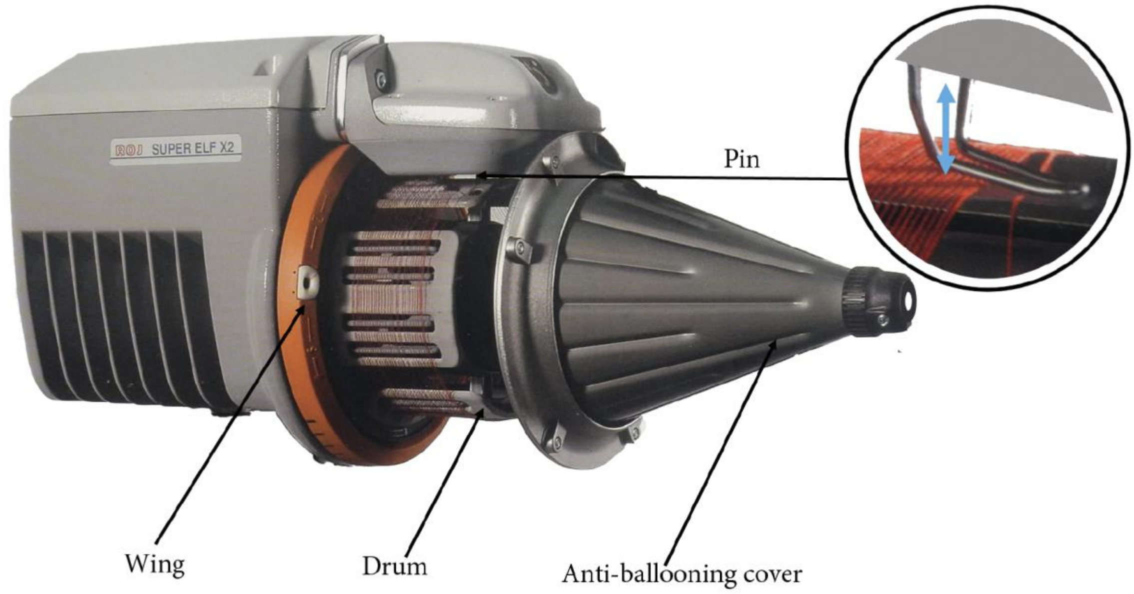


Figure 166: Feeder of the ROJ company (source [33])

Main nozzle

Air pressure energy is transferred into kinetic energy in the nozzle. The momentum of the air jet ($H = m. v$) is transferred to the weft, thus giving the velocity to the weft thread. The nozzle comprises a duct for the air supply, duct for the weft thread and a relatively long sleeve, which guides the air jet and the weft thread to the left side of the reed.

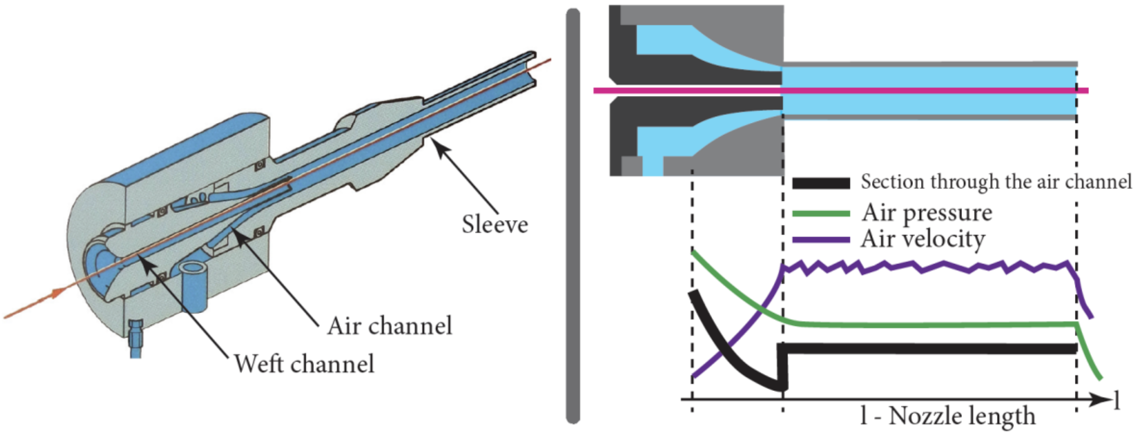


Figure 167: Main nozzle

Note: The relation between the outlet air velocity from the nozzle and the filling pressure can be derived by means of thermodynamics (equation of state for gas, continuity equation for compressible gas and the Bernoulli's equation). This issue is addressed in the theory of weaving.

Relay nozzles

The air jet from the relay nozzles passes momentum to the weft during the motion of the weft thread through the shed, thus allowing its insertion to a larger reed width. In the open shed position, the relay nozzles are inserted between the warp threads, which form the bottom shed position. To avoid damage to the warp threads, the relay nozzles have the shape of "flat tubes". The shape of the air channel of relay nozzles is designed so that even large changes in filling pressure cause minimal changes in the angle of air jet at the outlet of the nozzle.

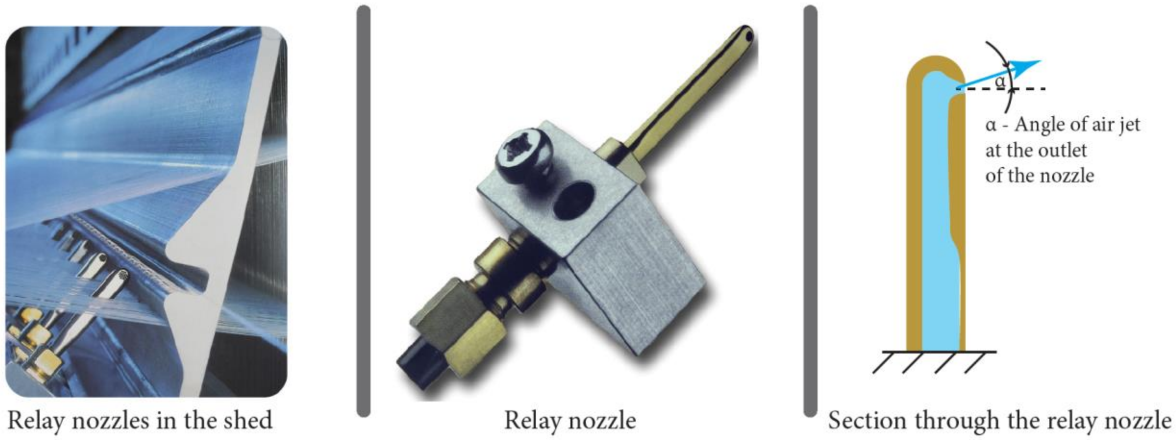


Figure 168: Relay nozzles

Profile reed

The so-called “profile reed” must be used on the air-jet weaving machines. The shape of the dents of the reed is shown in Figure 169. The dents on the reed form a “slot”, in which a jet of air with the weft moves. In addition to standard functions (guiding the warp threads in the required number of threads per unit length and ensuring the weft beat-up), the profile reed restricts the air jet dispersion in the environment, thereby allowing the weft insertion to a larger reed width.

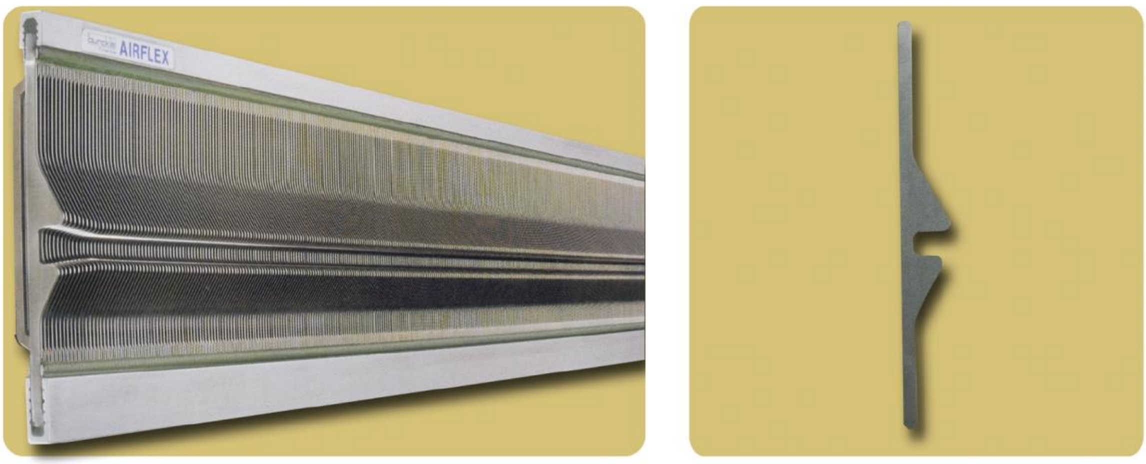


Figure 169: Profile reed and its dent

Weft stop motion and tensioning nozzle

Proper weft insertion over the total reed width of fabric is controlled by the weft stop motion. The stop motion is located on the right side of the reed and works on the optoelectronic principle. An optocoupler [34] is positioned in the lamella of the weft stop motion, which is composed of a light source (light emitting diodes) and a light radiation receiver (photodiodes). In the case that the light radiation does not fall onto the photodiode (it is covered), only a small residual current flows in its outside circumference. Diode irradiation is shown by the increase in current in its the outside circumference. Therefore, if the weft is correctly inserted (face of the weft is transported to the right side of the reed), the weft thread will cover the photodiode and the weaving machine continues to operate. If there is a break or another defect of the weft thread and the weft forehead is not transported to the right side of the reed, the photodiode will be irradiated (it will not be covered by the weft thread). Diode irradiation is then shown by the increase in current, which is the signal to stop the weaving machine.

After completion of the picking stage, it is necessary to create a force coupling between the inserted weft and the reed. The tensioning nozzle serves this purpose, which is mounted on the right side of the reed. This nozzle sucks air and after completion of the picking stage, sucks the face (end) of the weft thread. This creates the force coupling between the tensioning nozzle and the weft until its tying.

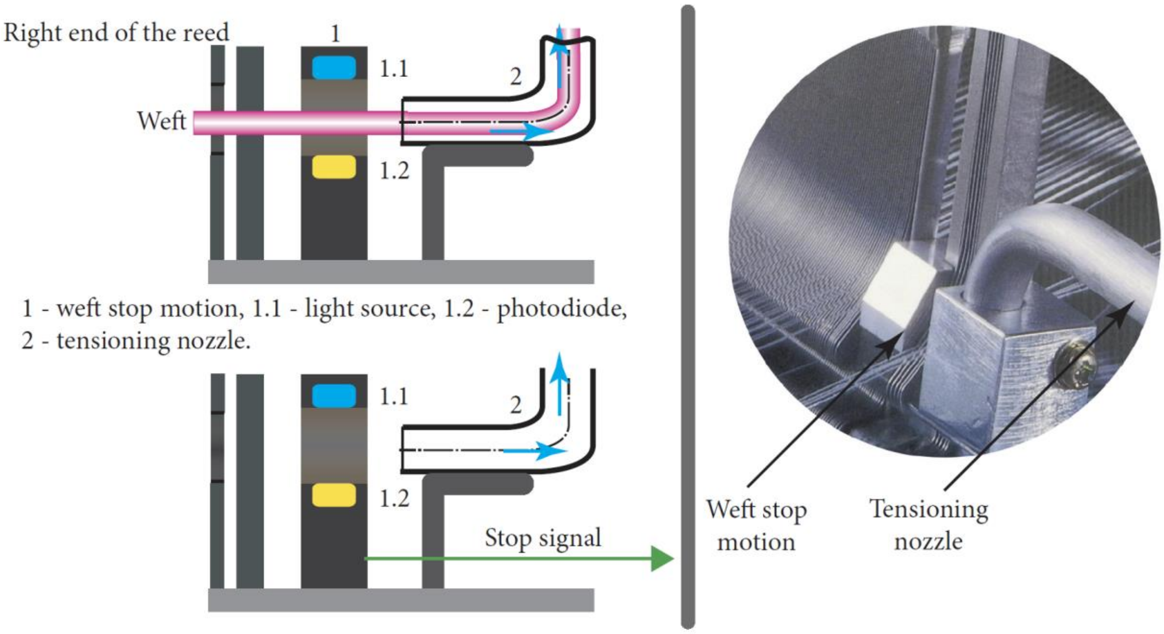


Figure 170: Weft stop motion and tensioning nozzle

Function of the air-jet picking mechanism

Operation of the air-jet picking mechanism with relay nozzles is shown in a simplified diagram in Figure 171. Before the acceleration stage, the feeder unwinds from the cone the weft length required for one weft pick. The acceleration stage is initiated by opening the valve of the main nozzle. Air flows through the air duct of the main nozzle and comes into contact with the weft thread in the sleeve. The air jet passes the momentum of the weft and the face of the weft starts moving with a certain velocity.

Subsequently, the face of the weft leaves the sleeve of the main nozzle, thus starting the picking stage. At this stage, the air jet with the weft thread moves in the groove of the profile reed. The air jet breaks up with increasing distance from the main nozzle. That is why the valve of the first section of the relay nozzles opens at the beginning of the picking stage. The air jet from these relay nozzles transfers the momentum to the weft thread, thereby limiting the decrease in its velocity. With the movement of the face of the weft, the valves of the downstream sections of the relay nozzles are gradually opened and the upstream valves are closed. The continuity of operation of individual sections of the relay nozzles reduces the drop in weft velocity during the picking stage. Air flow rate is always greater than the velocity of the weft and their difference creates an internal tensile stress in the weft thread.

After insertion of the weft thread over the total reed width, the tensioning nozzle sucks the face of the weft, thus creating a force coupling between the weft and the reed on the right side of the machine. At the same time, the pin of the feeder creates a force coupling between the drum of the feeder and the weft thread. This will stop the weft. After tying, the weft thread between the main nozzle and the left edge of fabric is cut.

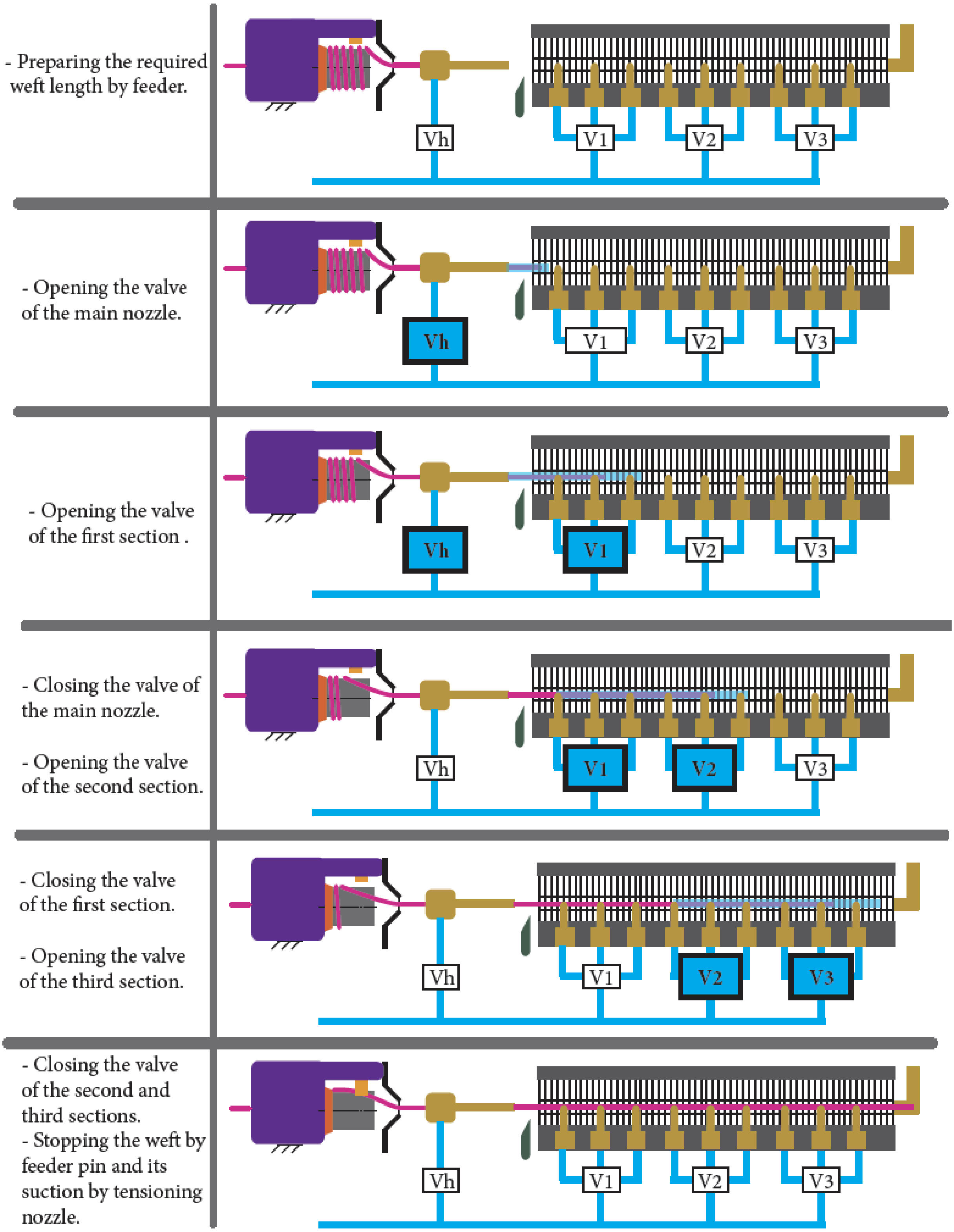


Figure 171: Diagram of weft insertion on the air-jet weaving machine

Note: The opening of each valve is controlled electronically depending on the rotation angle of the main shaft (for more information see Chapter 4.8). Setpoints for the valve of the main nozzle as well as the valves of the individual sections of the relay nozzles are entered by the operator through the appropriate computer interface. Adjustment of the air-jet pick, which is in practice also called the valve timing, is based on an empirical choice of suitable values of the rotation angle of the main shaft, which results in opening and closing valves of individual sections. Operations of the individual sections, with given parameters of the weft thread, must appropriately follow each other so as to result in reliable weft insertion. Since the velocity course of the weft is dependent on the drag forces of the surrounding environment and its mass (or fineness), the adjustment of the picking mechanism of the air-jet machine places increased demands on the operator (compared with the rapier picking mechanism). The following table shows an example of valve timing for the air-jet picking mechanism with seven sections of the relay nozzles. Figure 172 shows the data in the form of a graph that shows the operation of the valves depending on the picking path and the rotation angle of the main shaft. The graph is supplemented by an approximate velocity waveform of the face of the weft thread.

Valve timing of the air-jet picking mechanism		
	Valve opening	Valve closing
Main nozzle	90°	225°
Section 1	90°	140°
Section 2	130°	180°
Section 3	160°	210°
Section 4	180°	230°
Section 5	200°	250°
Section 6	220°	270°
Section 7	240°	280°
Tensioning nozzle	260°	320°

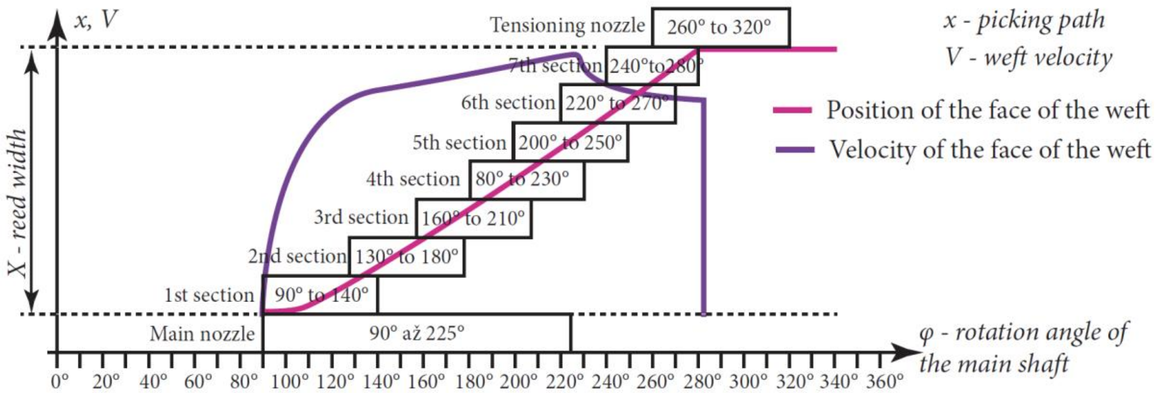


Figure 172: Valve timing and dependence of the weft velocity on the rotation angle of the main shaft

Colour change

At the time of creation of the textbook, there are air-jet weaving machines with two-colour, four-colour, six-colour and eight-colour change.

Colour change configuration: Four weft pirns of different colours are mounted on the creel. The thread is unwound from each pirn by a separate feeder. The machine is equipped with four main nozzles and each weft thread is guided into a separate nozzle. The air supply to each nozzle is controlled by an individual valve. Opening the valve of the main nozzles in individual weaving cycles is program-controlled according to the desired picked pattern, i.e. in each weaving cycle, the weft of the desired colour in inserted in the shed.

On machines with two-colour and four-colour change, the standard profile reed is used, whose dents have the same shape. On machines with six- and eight-colour change, the so-called “funnel-shaped reed” is used. Dents on the left side of the reed are shaped so that the groove in these areas is expanded, allowing placement of a larger number of the main nozzles.

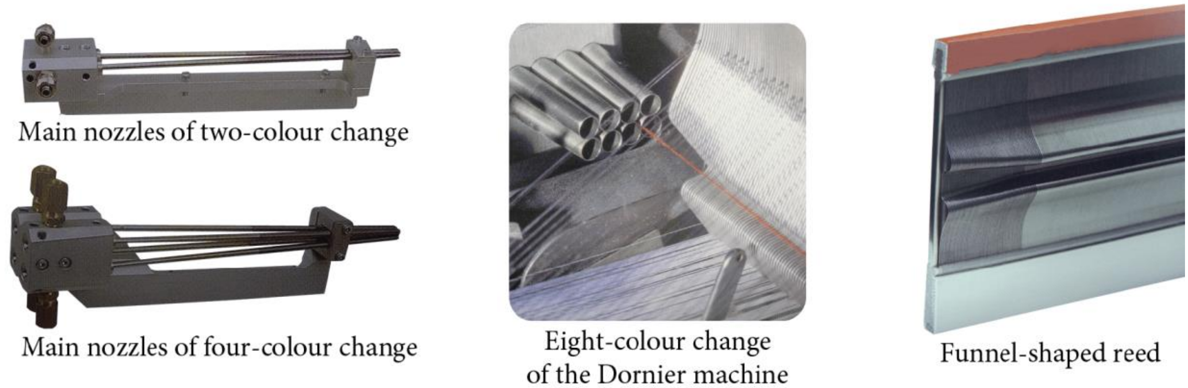


Figure 173: Main nozzles of the colour change of the air-jet weaving machines

4.5.3 Reinforcing the edges of fabric

On all types of shuttleless weaving machines, the edge of fabric must be reinforced in a certain way, which can be implemented in various ways. For example, on water-jet weaving machines, which process synthetic (thermoplastic) materials, the edges of fabric may be reinforced by fusing. When processing textile materials that cannot be fused, the edges of fabric are reinforced by folding the protruding ends of the weft in the following shed or by means of the so-called “leno weave”.

Reinforcing the edges of fabric by folding the edges of weft

In this case, the edge of the fabric produced on the shuttle weaving machine is imitated. A special mechanism grabs the protruding end of the weft on the left and right sides of fabric and inserts the ends in the shed in the next weaving cycle. Tying the inserted weft end will reinforce the edge. However, double number of weft threads per unit length is created in the edges of fabric (see Figure 174).

Reinforcing the edges of fabric by leno weave

Leno weave provides a high consistency between the warp and the weft (for more information see Chapter 6) through mutual interlacing (interweaving) of the warp threads. This feature is useful in the reinforcement of the edges of fabric. The first and second threads in fabric interlace in the leno weave and also the next-to-last and last threads interlace in the same way. The threads that form leno weave in the edge of fabric are generally wound on separate bobbins and the mechanism for reinforcing the edges is able to change their positions in the individual weaving cycles. Various mechanisms are used for reinforcing the edges by leno weave. For example, the rotating device of the Dornier company (see Figure 175). At the time of creation of the textbook, the leno weave is the most common way to reinforcing edges on the shuttleless weaving machines.

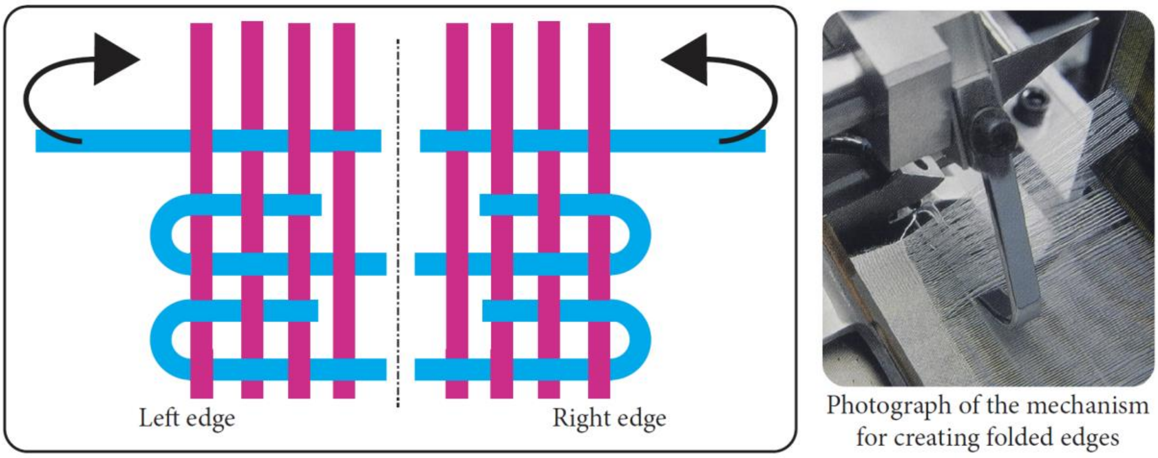


Figure 174: Reinforcing the edges of fabric by folding the edges of weft

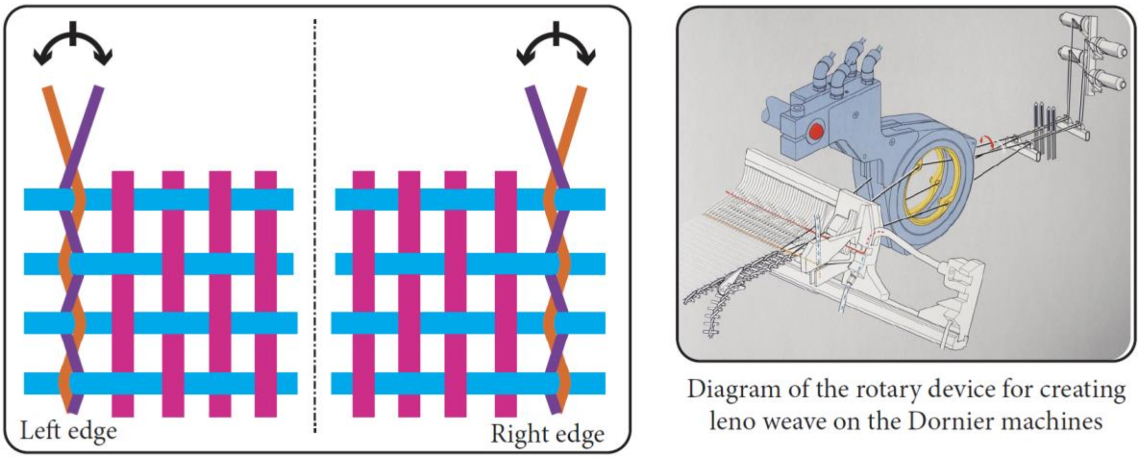


Figure 175: Reinforcing the edges of fabric by leno weave

Important findings of the chapters:

1) We know the division of weaving machines by the weft carrier used.
2) We can explain the difference between the weft insertion on the shuttle and shuttleless weaving machines.
3) We can describe the rapier picking mechanism and explain its function.
4) We can describe the air-jet picking mechanism and explain its function.
5) We know the function of the colour change mechanism on weaving machines and its implementation on rapier and air-jet machines.
6) We know how the edges of fabric are reinforced on shuttleless machines.

4.6 Weft beat-up

After completion of the weft insertion phase, the weft thread is located at a certain distance from the face of fabric (last woven weft). The weft beat-up phase follows, in which **the weft thread is transported by the reed to the face of fabric and pressed into the fabric** so that the spacing *B* between the weft threads corresponds to the desired number of weft threads per unit length *du* ($B = 1 / du$). At the same time, the shed is closed and in the position of the line heddles, the weft beaten up interlaces with the warp threads. This will complete the weaving cycle.

4.6.1 Parts of the beat-up mechanism

As mentioned in Chapter 4.1, the weft is beaten up by the reed. The reed is mounted on the slay, which performs a rotational reciprocating motion with a period of one weaving cycle. The slay is driven by fourbar or cam mechanism.

Reed

Dents are the main part of the reed, which are in contact with the textile material during the weaving process. The dents are interconnected with metal coupling inserts of a semicircular cross-section and a steel spring. The coupling inserts are attached on both sides to the dents in their upper and lower parts, thereby ensuring flatness of the reed. The spring encircles the dents and inserts in such a way that its individual coils separate the dents from each other. This provides the spacings of dents, which are determined by the diameter of the spring wire. The upper and lower support of the reed consists of an aluminium "U" section. The protruding ends of dents are inserted in the grooves of these sections. Interconnection of the dents, coupling inserts and carrying wires with the supports of the reed is made using an epoxy resin. The reed frame is enclosed by columns made of flat steel.

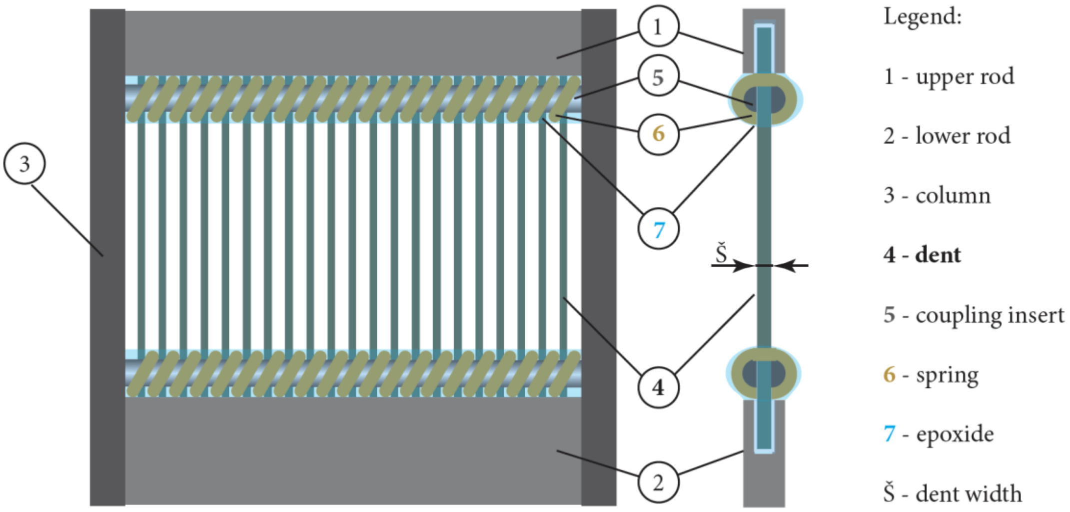


Figure 176: Diagram of the main parts of the reed (front and side views)

The dents are made of carbon or stainless steel and, in some cases, are provided with special surface treatment [35]. Dent width means a dimension of the dent in the direction of the warp threads and dent thickness means a dimension of the dent in the direction of the weft threads. The proper function of the beat-up can only be ensured by the reed, which is equipped with sufficient rigid dents. Therefore, reeds with different width of the dents in the range from 2 mm to 8 mm are manufactured by default. The reeds with smaller dent width are suitable for the production of lighter fabrics with lower number of weft threads per unit length, where relatively small forces act on the reed (for more information see below). On the contrary, the reeds with greater dent width should be used in the production of heavier fabrics with high number of weft threads per unit length.

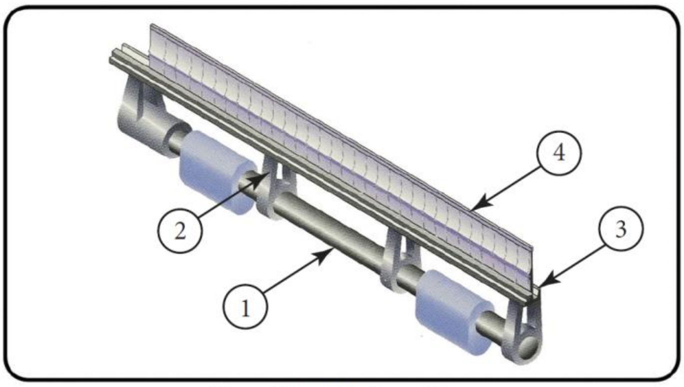
The length of the reed or its working width determines the reed width of fabric and is therefore another important parameter. At the time of creation of the textbook, reed widths of the standard weaving machines most often range between 2 m and 3 m, which also correspond to the working widths of the most often manufactured reeds. The maximum working width of conventionally manufactured reeds then ranges from 5 m to 6 m.

The last parameter, which characterises the reed, is its inside diameter, which is the distance between the lower and upper coupling inserts. The reed must have sufficient inside diameter so as to avoid contact between the warp threads and the coupling inserts in the upper and lower parts of the reed at maximum shed opening.

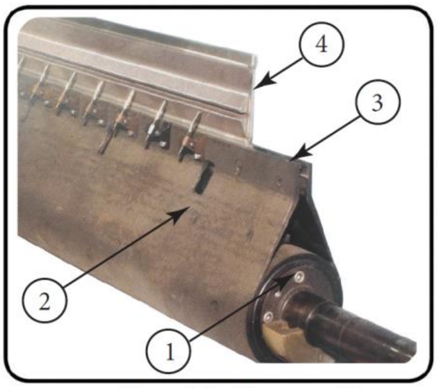
Specialised companies are engaged in reed making. At the time of creation of the textbook, the significant manufacturers of reeds include the Naveta company that has heddles in addition to reeds in its production program.

Slay

Slay is an output working member of the beat-up mechanism that enables the mounting of the reed and its rotational reciprocating motion implements the weft beat-up. The slay consists of a rocking rail, which is a steel rod of circular cross-section. Slay swords, which are made of steel, are attached to the rocking rail. Some manufacturers replace conventional steel swords with a continuous prismatic support made of composite materials. A beam is mounted in the upper part of the slay (on swords or on support), which is a "U" section bar. The bottom support of the reed is inserted in the groove of the beam and secured by bolts. The slay as a whole must be characterised by sufficient rigidity (due to the correct operation of beat-up) and low weight (to minimise the dynamic forces).



Slay of the ZAX machine
of the Tsudakoma company



Slay of the Vera machine
of the VÚTS Liberec company

1 - rocking rail, 2 - sword (for the Vera machine, continuous prismatic support), 3 - beam, 4 - reed

Figure 177: Main parts of the slay (source [20],[19])

Slay drive

The slay performs a rotational reciprocating motion with a period of one weaving cycle. The slay is driven by means of a fourbar mechanism (for example, four-joint mechanism) or a mechanism with complementary cams.

The four-joint mechanism is composed of a crankshaft, a connecting rod and a slay. The course of lifting of the slay can be influenced only to a limited extent by choosing the ratio between the length of the crank and the connecting rod. Accordingly, the fourbar mechanism is not able to create the rest position of the slay in the back dead centre. Its use, however, minimises the dynamic forces that are generated by the beat-up mechanism during operation of the machine and thus allows achieving higher weaving frequencies.

For beat-up mechanisms with the complementary cams, the course of lifting of the slay is determined by the shape of the cams. The shape of the cams is designed so that the slay has the static angle in its back dead centre, which increases acceleration and usually the dynamic forces generated by the beat-up mechanism during operation of the machine.

Selection of the mechanism for driving the slay depends on the picking mechanism used. The air-jet weaving machines do not require the rest position of the slay in the back dead centre. The (main and relay) nozzles are mounted on the slay and the weft can be inserted in the motion of the slay. Therefore, the fourbar beat-up mechanism can be used on the air-jet machines. The fourbar beat-up mechanism is also used for the water-jet weaving machines. Other systems (rapier, gripper) have the picking mechanism fixed to the machine frame in such a manner that the weft insertion requires to create the rest position of the slay in the back dead centre (the weft cannot be inserted in the motion of the slay). Therefore, the beat-up mechanisms with complementary cams are used on these machines.

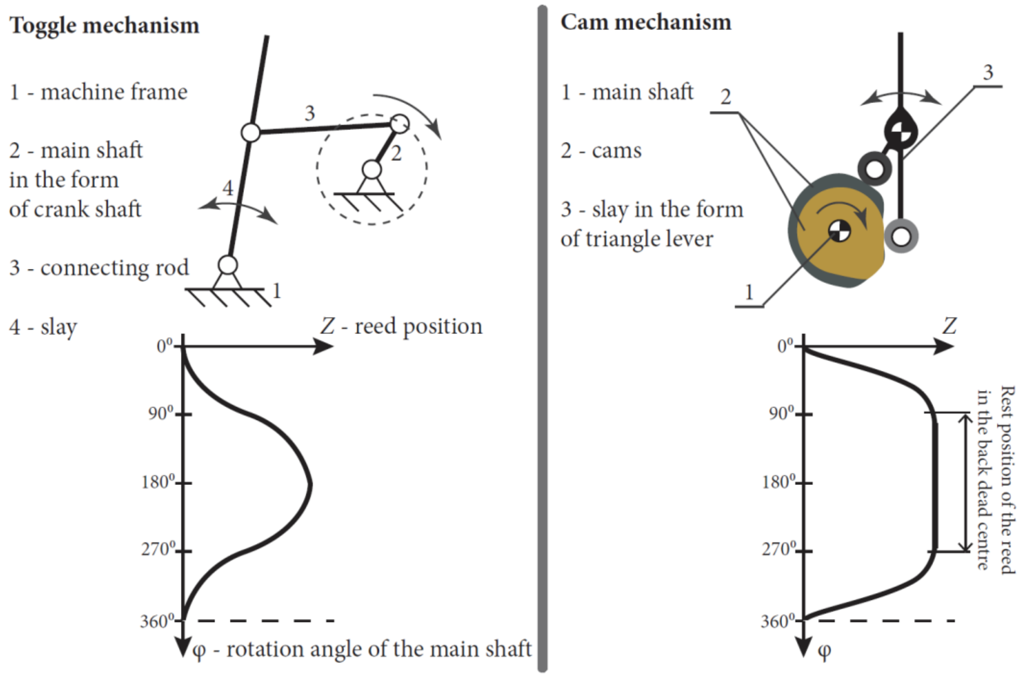


Figure 178: Kinematic diagram of the fourbar and cam beat-up mechanisms

4.6.2 Action of forces between the reed and the face of fabric

As mentioned above, the beat-up phase is implemented in two stages. First, the weft is transported by the reed to the face of fabric (transport phase) and then is pushed into the fabric at the spacing determined by the desired number of weft threads per unit length (beat-up phase). In the beat-up stage, there is an interaction of forces between the reed and the face of fabric. The size of acting forces depends on the weaving resistance.

The desired number of weft threads per unit length is ensured by take-up velocity (see Chapter 4.3.2). The position of the face of fabric is determined by the weaving resistance. At smaller weaving resistance, the face of fabric is more distant from the heald (see Figure 179-A). At high weaving resistance, the face of fabric moves to the heald and the amplitude of the beat-up pulse increases (see Figure 179-B). This leads to an increase in beat-up force.

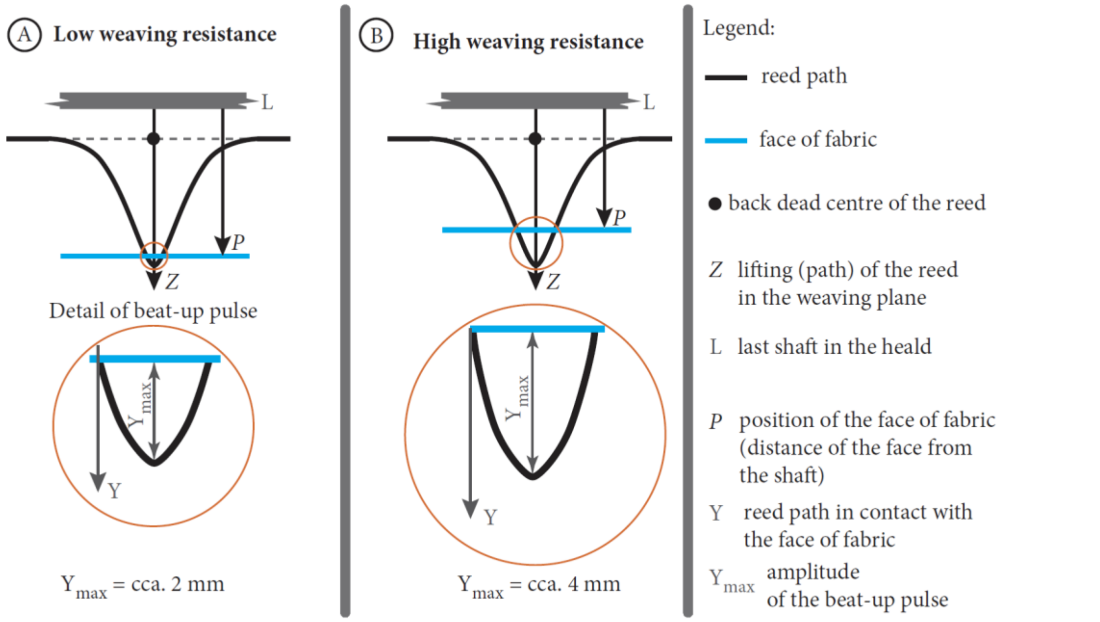


Figure 179: Plan view of the lifting of the reed with the position of the face of fabric for the various numbers of weft threads per unit length

In the beat-up stage, the reed moves in contact with the face of fabric towards the beat-up bar, i.e. to its front dead centre. This leads to elongation of the warp and shortening of fabric by value X (see Figure 180). Therefore, in the beat-up stage, there is an increase in tensile force in the warp Q_1 and decrease in tensile force in the fabric Q_2. The difference between the tensile force in the warp and in the fabric determined the so-called "beat-up force" F_P ($F_P = Q_1 - Q_2$), applied by the reed on the face of fabric. The beat-up force F_P generates the reaction force in fabric R, which is called the weaving resistance ($F_P = R$). Higher numbers of weft threads per unit length involve higher amplitude of the beat-up pulse, and thus the value X of elongation of the warp and shortening of fabric. Therefore, the beat-up force and the weaving resistance increase with the increasing number of weft threads per unit length.

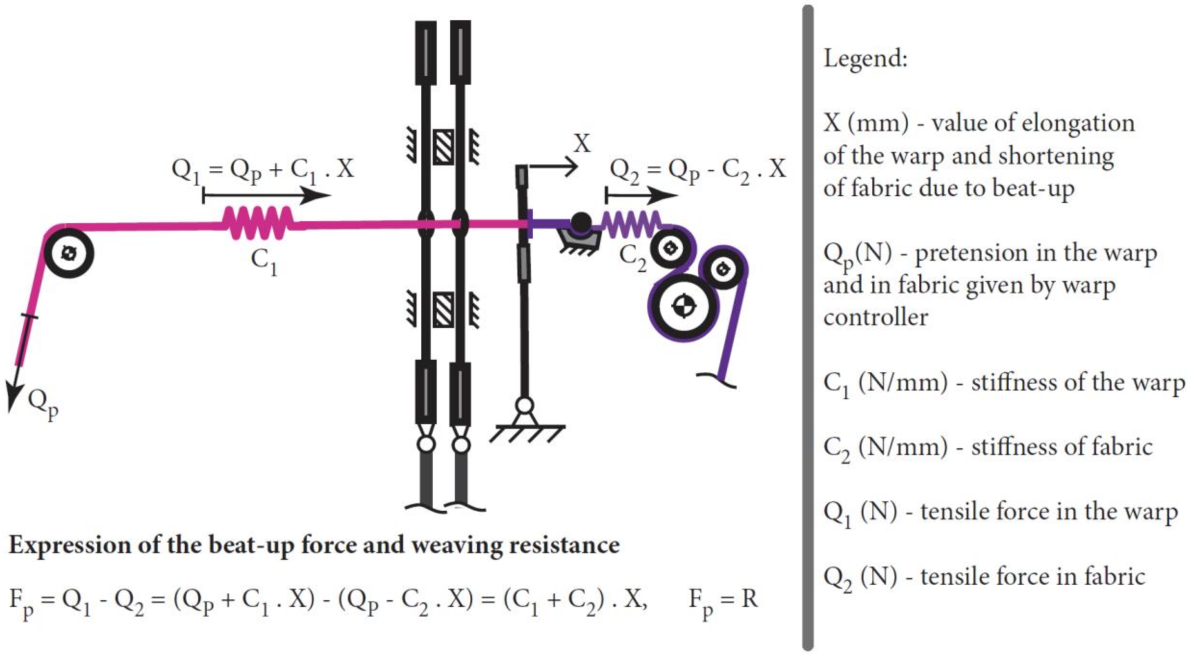


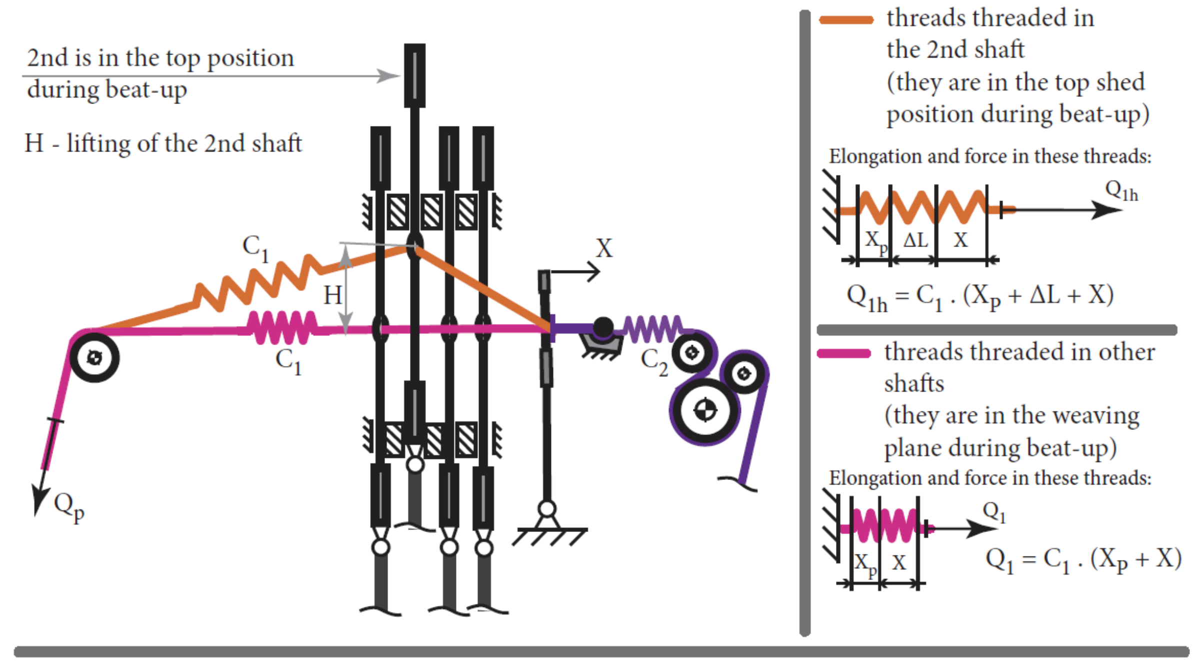
Figure 180: Diagram for expressing the beat-up force and the weaving resistance

Note: All geometric and force variables of the beat-up process are exactly described and defined in the previously published literature [36] and [37]. The beat-up process modelling is addressed in the theory of weaving.

4.6.3 Beat-up in the closed and open shed

When using the single-lift shedding mechanisms (see Chapter 4.4.2), the beat-up is always made in the so-called "closed shed". During the beat-up, all warp threads are in the weaving plane as shown in Figure 180. This means that during the beat-up stage, all warp threads have the same elongation X, which is generated by the reed and elongation X_p, which arises as a result of pretension Q_p (generated by the warp controller).

In current technological practice, however, the double-lift shedding mechanisms significantly predominate (because of the ability to achieve higher weaving frequencies). In the case of certain weaves, the beat-up is made in the so-called "open shed" on the weaving machines with double-lift shedding mechanism. As already mentioned in Chapter 4.4.2, in this case, all threads are not in the weaving plane during the beat-up, but some threads remain in the top shed position (see Figure 181).



Legend:

X_p - elongation created as a result of action of force Qp (pretension created by warp controller)

ΔL - elongation due to shed opening, which is the function of shaft lifting and geometric parameters of the shed

X - elongation due to beat-up, which depends on the achieved number of weft threads per unit length

C_1 - stiffness of the warp thread

Q_1 - tensile force in the warp thread, which is in the weaving plane during beat-up

Q_{1h} - tensile force in the warp thread, which is in the top shed position during beat-up

Figure 181: Diagram for expressing different elongation of the warp threads during beat-up in the open shed

The total elongation of the warp threads X_C in the weaving plane is determined by the sum of the elongation X_p (elongation generated by the warp controller) and the elongation $X(du)$, which is generated by the reed and depends on the achieved number of weft threads per unit length:

- elongation of the threads in the weaving plane: $X_C = X_p + X(du)$.

The total elongation of the warp threads X_C in the top shed position is determined by the elongation X_p and $X(du)$ but also by the elongation $\Delta L(H)$, which is the function of the shaft lifting and other geometrical parameters of the shed (see Chapter 4.4.5)

- elongation of the threads in the top shed position: $X_C = X_p + X(du) + \Delta L(H)$.

The elongation of threads, which are in the top shed position during beat-up, is greater than the elongation of threads in the weaving plane. Therefore, the warp threads in the top shed position during beat-up are subjected to increased internal tensile stress. In addition, a relatively large angle of wrapping in the heddle eye is created for these threads during beat-up. This angle is the source of friction forces, which apply abrasion stress on the threads. Increased stress of the warp threads, which remain in the top shed position during beat-up, it the main disadvantage of the beat-up in the open shed.

Important findings of the chapter:

1) We know at what stages the weft beat-up takes place.
2) We know the individual parts of the beat-up mechanism and their functions.
3) We can describe interaction of forces between the reed and the face of fabric.
4) We know the difference between the stress on the warp threads during beat-up in the closed shed and the open shed.

4.7 Back rest

As mentioned in Chapter 4.1, the back rest generally performs the following functions on the weaving machine: threading the warp in the weaving plane, sensing the tensile force in the warp, compensation for changes in tensile forces in the warp in the creation of the shed and response to the beat-up process. But the design of the back rests of current weaving machines is not able to provide full performance of those functions. At the time of creation of the textbook, the manufacturers of weaving machines use a relatively wide range of different designs of the back rest (see [28] and [38]). Only the selected types of back rests with the characteristic properties are mentioned hereinafter and these back rests are described in terms of their abilities to perform the above functions.

Threading the warp in the weaving plane

This function can be ensured by the **simplest back rest, consisting of a feeding roller with a rotary connection to the machine frame**. The position of the feeding roller is usually adjustable. Its horizontal and vertical positions are adjustable within certain limits. The horizontal position affects the length of the shed, thereby the elongation of the warp threads in its opening. Vertical adjustment can create a slightly tilted weaving plane, thus compensate for the elongation of the warp threads to a certain extent, which remain in the top shed position during beat-up to the detriment of the threads that are in the weaving plane during beat-up.

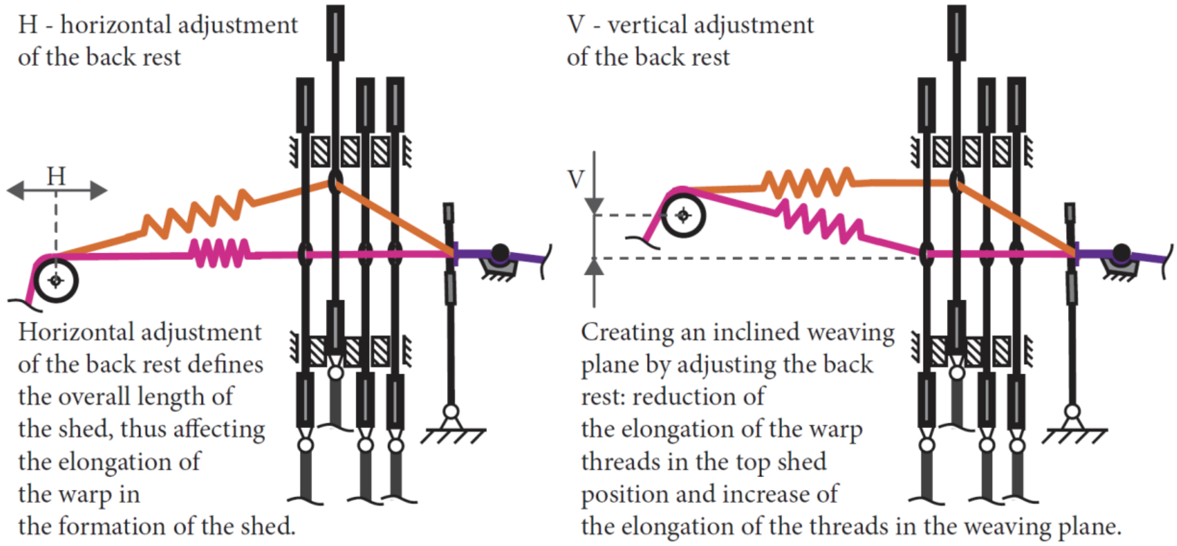


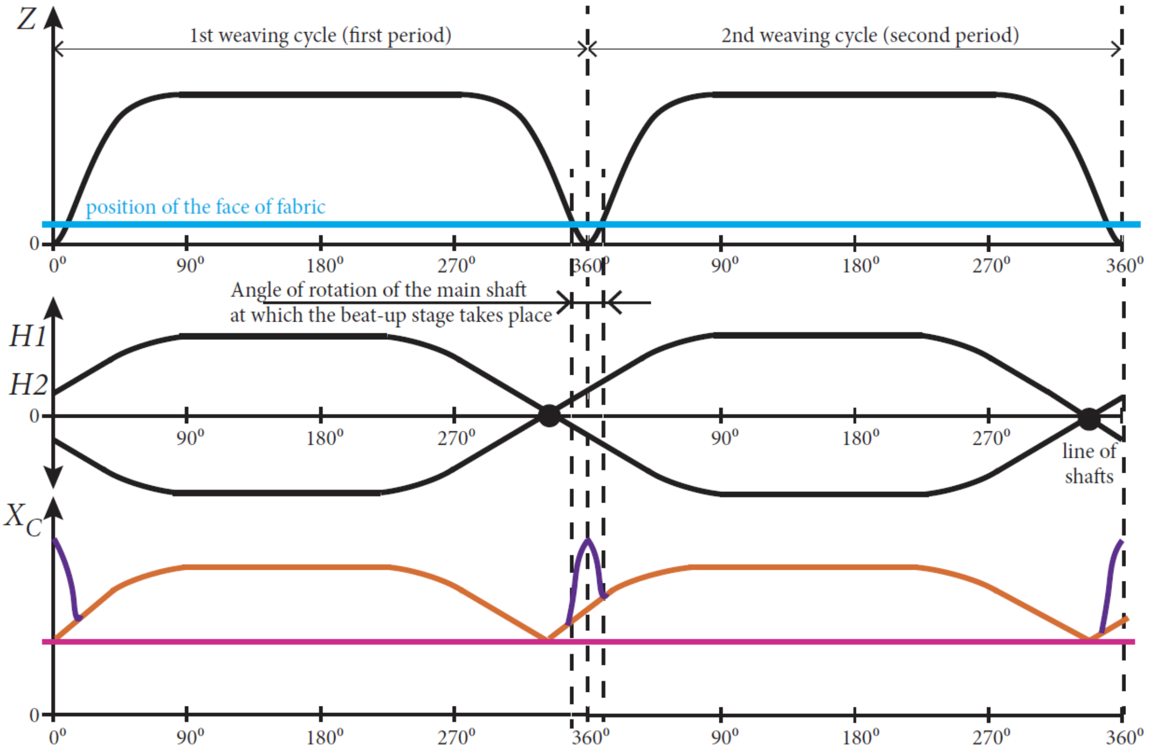
Figure 182: Horizontal and vertical adjustment of the feeding roller (back rest)

The back rest in the form of feeding roller is not able to provide sensing of the tensile force in the warp, compensate for the changes in tensile forces caused by the formation of the shed, and react to the beat-up process.

Note - elongation of the warp threads during the weaving cycle: When using the back rest in the form of feeding roller, the elongation of the warp threads during the weaving cycle is determined by three components:

1. Elongation X_P produced by the warp controller, which is constant during the weaving cycle (see Chapter 4.3.1),
2. Elongation ΔL generated due to the formation of the shed, whose course is defined by the lifting function of shafts (see Chapter 4.4.5),
3. Elongation X generated in the beat-up stage, whose course (amplitude) is determined by the required number of weft threads per unit length (see Chapter 4.6.2).

The graph shown in Figure 183 illustrates the dependence of the total elongation of the warp threads X_C on the rotation angle of the main shaft during two weaving cycles including the lifting function of the reed and shafts.



Z - lifting of the reed, H1 - lifting of the 1st shaft, H2 - lifting of the second shaft (formation of plain weave),

X_C - total elongation of warp threads
X_p - elongation from warp controller
ΔL - elongation due to creation of the shed
X - elongation due to beat-up

Figure 183: Dependence of the reed lifting, shafts and warp elongation on the rotation angle of the main shaft

Sensing the tensile force in the warp

The so-called **free back rest** with a restoring spring is used for sensing the tensile force in the warp. This means that the feeding roller of the back rest is not mounted on the machine frame but on one of the arms of the double-arm lever (see Figure 184). The restoring spring is mounted on the other end of the lever arm (*R2*), which creates a constant moment of force M_D. On the first arm (*R1*), the moment of forces M_Q is created, which depends on the value of tensile force in the warp *Q*. If the force balance on the double-arm lever is impaired (for example, due to an increase in the tensile force in the warp), the position of the double-arm lever will change and the strain gauge will deform, which is mounted on one of its arms. The output signal of the strain gauge *U* is thus proportional to the tensile force in the warp. This signal is then used within the feedback circuit of the warp controller (see Chapter 4.3.1).

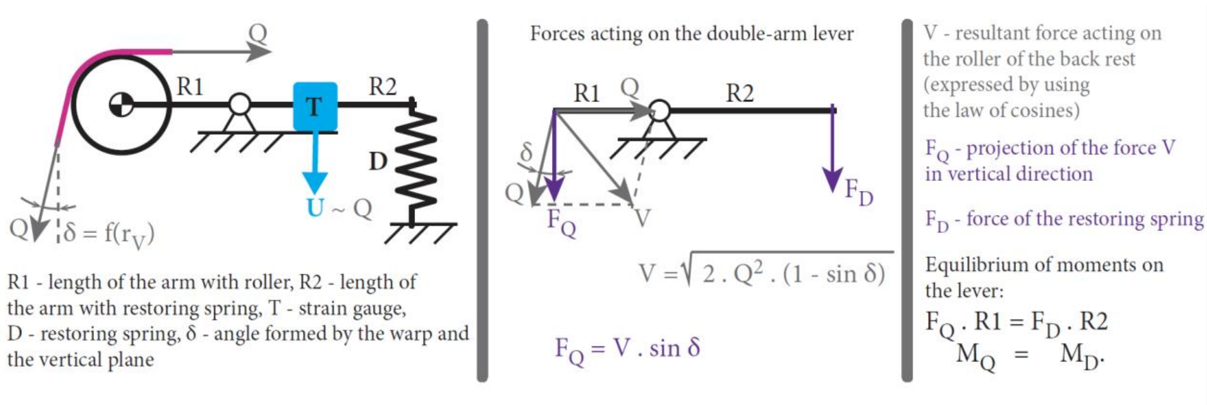


Figure 184: Single-roller free back rest

During emptying of the warp beam, the angle δ and the resulting force V change. The projection of this force F_Q, which determines the appropriate moment of forces, is dependent on the radius of the roll of the warp r_V and changes in the emptying of the warp beam. These changes must be appropriately compensated so that during the emptying of the warp beam there are no changes in tensile force Q. This problem is eliminated by the double-roller back rest.

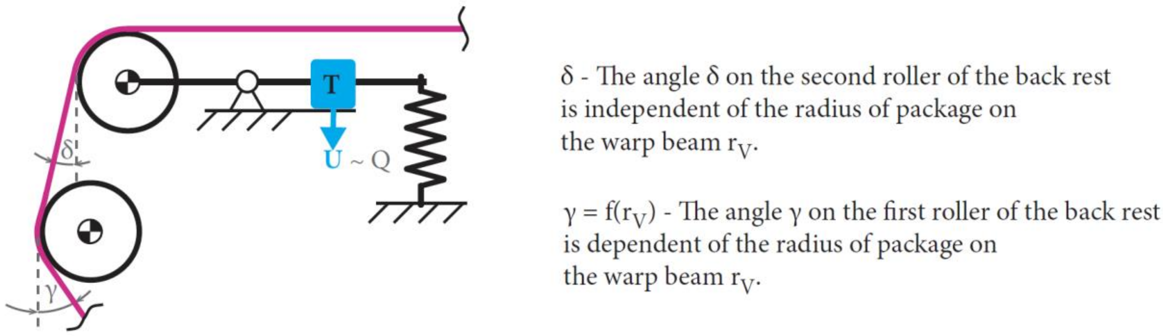


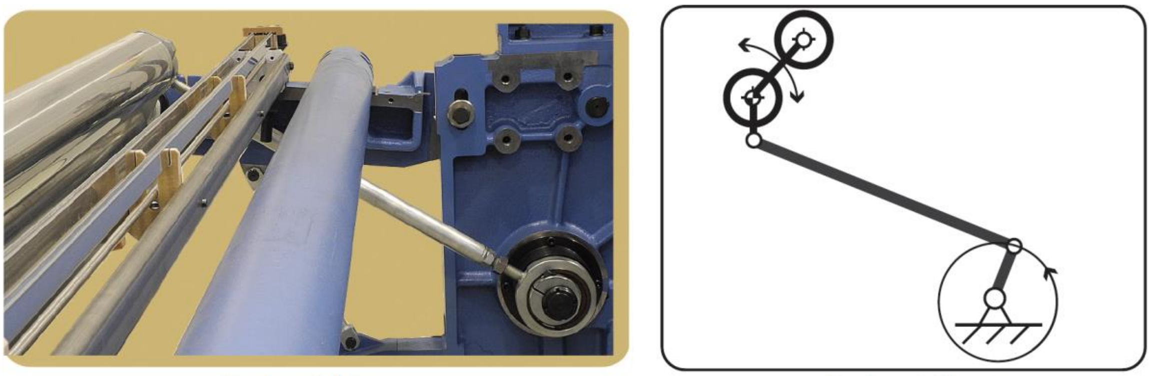
Figure 185: Double-roller free back rest

The position of the free back rest is adjustable in horizontal and vertical direction. In addition, this back rest is able to sense the tensile force in the warp and is therefore useful as part of a warp controller. Due to the frequency characteristics of free back rest, which are determined by relatively large mass of the feeding roller, stiffness of the restoring spring and rigidity of the warp threads, this back rest cannot be effectively used in compensating for the changes in tensile forces generated in the formation of the shed. This type of back rest is not able to respond appropriately to weft beat-up.

On the contrary, motion of the feeding roller of the back rest (its oscillation), which is excited during the weaving cycle by opening the shed and beating up the weft, produces undesirable changes in the elongation of the warp threads. Elongation of the warp during the weaving cycle is then determined not only by the three above mentioned components, but there is also another component, which is formed by the oscillations of the feeding roller of the free back rest. Despite this negative feature of the free back rest, this solution is still used by the manufacturers of weaving machines. At the time of creation of the textbook, most weaving machines are equipped with free back rest of the single-roller or double-roller design.

Compensation for changes in tensile forces in the formation of the shed

Compensation for changes in tensile forces in the formation of the shed under certain conditions is provided by the **back rest with forced drive**. The back rest is driven by the main shaft by means of a crank or a tappet. The feeding roller performs periodic motion with the frequency identical with the weaving frequency and amplitude ΔLs_{MAX}, determined by elongation of the warp threads ΔL_{MAX} with the fully open shed.



Back rest drive Back rest diagram

Figure 186: Back rest with forced drive

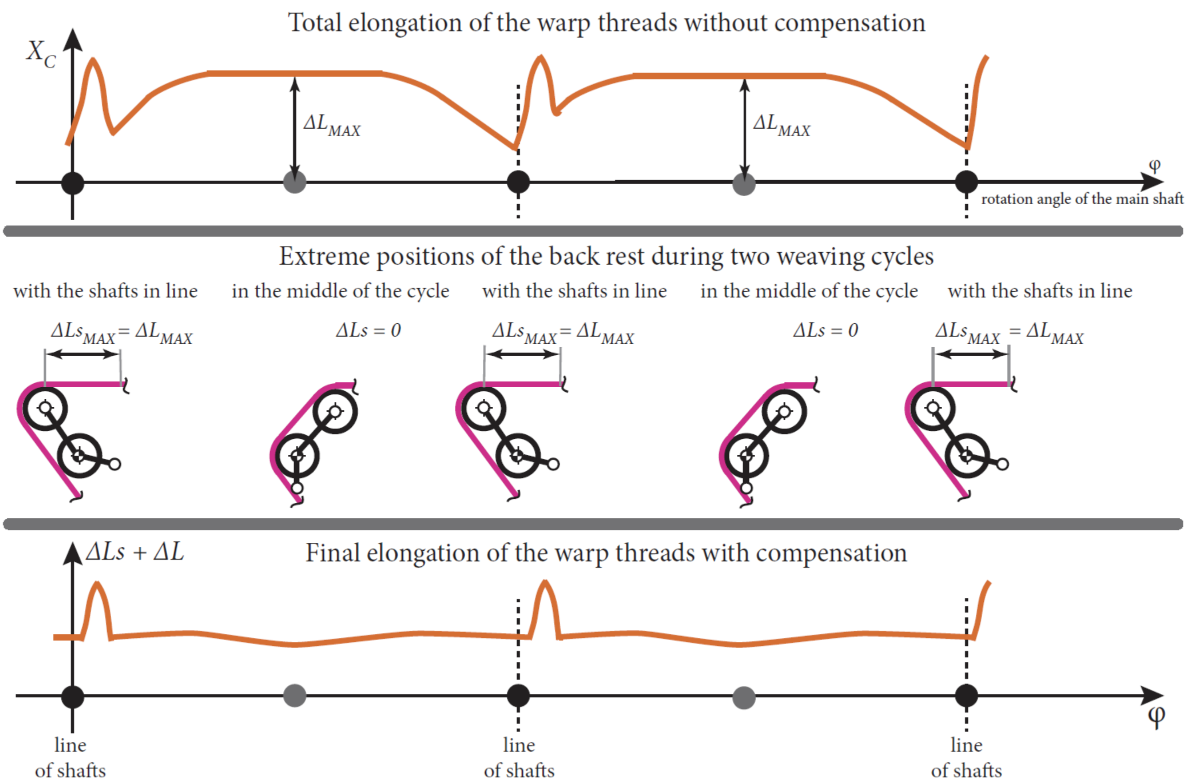


Figure 187: Operation of the back rest with forced drive in compensation for elongation of the warp threads

Operation of the back rest during compensation is shown in Figure 187. With the shafts in line, when the elongation of the warp from the shed ΔL equals to zero, the feeding roller of the back rest is in its back dead centre. Therefore, the back rest in this position produces the maximum elongation of the warp ΔLs_{MAX}, whose value is equal to the maximum elongation from the shed ΔL_{MAX}. During the opening of the shed, the feeding roller reaches its front dead centre and the elongation produced by the back rest ΔLs gradually decreases. This compensates for the increase in elongation ΔL, generated as a result of shed opening. In the middle of the weaving cycle, when the elongation from the shed is at its maximum value (ΔL_{MAX}), the feeding roller of the back rest is in its front dead centre and the elongation of the warp produced by the back rest ΔLs equals to zero. In the second half of the weaving cycle, the shed is closed, thus decreasing the elongation of the warp from the shed ΔL. At the same time, the feeding roller of the back rest reaches its back dead centre, thereby increasing the elongation from the back rest ΔLs. This creates a "more uniform" course of the total elongation of the warp during the weaving cycle.

Ideally, the back rest will compensate for elongation of the warp from the shed in such a manner that the total elongation remains almost unchanged in greater part of the weaving cycle and its value is approximately constant. Changes in elongation occur only during the beat-up stage. The elongation of the warp threads in the beat-up stage generates forces that shape the fabric (see Chapter 4.6.1). Therefore, the changes in elongation of the warp caused by the beat-up are desirable and necessary for the shaping of the fabric. On the contrary, it is advisable to compensate for changes in elongation of the warp from the shed as described above.

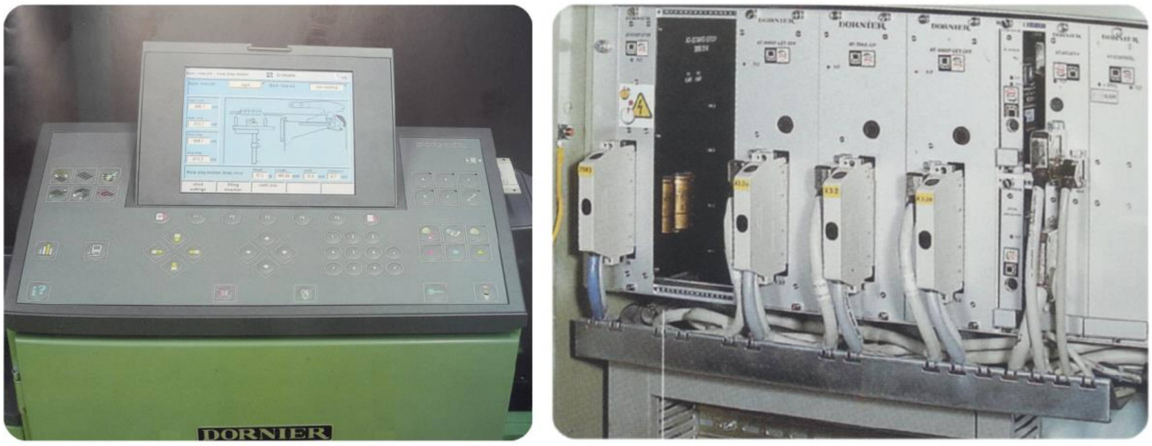
In addition to the position, the amplitude of oscillation is adjustable for the back rest with forced drive and its operation can thus be adapted to different values of maximum elongation of the warp in the formation of the shed. The back rest with forced drive can be used for sensing the tensile force in the warp. In this case, the strain gauge is mounted on the support of the top back-rest roller or between the bearing bracket of the bottom back-rest roller and the machine frame. In addition to the above described compensation function, this back rest is able to positively affect also the beat-up process. During beat-up, its feeding roller is in the back dead centre. In the beat-up process, this increases the elongation of the warp threads, and hence the forces involved in fabric formation. Unlike the free back rest, the back rest with forced drive is frequency-independent.

Important findings of the chapter:

1) We know all functions of the back rest.
2) We know all basic types of the back rests and we know how they are able to perform the above functions.

4.8 Control of the mechanisms and monitoring of the weaving machines

Implementation of the weaving process requires interoperability of the individual mechanisms of the weaving machine. **The weaving machine is controlled by a computer with terminal and peripherals.** The incremental rotary encoder (IRC) serves as the control signal, which detects the rotation angle of the main shaft. Communication with the subsystems of the weaving machine is implemented electronically through an industrial serial communication bus (CAN-BUS, PROFIBUS, etc.).



Terminal of the Dornier machine CAN bus

Figure 188: Computer and bus on the Dornier machine (source [30])

In addition to the control and synchronisation function, **the computer has the information function**. Input signals from the IRC sensor, stops and other sensors are software-processed in the computer. The results in the form of important operational data are displayed on the computer display or further processed in bulk. In this way, the monitoring of operation of the individual machines or the weaving mill as a whole can be effectively carried out.

The manufacturers of weaving machines use software with different user interface. The range of available functions or information provided is usually determined after the user logs in any of these modes:

1) **Operator mode** (weavers) provides access to the basic functions of the weaving machine, which are needed for standard operation: start, stop, calling the setter, etc. In addition, basic information of this type is provided: current number of picks, length of woven fabric, usable capacity, estimated time to empty the warp beam, etc. In case of stop, the display indicates the reason for stopping or machine position expressed by the rotation angle of the main shaft. Basic information includes information regarding the weaving frequency (machine speed).
2) **Setter mode** provides access to those parts of the user interface allowing input of data to specify the conditions of the weaving process. The setter enters data, which determines the parameters of woven fabric (number of weft threads per unit length, picked pattern, weave), provides appropriate interaction of mechanisms depending on the rotation angle of the main shaft (e.g. line of shafts, valve timing of the air-jet picking mechanism, weft cutting, etc.), and determine other conditions of the weaving process (weaving frequency, tensile force in the warp-fabric system, etc.). For specific weaving machines, adjusting manuals are available, which describe the procedures for adjustment and state the recommended values.

3) **Manager mode** provides access to detailed operating information. This information (usable capacity, number of picks, amount of woven fabric, etc.) can be displayed for each work shift and further processed in various reports for the purpose of production planning, calculation of wages, etc.

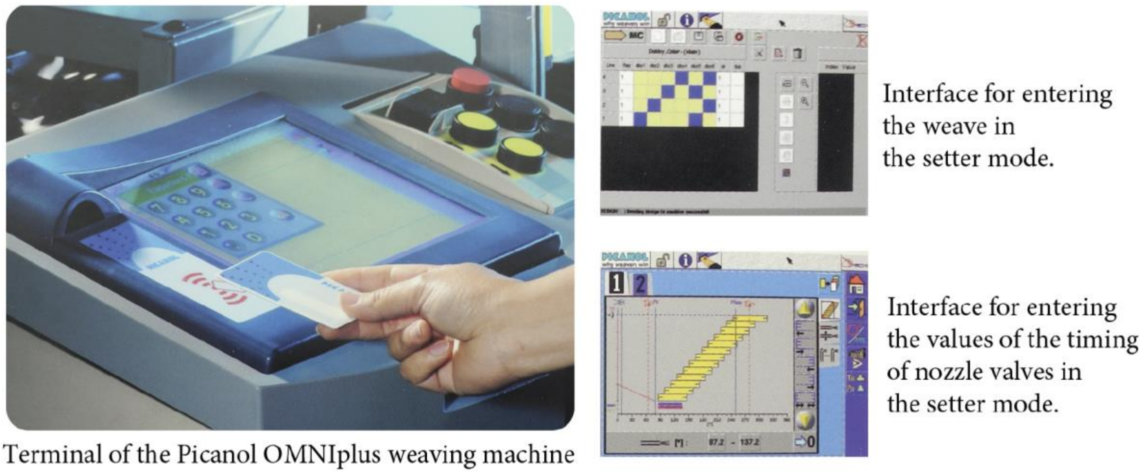


Figure 189: Terminal of the machine of the Picanol company with the interface for entering the weave and the timing of nozzle valves (source [16])

4.8.1 Control and synchronisation of the mechanisms of the weaving machines

Diagram of the control of the mechanisms of weaving machine is shown in Figure 190. The computer receives digital signal of the sensor of the rotation angle of the main shaft and binary signals of the warp and weft stop motions as well as signal generated by any of the buttons for the manual control of the machine (start button, stop button or slow motion button). **Input signals are processed by the microprocessor and signals for controlling the power modules of the individual mechanisms of the weaving machine are generated at the output**: drive, shedding and picking mechanism, weft unwinder or feeder, warp controller and fabric take-up mechanism.

The drive of the weaving machine (see drive type C in Chapter 4.2.1) is controlled by the output signal of the computer and based on this signal, the following is implemented: start, stop, reverse motion or operation of the machine in slow motion.

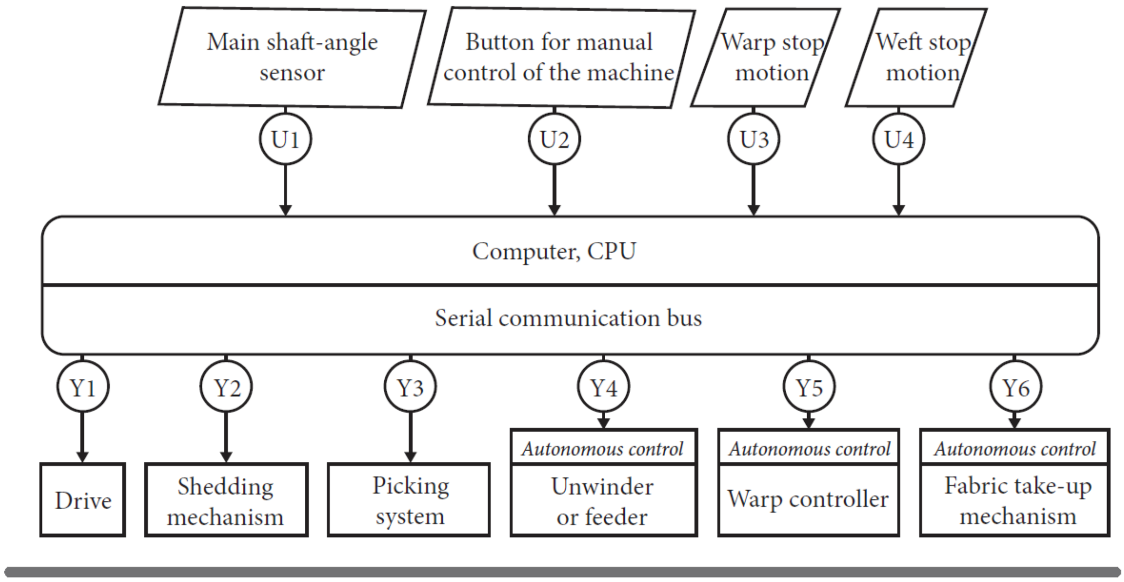
In the case of shedding mechanism, the output signal of the computer determines the position of the heddles (top or bottom) in each weaving cycle, and thereby determines the textile weave (see Chapter 4.4).

For rapier picking mechanisms, the output signal of the computer controls the motor for driving the weft feeder (see Chapter 4.5.1). On air-jet machines, the output signal of the computer controls the opening and closing of valves (see Chapter 4.5.2).

In terms of control, weft unwinders and feeders represent separate subsystems with autonomous control. They are equipped with a stand-alone microprocessor, which determines the angular velocity of the motor of unwinder or feeder. Communication of these subsystems with the central computer is provided by digital signal (on - off).

The warp controller is also a separate subsystem with autonomous management. The output signal of the central computer determines the desired value of the tensile strength in the warp. This value is compared with the actual value in the comparator term, which is part of the block of autonomous control of the warp controller. The angular velocity of the motor for driving the warp beam is then controlled by the output signal from the block of autonomous control of the warp controller (see Chapter 4.3.1).

The fabric take-up mechanism is implemented as the controlled drive of the sand roller. Therefore, this mechanism has its own autonomous control. The output signal of the central computer determines the fabric take-up velocity so as to create the desired number of weft threads per unit length at the given weaving frequency (see Chapter 4.3.2). In this case, the block of autonomous control ensures control of the desired fabric take-up velocity and in case of deviations, makes corrections.



Vstupní signály: U1 - digital signal, which determines the angle of rotation of the main shaft
U2 - binary signal, which determines the state of the button (on, off)
U3 - binary signal of the warp stop motion, U4 - binary signal of the weft stop motion

Výstupní signály: Y1 - digital signal for drive control,
Y2 - binary signal for communication with the shedding mechanism,
Y3 - signal for picking system control,
Y4 - binary signal, which ensures communication between the computer and the autonomous control of the unwinder or feeder,
Y5 - signal, which provides information about the required tensile force in the warp,
Y6 - signal, which provides information about the required fabric take-up velocity.

Figure 190: Diagram of the control of the mechanisms of the weaving machine

Synchronisation of operation of the mechanisms

Synchronisation (ensuring interaction) of the mechanisms of the weaving machine allows their control depending on the rotation angle of the main shaft. As stated in Chapter 4.1.1, the 0° rotation of the main shaft is defined by the position of the reed in front dead centre. The phase displacement of the lifting function of the reed within the operation diagram of the machine cannot be changed. The operation of all the remaining mechanisms of the weaving machine is controlled depending on the rotation angle of the main shaft, i.e. relative to the position of the reed. Interaction of the mechanisms may be represented by a graph, which shows continuous lifting functions or discrete functions of the mechanisms depending on the rotation angle of the main shaft. This chapter shows interaction of the mechanisms of the air-jet weaving machine (see Figure 191).

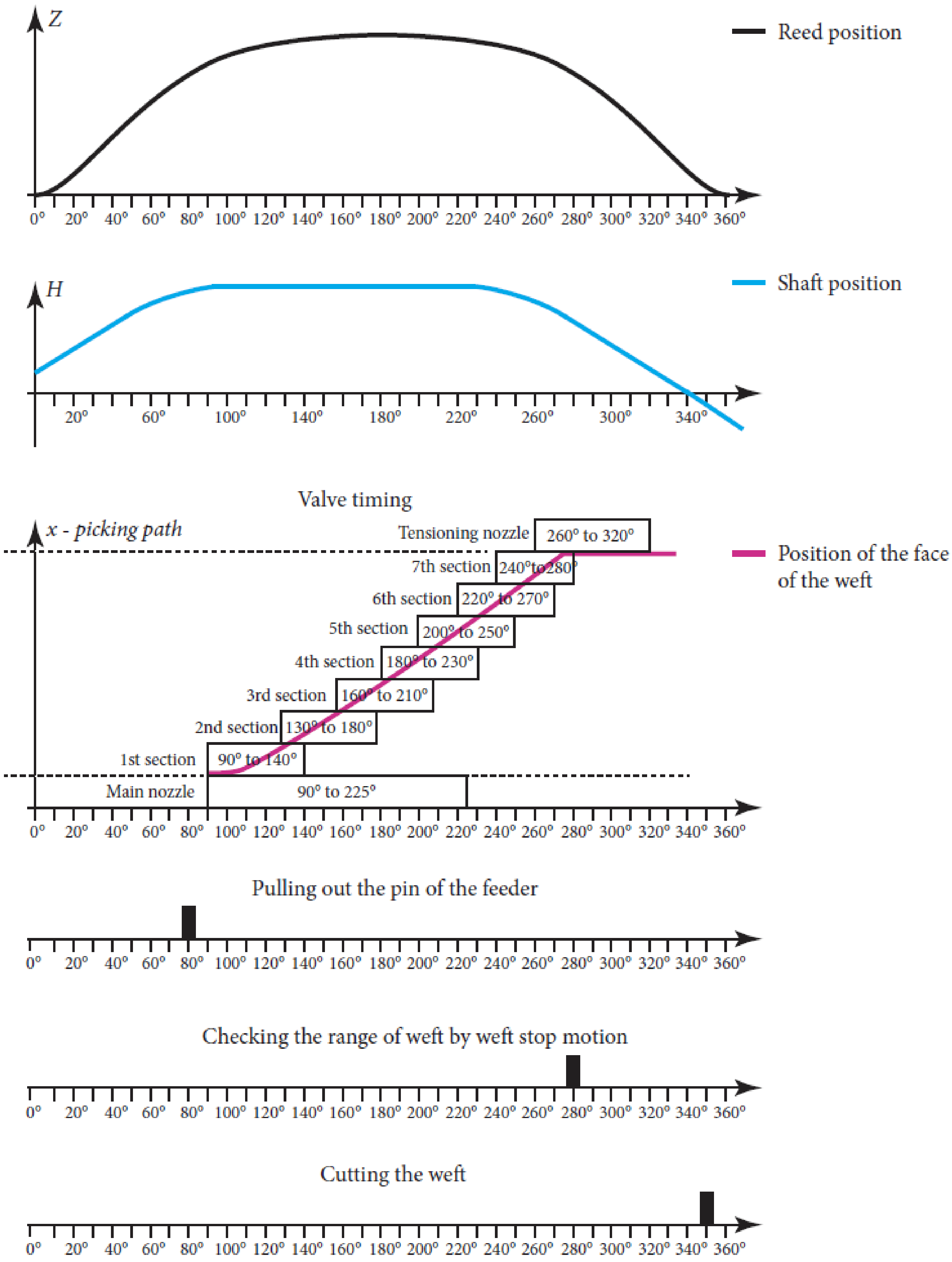


Figure 191: Operation of the mechanisms of the air-jet weaving machine depending on the rotation angle of the main shaft

4.8.2 Monitoring of the weaving machines

On the basis of the signal from the warp and the weft stop motions, information is provided with regard to the number of machine stops due to break of the warp or weft thread over a certain time period (such as work shift). The relevant computer interface usually provides information on the number of stops divided into three groups: stop by warp stop motion, stop by weft stop motion and other stops (for example, manual stop by the machine operator). Thus structured information enables to exactly assess the impact of quality of the warp and weft threads on the operation of weaving machine.

The most important operating parameters of the weaving machine include its usable capacity within the given time interval (for example, within a certain work shift). The usable capacity η is defined by the product of the time T_P of operation of the machine and the total time T_C of the given time interval:

$$\eta(\%) = \frac{T_P}{T_C}.100,$$

where T_P is the time of operation of the weaving machine and T_C is the total time of the given time interval.

The computer monitors not only the number of stops due to a certain defect but also the time required for restarting the machine after stop. Therefore, the relevant computer interface can display the current (continuous) values of usable capacity in the ongoing work shift or display the usable capacity of machine in the previous work shifts. The system often includes current information about the length of the fabric produced, the approximate time to empty the warp beam, the number of picks, etc.

The weaving machines (their control system) can be connected to the local network, which allows tracking of information on their operation through a single (central) computer. The central computer is equipped with the data processing system of the weaving machines and is able to generate summary reports for the individual machines or the whole weaving mill.

Important findings of the chapter:

1) We know the method of controlling the individual mechanisms of the weaving machine and the method of ensuring synchronisation of their operation.
2) We know the function of the individual modules of the user interface of computer software of the weaving machine.
3) We know the most important operational data that can be used in production planning and impact assessment of the quality of textile material on the operation of weaving machines.
4) We know the definition of term “usable capacity”.

4.9 Automation and operator comfort

Some activities, which were previously performed manually by the operator, are automated on current weaving machines. At the same time, various elements are applied, which increase the comfort and facilitate the operation of weaving machines. This chapter describes the automation of selected activities and provides some examples of increasing the operator comfort, which could be observed on the weaving machines at the turn of the Millennium.

Positioning of the weaving machine

Automatic positioning of the weaving machine is one of the standard functions and is available on most existing weaving machines. In general, it is the ability of the weaving machine to automatically take such a position after the defect of the warp or weft thread, in which the relevant defect could be removed (manually).

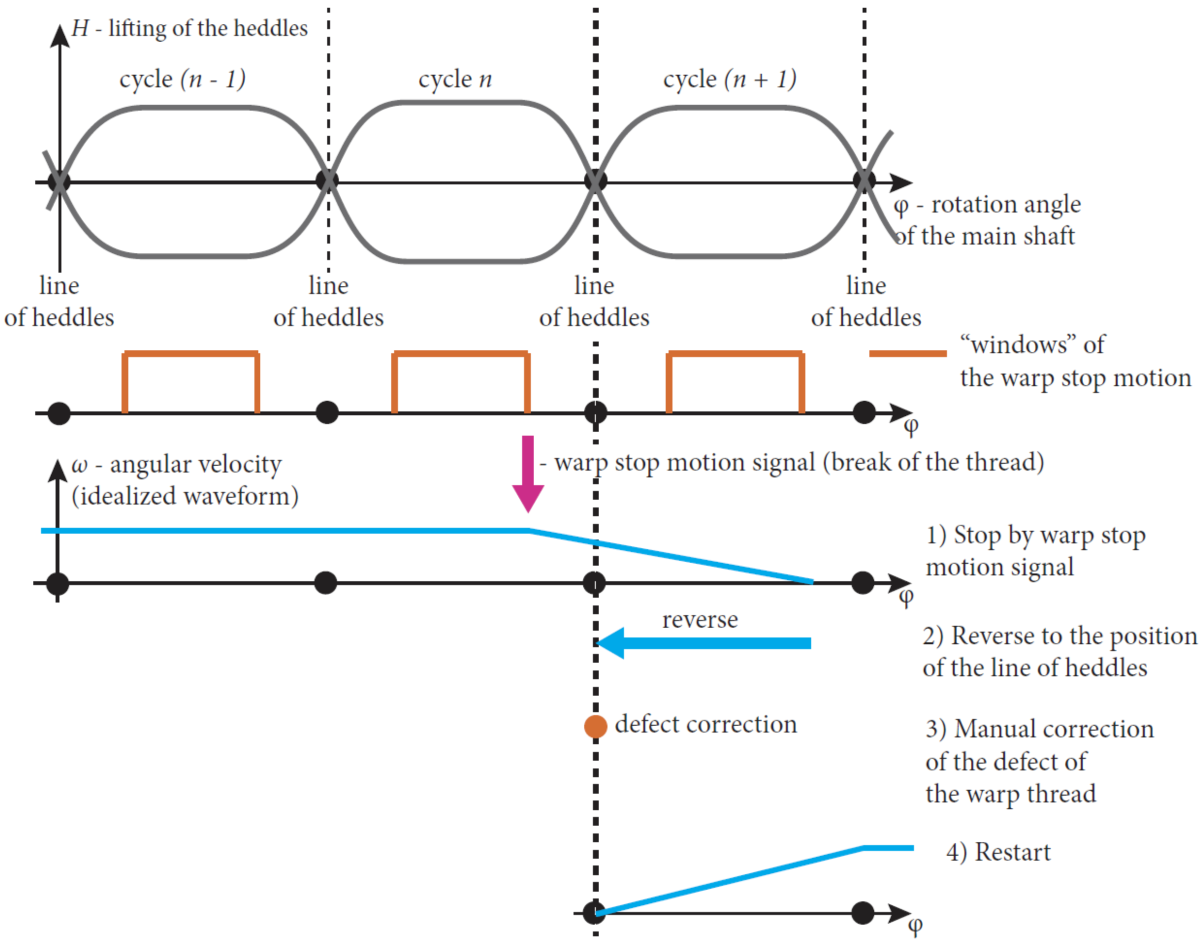


Figure 192: Positioning with warp thread defect

Any break of the warp thread must be repaired with the heddles in line. If, in the *n--th* weaving cycle, the warp stop motion detects break of the thread, the machine will stop in the next *(n + 1.)* cycle with the result that the weft insertion will be prevented in this cycle. The machine automatically reverses to the position of the line of heddles at the beginning of the *(n + 1.)* cycle. In this position, the machine stops. The operator manually corrects the defect of the warp thread (ties up the warp thread and guides it to all guiding points) and then presses the start button of the machine, which is the signal to restart it. The angular speed of the machine increases again to the value determined by operating speed of the machine and the weaving process continues in a standard way.

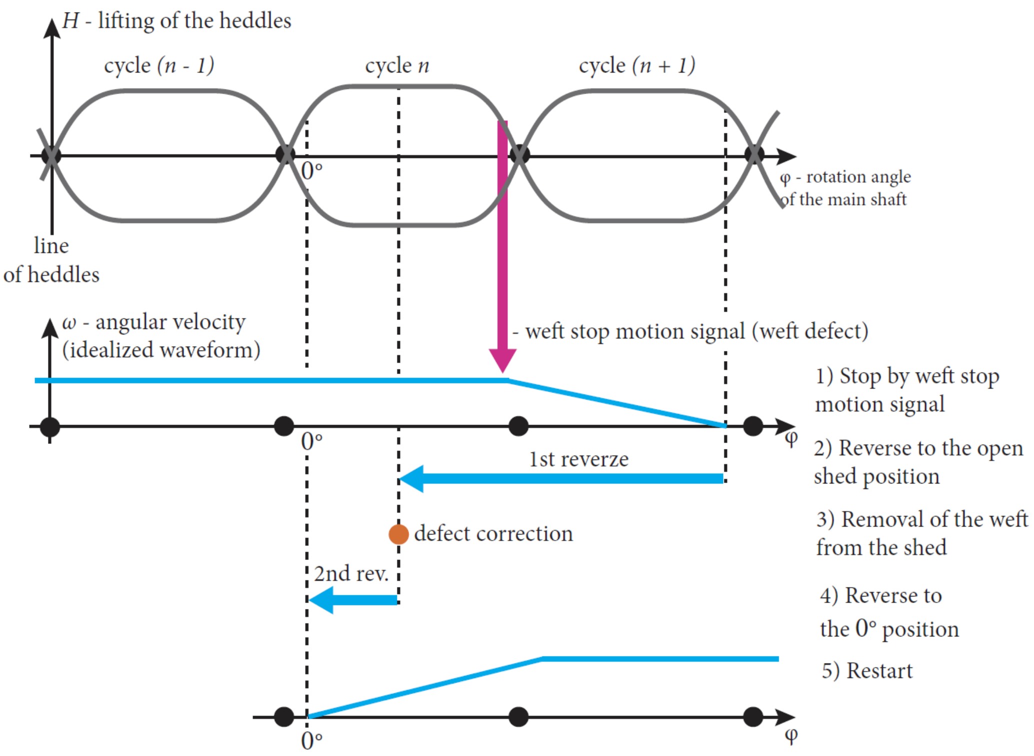


Figure 193: Positioning with weft thread defect

The defect of the weft thread should be corrected in the open shed position (incorrectly woven weft must be removed from the shed). If, in the *n--th* weaving cycle, the weft stop motion detects defect of the weft thread (its incorrect insertion in the shed), the machine will stop in the next *(n + 1.)* cycle with the result that the weft insertion will be prevented in this cycle. The machine automatically reverses to the position of open shed in the *n--th* cycle, thus releasing the incorrectly woven weft. In this position, the weft can be removed from the shed manually or by means of a device for automatic unweaving (for more information see below). Subsequently, the second reverse to the position with the reed in the front dead centre is carried out, i.e. to the position of 0° rotation of the main shaft within the *n--th* cycle. The machine is then restarted from this position.

Automatic unweaving

As already mentioned, the removal of the incorrectly inserted weft can be automated, i.e. implemented without manual operator intervention. The text below describes the method for automatic removal of the weft from the shed (automatic ripping), which can be applied on the air-jet machines.

1) The weft stop motion detects the incorrectly woven weft and generates the signal to stop the machine. At the same, shears are deactivated so as not to cut the weft between the main nozzle and the left edge of fabric.
2) After stopping the machine, the weft in the shed is released by positioning as described above.
3) Subsequently, the weft insertion process is performed and the newly inserted segment of the weft thread creates a loop in the shed, having a force coupling with the tensioning nozzle.
4) Then, the weft is cut and the tensioning nozzle sucks the weft thread out of the shed.
5) The weft stop motion checks whether the weft thread was removed from the shed and in case of error, the operator is called.

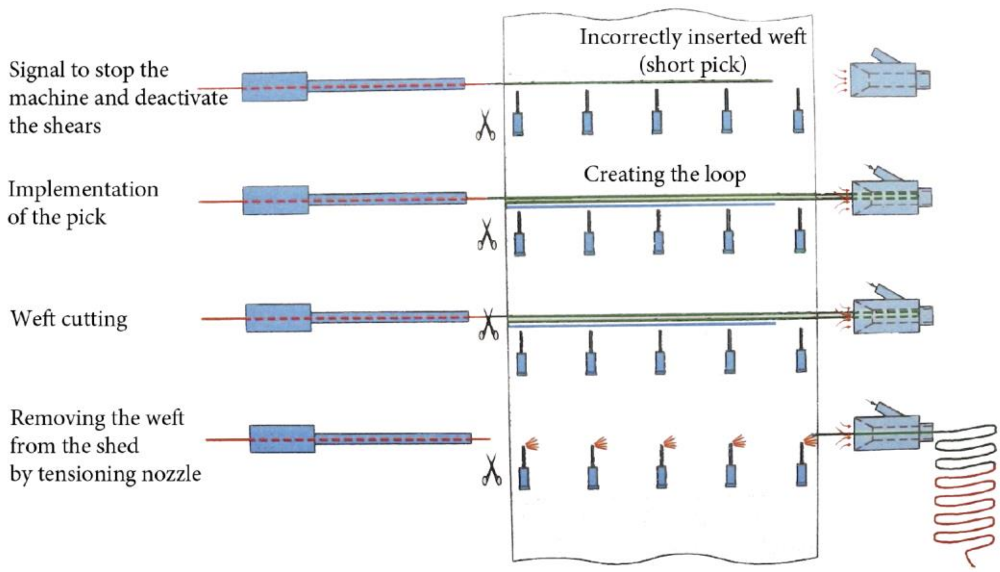


Figure 194: Diagram of the automatic unweaving on the Somet machine (source [15])

Quick style change (QSC)

Setting up the warp beams is a relative frequent activity in the weaving mill. At the turn of the Millennium, there are the weaving machines that are designated by the manufacturers using the abbreviation QSC (Quick Style Change). It is the commercial designation of weaving machines, whose design ensures easy placement (setting-up) of the warp beam (usually with the shaft heald and the reed) in the weaving machine. The operation is feasible in a relatively short time and with a minimum operator effort.

In terms of construction, the weaving machine is prepared so that releasing the relatively small number of fasteners will separate the front and back of the machine. The back of the machine consists of the warp beam stand, which can be transported after separation outside the weaving mill and simultaneously replaced by another stand with the warp beam already set up. The weaving machines are provided with suitable handling devices to facilitate the transport of the stand with warp beam, shaft heald and reed. Besides reducing the loss of time in setting up the warp, this system allows very quick change of the produced item. Figure 195 represents the weaving machine of the Picanol company when changing the warp beam.

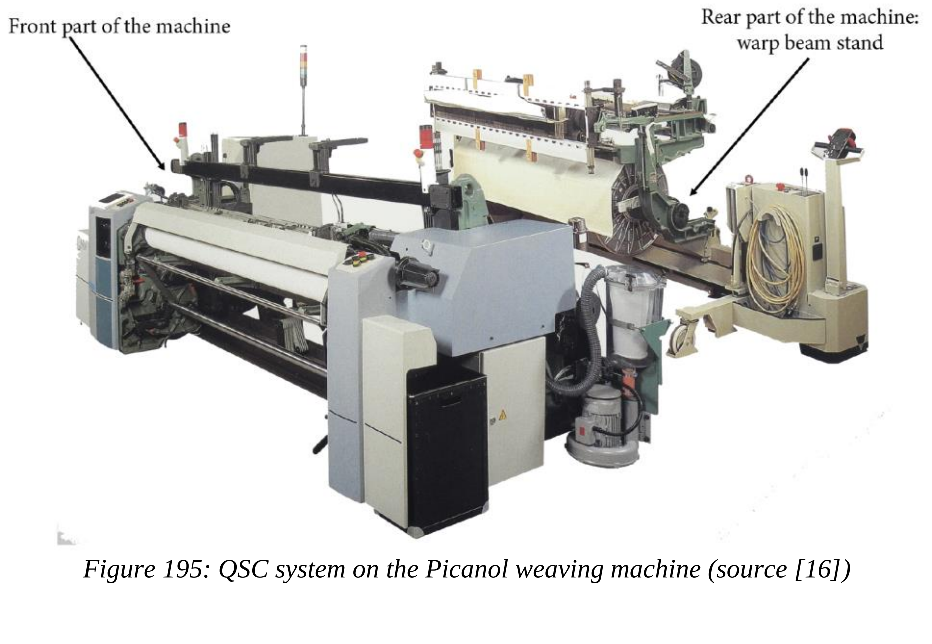


Figure 195: QSC system on the Picanol weaving machine (source [16])

Terminal

Operator comfort, especially when adjusting the weaving machines, is significantly increased by the terminal. Most of the data for specifying the conditions of the weaving process can be entered via keyboard or touch screen. Relevant data can be stored on portable storage media and then reused in the adjustment. Connection of the computers of the weaving machines to the network not only facilitates the collection of operational data, but also allows remote diagnostics and solving any problems in the operation of weaving machines.

Recapitulation of the part "Weaving machines and their mechanisms"

Now, this is the end of the main part of the textbook dealing with the mechanisms of weaving machines. We know the general layout of weaving machines and the definition of weaving cycle. The method of driving the weaving machines are described in terms of trends at the turn of the Millennium. In addition, the functions of warp controller and fabric take-up mechanism are explained. The shedding mechanisms are described in terms of longer-term trends. The Chapter "Weft insertion" provides an overview of all systems, but more attention is paid only to those picking mechanisms, which proved in practice at the turn of the Millennium. The conclusion of this chapter deals with the description of the mode of control of the current weaving machines, monitoring and acquisition of operational data, and automation and operator comfort.

The main purpose of this part is to generally explain the principles of fabric production and the principle of operation of the mechanisms used on current weaving machines. Specific design solutions are given as an illustrative example. Together with the findings of the previous part of the textbook (part "Design parameters of woven fabric"), the reader gains an overview of the correlations between the parameters of fabric and the individual mechanisms of the weaving machine, its layout and functions.

5 Performance and production rate of the weaving machines

This chapter deals with the definition of performance parameters of weaving machines and the method of expressing their production rates. Performance parameters are used for mutual comparison of the weaving machines with different designs or systems, which was used in Chapter 4.5 for comparison of the weaving machines with different picking mechanism. The production rate of the weaving machines is used in common technological practice for production planning of fabrics with specific design parameters at the given weaving frequency or reed width of the weaving machines.

5.1 Performance parameters of the weaving machines

In the simplest case, performance of the weaving machine can be indicated by its speed *n*, i.e. the number of wefts woven per minute. But this parameter ignores the reed (weaving) width of the machine. Therefore, it is preferable to express the performance of the weaving machine using the parameter called "weft performance".

The weft performance is defined by the amount of weft in metres, which the weaving machine is able to weave in per minute. The weft performance is determined by the product of the speed of the weaving machine and the reed width of fabric:

$$U(m/min) = n\,.\,\check{S}_P,$$

where U (m/min) is the weft capacity, n (rpm) is the speed of the weaving machine and $\check{S}_P$ (m) is the reed width of fabric.

The following graph shows the values of top weft performance weft of the gripper, rapier, water-jet and air-jet machines as achieved at the Itma exhibitions between 1967 and 2015. In this period, the shuttle machines were not presented at the Itma exhibitions and the maximum weft performance, which has been achieved in the history of these machines, is 600 m/min.

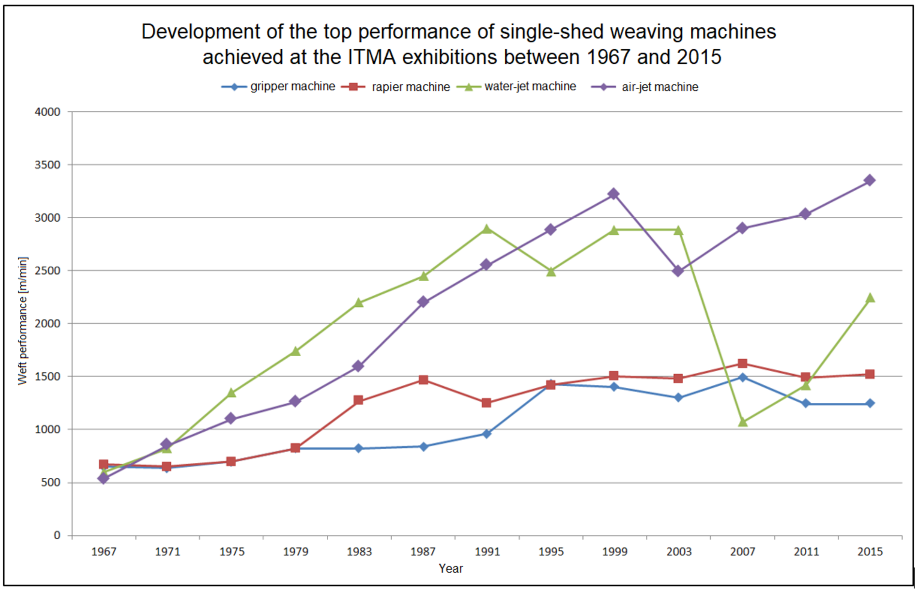


Figure 196: Top weft performance achieved at the Itma exhibitions between 1967 and 2015

Note: The Itma exhibition is held with the four-year period in various European cities. It is sometimes referred to as the "Olympics" of the manufacturers of textile machinery [17]. The exhibition is participated not only by the manufacturers of weaving machines but also machines designed for all areas of the textile industry are presented at this exhibition. The Itma exhibition has the longest tradition of all textile machinery exhibitions. The first year was held in the city of Lille, France, in 1951.

5.2 Production rate of the weaving machines

Production rate of the weaving machines is defined by the amount of fabric, the weaving machine is able to produce per a certain unit of time (e.g. one hour). The amount of fabric can be given in units of length (linear metres), units of area (square metres) or units of weight (in kilograms). Therefore, linear, surface or mass production rate of the weaving machine can be expressed.

Linear production rate

Linear production rate of the weaving machine V_L is defined by the amount of fabric in linear metres (lm), which the weaving machine is able to produce per hour (hour).

In practice, linear production rate can be determined using the following data: speed of the weaving machine *n (rpm)* and the number of weft threads per unit length *du (threads / 1 cm)*. Speed of the weaving machine determines the number of wefts woven per minute. The number of weft threads per unit length determines the number of wefts to be woven in order to produce one centimetre of fabric. Therefore, the length of fabric produced per minute can be expressed as the proportion of speed of the weaving machine and the number of weft threads per units length. Linear production rate in appropriate units (*lm/hour*) can thus be expressed by the following relation:

$$V_L(bm/hod) = \frac{n\ .\ 60}{du\ .\ 100},$$

where V_L (lm/hour) is the linear production rate, n (rpm) is the speed of the weaving machine and du (threads / 1 cm) is the number of weft threads per unit length of the fabric to be produced.

Note: The relation shows that the production rate of the weaving machine decreases with the increasing number of weft threads per unit length. High production rate is achieved at low number of weft threads per unit length. For example, if production of fabric with a given weight is desired, it will be advisable, in terms of production rate, to weave in the wefts with higher fineness in the units of tex and with lower number of weft threads per unit length. If the wefts with lower fineness in the units of tex are woven and the required weight is ensured by increasing the number of weft threads per unit length, reduced production rate should be taken into account.

Surface production rate

Surface production rate of the weaving machine V_S is defined by the amount of fabric in square metres (m^2), which the weaving machine is able to produce per hour (hour).

In addition to the above data (speed of the weaving machine and the number of weft threads per unit length), the surface production rate depends on the width of fabric $Š_{TK}$. Surface production rate can be expressed by means of the relation:

$$V_S = (m^2/hod) = V_L\ .Š_{TK} = \frac{n\ .60}{du\ .100}\ .Š_{TK},$$

where V_S (m^2/hour) is the surface production rate, V_L (lm/hour) is the linear production rate and $Š_{TK}$ (m) is the width of fabric.

Mass production rate

Mass production rate of the weaving machine V_M is defined by the amount of fabric in kilograms (kg), which the weaving machine is able to produce per hour (hour).

Surface production rate V_S can be converted into mass production rate V_M using the fabric weight M_S. The weight indicates the weight of one square meter of fabric in grams and this parameter can be determined by weighing a sample of fabric or by calculation according to the equation, which is derived in Chapter 3.9. Mass production rate can then be expressed by the following relation:

$$V_M(kg/hod) = V_S \,.\, \frac{M_S}{1000} = \frac{n \,.\, 60 \,.\, Š_{TK}}{du \,.\, 100} \,.\, \frac{M_S}{1000},$$

where V_M (kg/hour) is the mass production rate, V_S (m^2/hour) is the surface production rate and M_S (g/m^2) is the weight (weight of 1 m^2 of fabric in grams – see Chapter 3.9).

Appendix – theoretical and actual production rate: The above relations express the so-called "theoretical production rate" V_{TE}, which is the maximum production rate per unit of time (in our case, per hour). In calculating the theoretical production rate, it is assumed that the weaving machine does not stop in the given time interval and its usable capacity η (see Chapter 4.8.2) is 100%.

$$V_{SK} = V_{TE} \,.\, \frac{\eta}{100},$$

where V_{SK} is the actual production rate in (lm/hour), (m^2/hour) or (kg/hour), V_{TE} is the theoretical production rate in (lm/hour), (m^2/hour) or (kg/hour) and η is the usable capacity in %.

Production planning is necessary to implement on the basis of the actual production rate so as to take account of the average downtime (idle time) generated by the operation of the weaving machines.

Important findings of the chapter:

1) We know how to express the performance of weaving machines.
2) We know the methods of expressing the production rate of weaving machines and we know which parameters of the machine and fabric are necessary for their calculation.

6 Production of leno weave fabrics

Leno weave fabrics are a special type of fabric, whose design (layout of the interlacing point) provides a high consistency between the system of warp and weft threads. Leno weave fabrics or their equivalents are known from the ancient past. Archaeological findings (see Chapter 2.2.1) show that the oldest fabrics contained interlaced weft threads. Later, fabrics with the interlaced warp are produced by means of the so-called "cards" (see [5]). The design of these fabrics fully correspond to leno weave fabrics in the modern sense. Information regarding the leno weave fabrics and the principle of their production can be found in previously published literature (for example, [29]). At the turn of the Millennium, we see quite interesting development of machinery for the production of leno weave fabrics, which is driven by increased consumption of these fabrics in technical areas. Development trends in the area of weaving machines for the production of leno weave fabrics diffuse into development trends in the area of standard weaving machines (for example, see Chapter 4.2.1 - drive type E). Therefore, the textbook includes this chapter to make the reader familiar with design of leno weave fabrics and their production methods as implemented at the time of creation of the textbook.

6.1 Leno weave fabric and its interlacing point

As mentioned above, the leno weave provides a high consistency between the warp and weft systems, particularly in the longitudinal direction of fabric. The consistency can be exactly expressed through the value of external force, which is able to disrupt the force balance and thereby cause displacement of the warp and weft threads in fabric. The consistency affects the coefficient of friction between the warp and weft threads, which is determined by their surface treatment or the type of fibres, of which they are made. Other factors include force couplings between the elements of the warp and weft threads that are dependent on the wrapping angle of the warp and weft. The relation expressing the respective external force that is able to disrupt the force balance is given by the Euler's equation:

$$F > S_O \, . e^{\alpha . f},$$

where S_o is the axial force in the warp thread, f is the coefficient of friction between the warp and the weft and α is the angle of wrapping of the warp thread around the weft thread (the condition for moving the weft in the direction of the warp).

High consistency of the warp and weft threads in standard fabrics can be ensured by using suitable weave (plain weave) and creating a large wrapping angle of the warp and weft threads, which is determined by the angle of interlacing (see Figure 4 in Chapter 2.1). However, with the given fineness of the threads, the wrapping angle can be increased only by increasing the number of warp and weft threads per unit length. Different industrial fabrics (screens, grids ...) require high consistency of both thread systems even at low numbers of warp and weft threads per unit length. Standard fabrics are not able to meet this requirement and leno weaves are used in the production of the respective products.

Two adjacent warp threads usually interlace in leno weave fabrics. The warp threads thus cross each other between the individual wefts and the force coupling is created between these threads. Leno weave interlacing point then consists of three elements: a pair of warp threads and one weft. Unlike the interlacing point of standard fabric, which consists of only two elements (warp and weft), configuration of the leno weave interlacing point provides a relatively large wrapping angle at even small numbers of warp and weft threads per unit length. The increased number of elements in the leno weave interlacing point, high wrapping angle of the warp and weft threads, and the wrapping angle at the point of intersection of the warp threads minimise the displacements of wefts along the warp threads under the action of external forces.

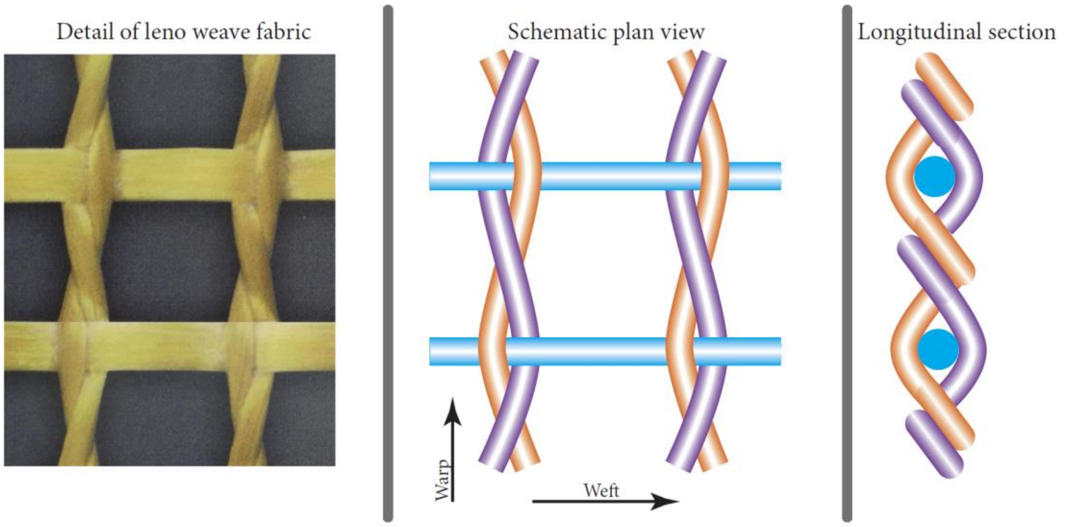


Figure 197: Detail of leno weave fabric, its schematic plan view and longitudinal section

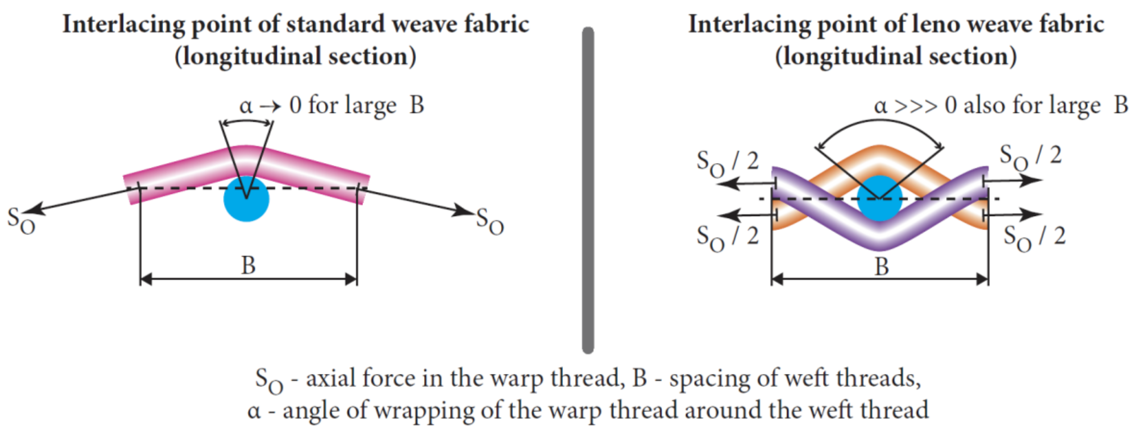


Figure 198: Interlacing point of standard and leno weave fabric at low number of weft threads per unit length (in longitudinal section)

Leno weave fabrics are used not only as industrial textiles. Intersection of the warp threads can create different decorative effects on fabric and these effects can be combined, for example, with the picked pattern or with different number of weft threads per unit length in fabric. Leno weave fabrics of this type are used as curtains, drapes or other decorative products.

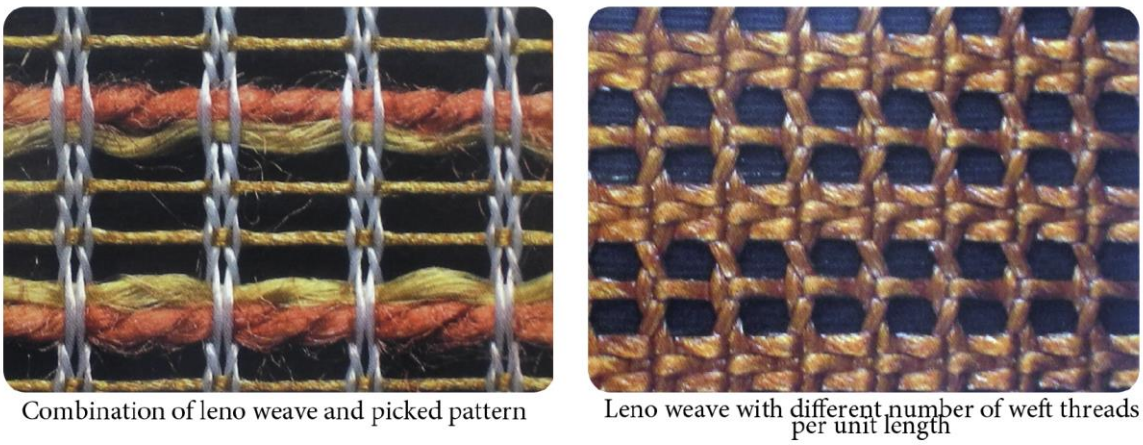


Figure 199: Examples of decorative leno weave fabrics

6.2 Methods of producing leno weave fabrics

In terms of production technology, **some warp threads in leno weaves are referred to as stationary threads and some threads are referred to as rotary**. Stationary and rotary threads generally alternate in fabric at the ratio of 1:1 and form a pair of the warp threads interconnected through the force coupling. In the production of fabric, the stationary threads do not change their position. The rotary threads interlace with the weft alternately on the left and right side of the stationary threads.

The weaving machines for the production of leno weave fabrics can be divided into two groups. Machines, which use special heddles arranged in shafts in the formation of the shed and in the change of the rotary warp threads are hereinafter referred to as the **machines with "heddle heald"**. At the turn of the Millennium, the production program of major manufacturers (Dornier, Picanol, VÚTS Liberec) includes special weaving machines for the production of leno weave fabrics that work without heddles. These machines are hereinafter referred to as the **machines with "heald without heddles"**. Removing the heddles allows the production of leno weave fabrics at higher weaving frequencies.

6.2.1 Production of leno weave fabrics on machines with heddle heald

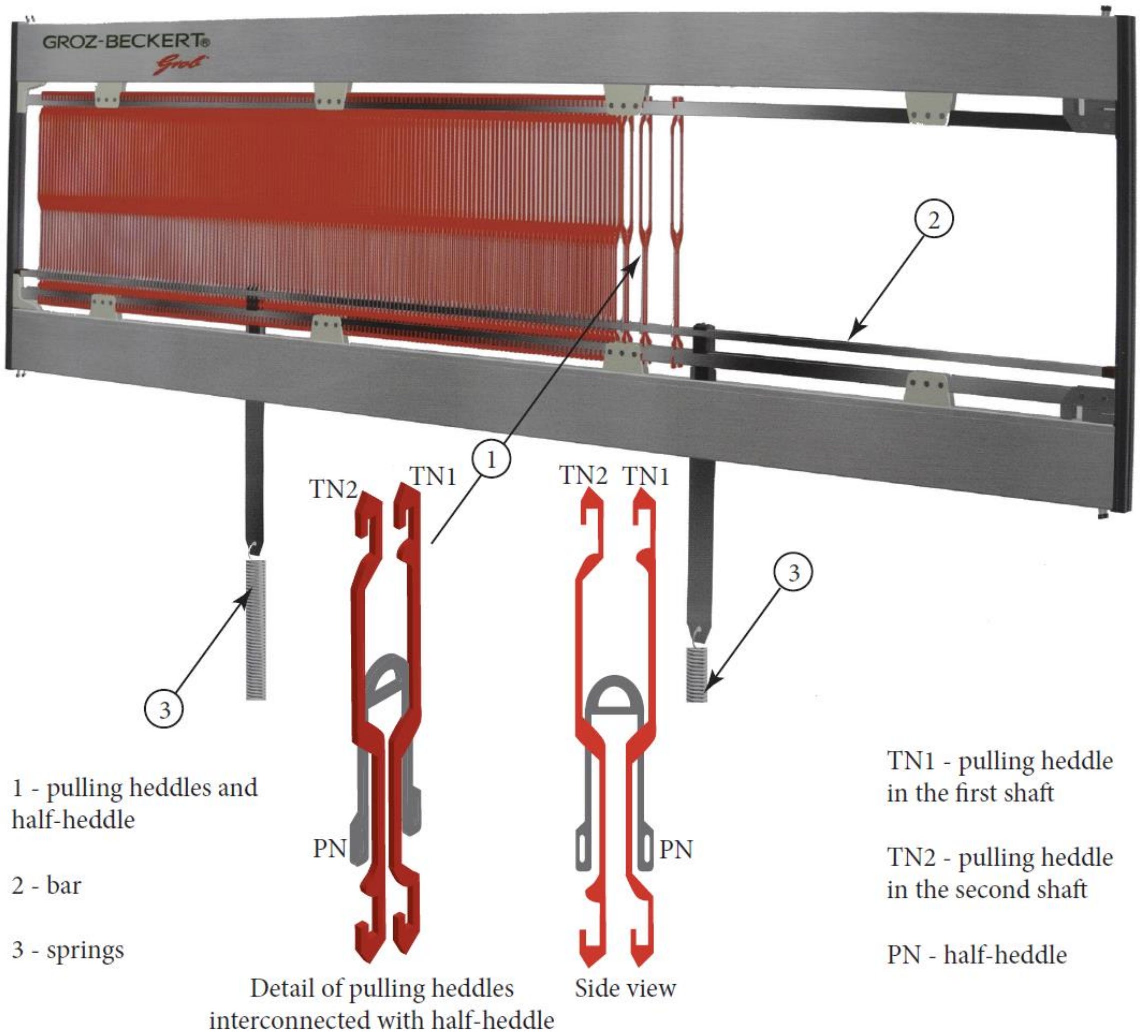
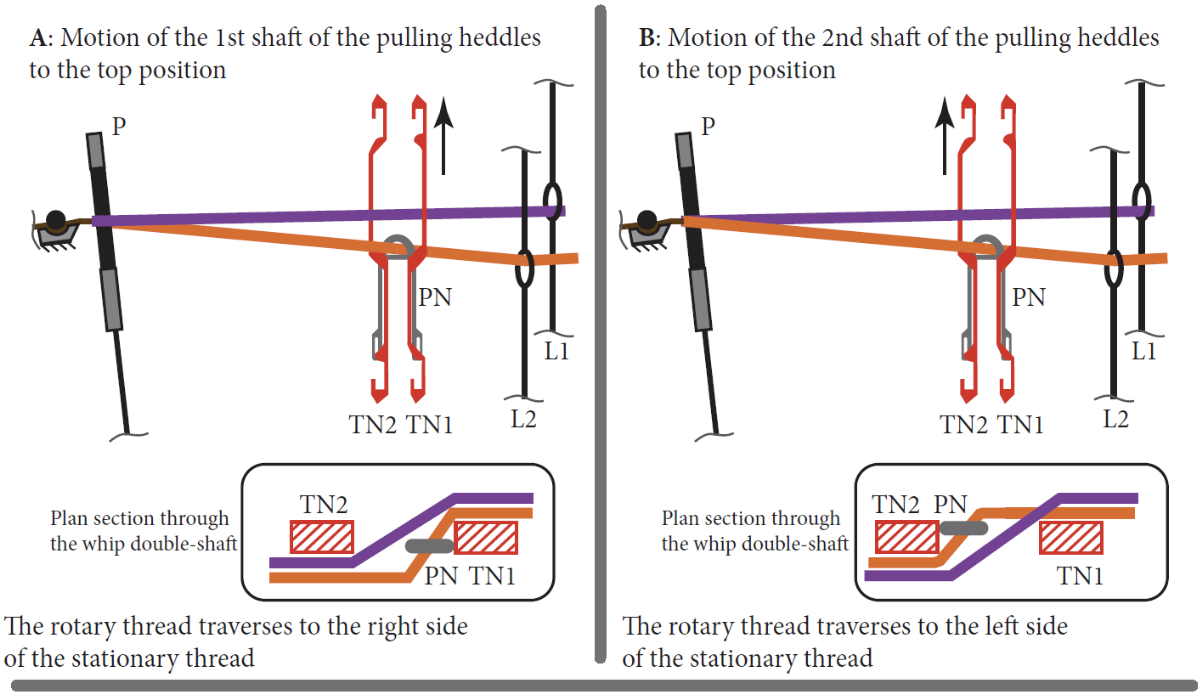


Figure 200: Main parts of the whip heald (whip double shaft)

Changing the position of the rotary threads allows a **whip heald,** whose main parts are shown in Figure 200. The whip heald is composed of two shafts with pulling heddles. These heddles consist of two steel parts that are bent in the middle of their length and connected to each other below this point so as to form a groove between the two parts. The half-heddle is inserted into grooves of the pulling heddle in the first and second shafts, i.e. one foot of the half-heddle is inserted in the pulling heddle of the first and second shafts. The half-heddle rests on the joints of both pulling heddles and can freely moves in their grooves in the vertical direction. If any of the pulling heddles is lifted, the half-heddle is also lifted. The half-heddles are used to connect all pulling heddles of the first shaft and the pulling heddles of the second shaft. A bar runs through the bottom holes in the feet of the half-heddles. Springs are mounted on this bar, which lower the half-heddles into the bottom position when closing the shed. The springs may be replaced by a fourbar mechanism that produces the forced motion of the bar relative to the shaft frame (see note hereinafter). The double shaft thus configured ensures the change to be made in the position of the rotary threads in relation to the stationary threads in each weaving cycle (see description of the operation hereinafter).

Layout of the leno heald on the weaving machine: The heald of the weaving machine for the production of leno weave fabrics is divided into two parts: ground and whip. The ground heald consists of standard shafts, which ensure the order of the warp threads (facilitating their threading) and compensate for the tensile forces in the rotary warp threads. The operation of the weaving machine in the production of the leno weave fabric will be described for the heald composed of two standard shafts and one whip double shaft (see Figure 201). The stationary threads are threaded through the heddles of the first shaft of the ground heald. The rotary threads are threaded through the heddles of the second shafts of the ground heald and through the half-heddles of the whip heald. One stationary thread and one rotary thread are always threaded through the reed dent, i.e. the warp is guided by two threads through the dents of the reed.



Legend:
L1 - heddle of the 1st shaft of the ground heald, L2 - heddle of the 2nd shaft of the ground heald, TN1 - pulling heddle of the 1st shaft of the whip heald, PN - half-heddle, TN2 - pulling heddle of the 2nd shaft of the whip heald, P - reed.

Figure 201: Leno heald in the beat-up (reed in the front dead centre)

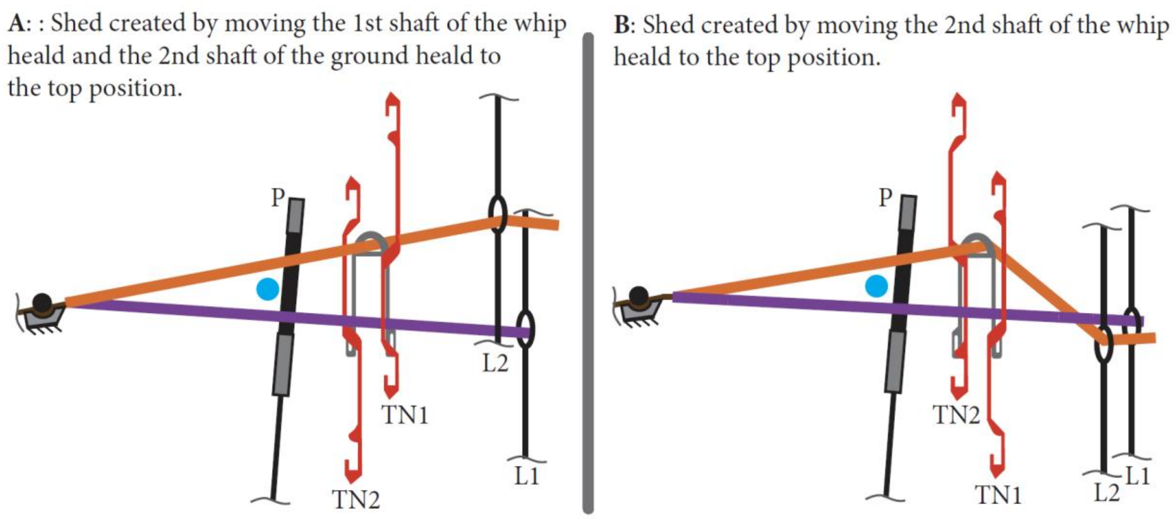


Figure 202: Leno heald with the open shed and weft insertion

Function: If, in the formation of the shed, the first shaft of the ship heald moves to the top position (see Figure 201-A), after opening of the shed (see Figure 202-A), the position of the rotary threads relative to the stationary threads is equal to the mutual position of the threads in the ground heald. Along with the first shaft of the whip heald, the second shaft of the ground heald moves to the top position. This reduces the wrapping angle of the rotary threads in the half-heddle eyes, thus reducing the friction forces, which apply stress in these threads. After the weft insertion, weft beat-up is performed while the shed is being closed, i.e. the first shaft of the whip heald together with the second shaft of the ground heald moves from the top position (Figure 202-A) to the bottom position (Figure 201). After completion of the first weaving cycle, the rotary threads create the warp interlacing points on the right side (seen from the reed) of the stationary threads.

In the following weaving cycle, the shed is formed by moving the second shaft of the whip heald to the top position (see Figure 201-B). In this case, the half-heddle runs below the stationary thread in the whip double shaft and he whip thread changes its position relative to the stationary thread (the so-called “traversing”). After opening the shed (see Figure 202-B), the whip threads are again in the top shed position (as in the previous weaving cycle), but their position relative to the stationary threads is reversed as compared to their position in the ground heald. After the weft insertion, weft beat-up is performed while the shed is being closed, i.e. the second shaft of the whip heald moves from the top position (Figure 202-B) to the bottom position (Figure 201). After completion of the second weaving cycle, the rotary threads create the warp interlacing points on the left side (seen from the reed) of the stationary threads. In this way, the leno weave shown in Figure 197 is created.

The method of forming the shed shows that the respective shaft should be moved to the top position and then returned to the bottom position within each weaving cycle. The **leno heald operates in the mode of single-lift shedding mechanism**, i.e. it ends its operation within one revolution of the main shaft.

Note: As mentioned above, the springs of whip shafts may be replaced by a fourbar mechanism (see Figure 203). The mechanism is attached by means of hinges on the upper or lower supports of both ship shafts and is connected to the bar by means of another hinge. The motion of whip shafts leads to the forced motion of the bar in the vertical direction relative to the shaft frame. The forced motion of the bar reduces the relative velocity of the heddles and thus the impact forces, which are generated in the warp threads in the formation of the leno weave, and allows to achieve higher weaving frequencies. At the time of creation of the textbook, this device is in the production program of the Groz-Beckert company, which distributes the device under the Posileno trademark.

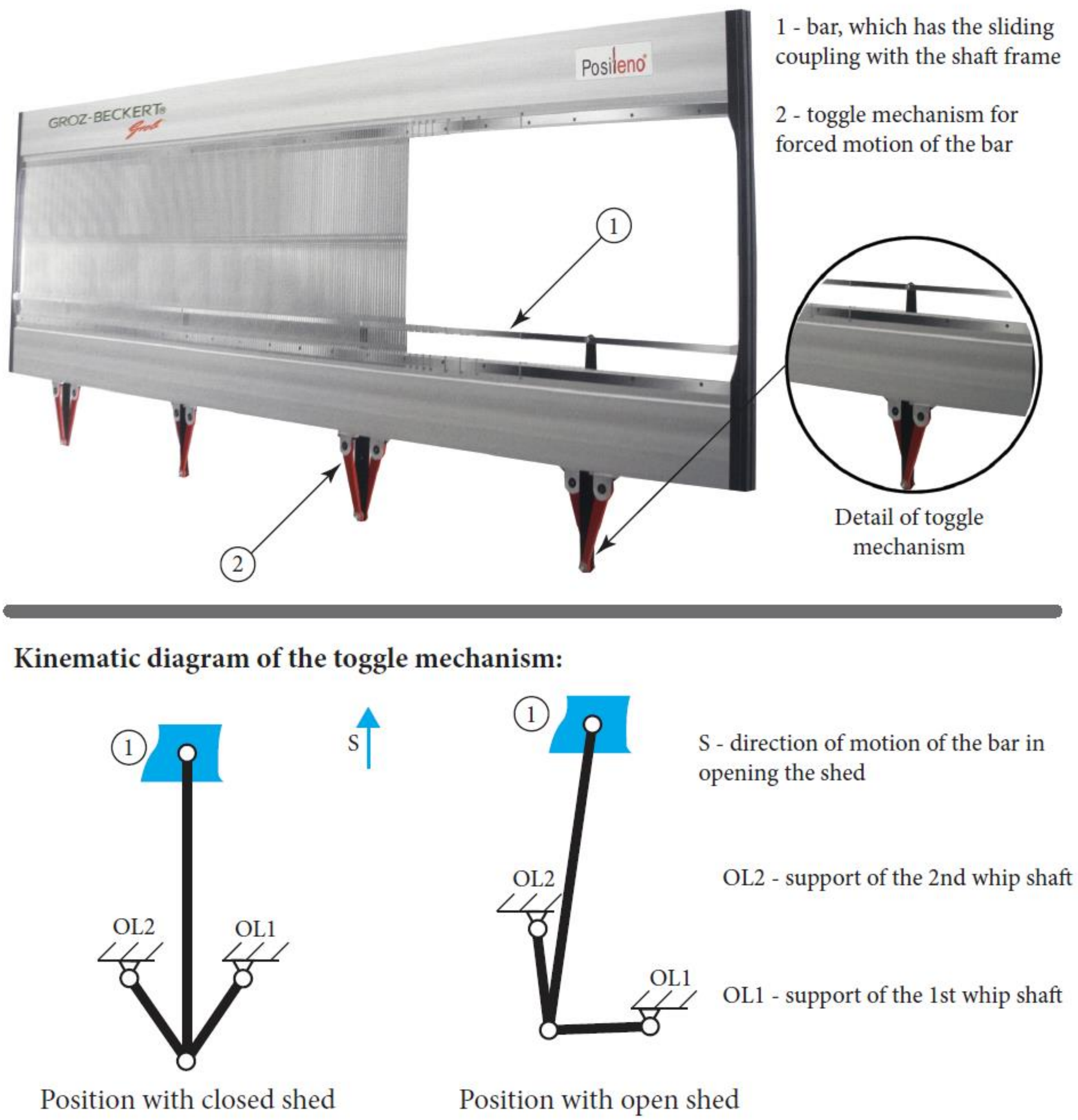


Figure 203: Forced motion of the bar using the fourbar mechanism (source [39])

6.2.2 Production of leno weave fabrics on machines with heald without heddles

On machines with the heald without heddles, the heddles are replaced by rapiers with an eye for threading the warp threads. The rapiers are mounted at the desired spacing on the supports, which replace the shafts. The motion of the supports creates the shed as well as the change in position of the rotary warp threads. The spacing (number of warp threads per unit length) of the warp threads on the weaving machine is ensured not only by the reed but also by the spacing of the rapiers in the heald.

The machines without heddles for the production of leno weave fabrics are generally designed for single purpose, i.e. they are capable of producing only leno weave fabrics as shown in Figure 197. In this case, the heald consists of two supports (see Figure 204). The stationary threads are threaded through the rapiers of the first support (shaft) that moves in the vertical direction. The rotary threads are threaded through the rapiers of the second support (rapier bar) that moves in the horizontal direction. The warp is guided by two threads through the dents of the reed, i.e. one stationary thread and one rotary thread are threaded through each dent. As an example, Figure 204 shows the heald of the EasyLeno machine of the Dornier company.

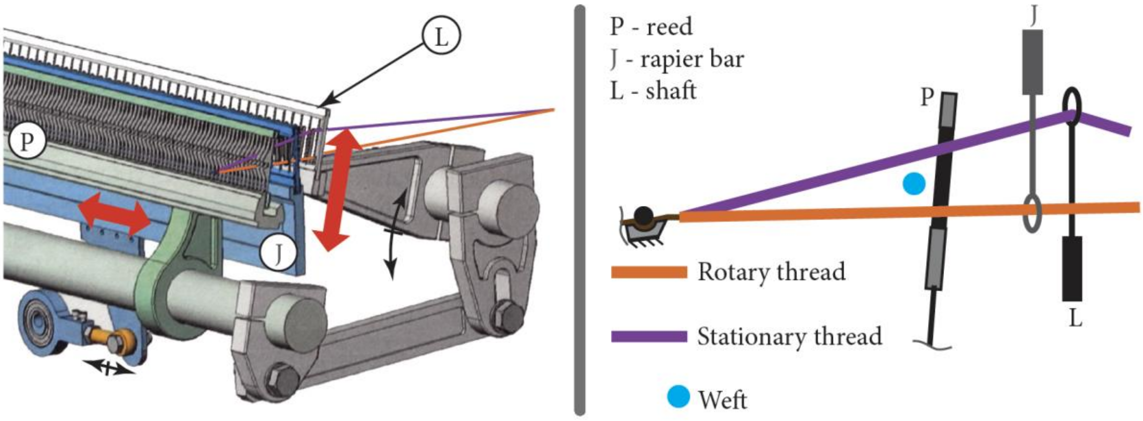


Figure 204: Diagram of the main parts of the rapier heald of the EasyLeno machine in the open shed position (source [30])

Function: The shed is opened by moving the shaft from the bottom position to the top position and the rapier bar moves simultaneously from left to right, i.e. the rotary threads traverse to the right side (seen from the reed) of the stationary threads (see Figure 205-A). With the open shed (see Figure 206-A), the rotary threads are on the right side of the stationary threads. After the weft insertion, weft beat-up is performed while the shed is being closed, i.e. the shaft moves from the top position to the bottom position. After completion of the first weaving cycle, the rotary threads create the weft interlacing points on the right side of the stationary threads.

In the second weaving cycle, the shed is opened again by moving the shaft from the bottom position to the top position. The rapier bar now moves from right to left, i.e. the rotary threads traverse to the left side (seen from the reed) of the stationary threads (see Figure 205-B). With the open shed (see Figure 206-B), the rotary threads are on the left side of the stationary threads. After the weft insertion, weft beat-up is performed while the shed is being closed, i.e. the shaft moves from the top position to the bottom position. After completion of the second weaving cycle, the rotary threads create the weft interlacing points on the left side of the stationary threads.

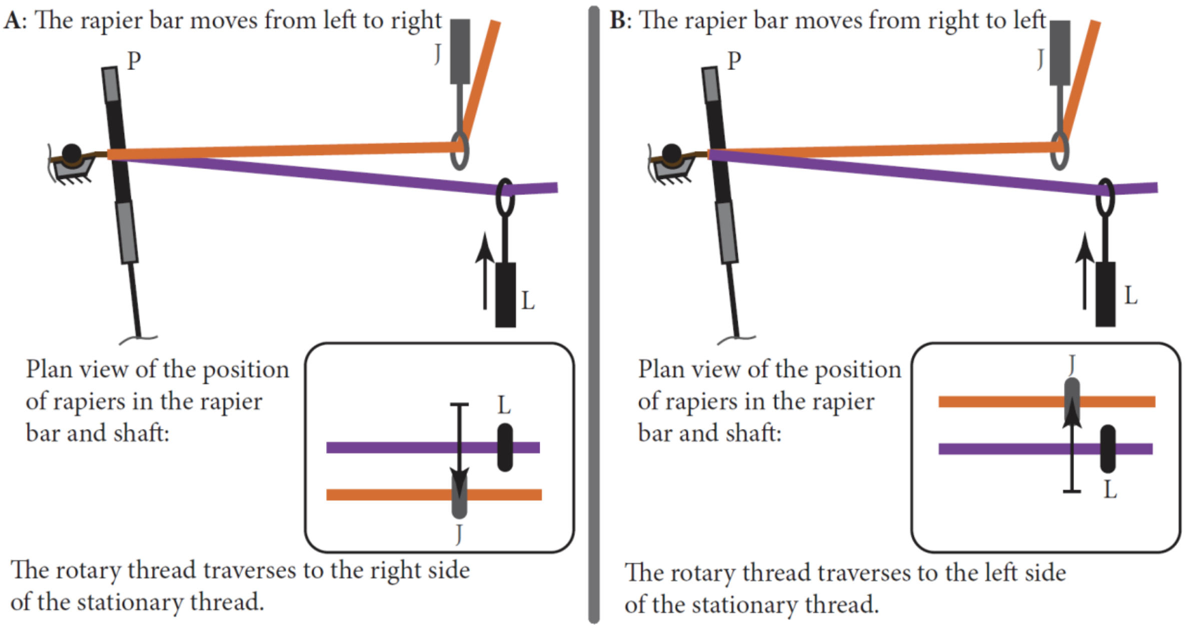


Figure 205: Rapier heald in the beat-up (reed in the front dead centre)

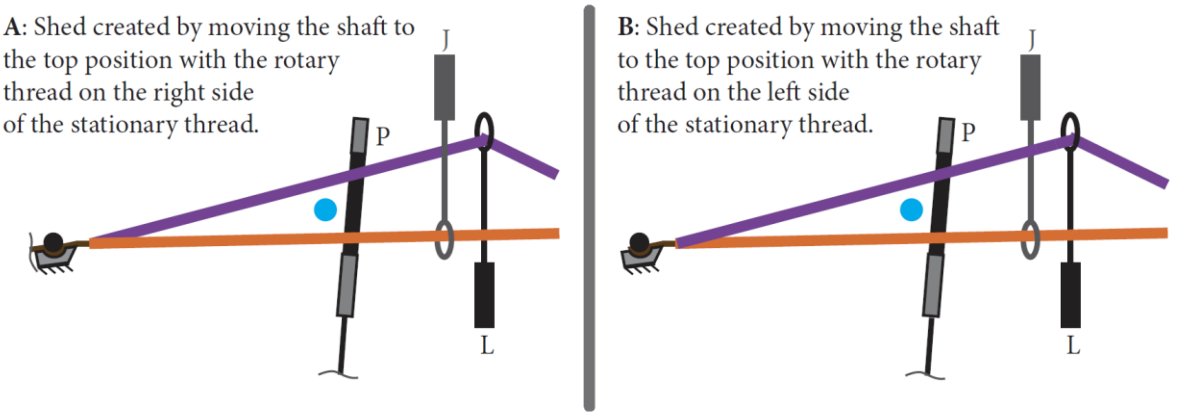


Figure 206: Rapier heald with the open shed and weft insertion

6.2.3 Production of fabrics in combines weave on machines without heddles

In addition to single-purpose machines without heddles for the production of leno weave fabric, the machine without heddles (the Combine machine of the VÚTS Liberec company) appears at the turn of the Millennium, which is able to produce fabrics with the so-called "combined weave". In general, these are fabrics, in which the plain and leno weaves are combined. The combination of plain and leno weaves increases (compared to conventional leno weave) consistency between the two systems of threads in fabric.

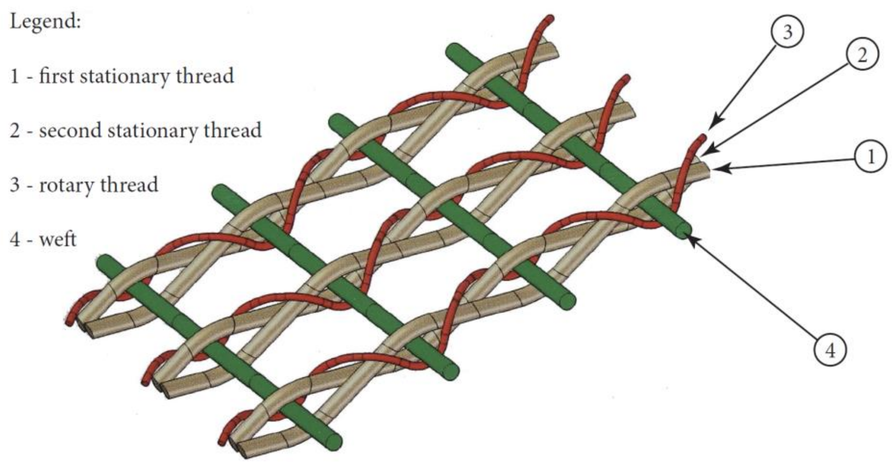


Figure 207: 3D diagram of the combined weave (source [19])

At the time of creation of the textbook, the Combine weaving machine is the single machine without heddles that is able to produce combined weave fabrics. In addition to the combined weave shown in Figure 207, this machine is able to create the leno weave shown in Figure 197 or the standard plain weave fabric.

Layout of the (rapier) heald without heddles of the Combine machine: The rapier heald of the Combine machine is schematically shown in Figure 208. The heald consists of two half-shafts, which are the supports, in which the rapiers with an eye for threading the stationary warp threads are mounted at the desired spacing. The half-shafts performs the motion in the vertical direction. The heald also includes the rapier bar with the support, in which the rapiers are also mounted at the desired spacing. The rotary warp threads are threaded through the eyes of the rapiers on the rapier bar. The rapier bar performs the motion in the horizontal direction.

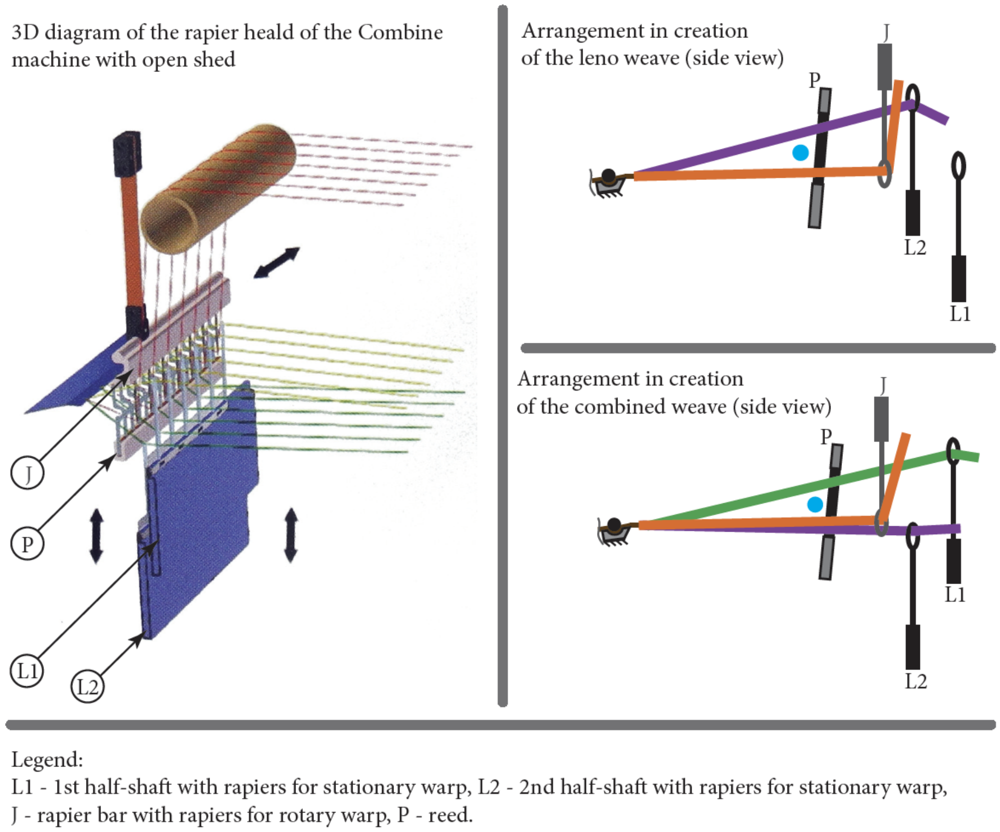


Figure 208: Diagram of the main parts of the rapier heald of the Combine machine (source [19])

The machine frame is adapted so as to allow the setting-up of two warp beams (see Figure 209) one above the other and the supply of the warp from each beam is controlled by a separate warp controller. The weft insertion is performed using an air-jet picking mechanism.

Figure 209: Photograph of the Combine machine (source [19])

Activity in the formation of the leno weave: One warp beam is set up in the machine and odd threads (rotary) are threaded through the rapiers of the rapier bar. Even threads (stationary) are threaded through the rapiers of the second half-shaft. The first half-shaft is not used in the creation of the leno weave (no threads are threaded through it). Two threads (one rotary thread and one stationary thread) are threaded through the dents of the reed. The principle of the creation of the leno weave is then identical with the formation of this weave on the above described EasyLeno machine (see Figures 205 and 206).

Activity in the formation of the combined weave: The activity in the formation of the combined weave is shown in Figures 210 and 211. In this case, two warp beams are set up in the machine. The stationary warp thread is on one of the beams and the rotary warp threads are on the other beam. The rotary threads typically have higher fineness in the units of tex than the stationary threads. Odd threads from the warp beam with the stationary warp are threaded through the rapiers of the first half-shaft and even threads through the rapiers of the second half-shaft. The rotary threads are threaded through the rapiers of the rapier bar. The warp is guided by three threads through the dents of the reed, i.e. two stationary threads (odd and even) and one rotary thread are together threaded through one dent.

The shed is opened by moving the first half-shaft from the bottom position to the top position. At the same time, the rapier bar moves from left to right, i.e. the rotary thread traverses to the right side (seen from the reed) of both stationary threads (see Figure 210-A). With the open shed (see Figure 211-A), the rotary thread is on the right side of both stationary threads. After the weft insertion, weft beat-up is performed while the shed is being closed, i.e. the first half-shaft moves from the top position to the bottom position. After completion of the first weaving cycle, the rotary threads create the weft interlacing points on the right sides of the pairs of stationary threads.

In the second weaving cycle, the shed is opened again by moving the second half-shaft from the bottom position to the top position. The rapier bar now moves from right to left, i.e. the rotary thread traverses to the left side (seen from the reed) of both stationary threads (see Figure 210-B). With the open shed (see Figure 211-B), the rotary thread is on the left side of both stationary threads. After the weft insertion, weft beat-up is performed while the shed is being closed, i.e. the second half-shaft moves from the top position to the bottom position. After completion of the second weaving cycle, the rotary threads create the weft interlacing points on the left sides of the pairs of stationary threads.

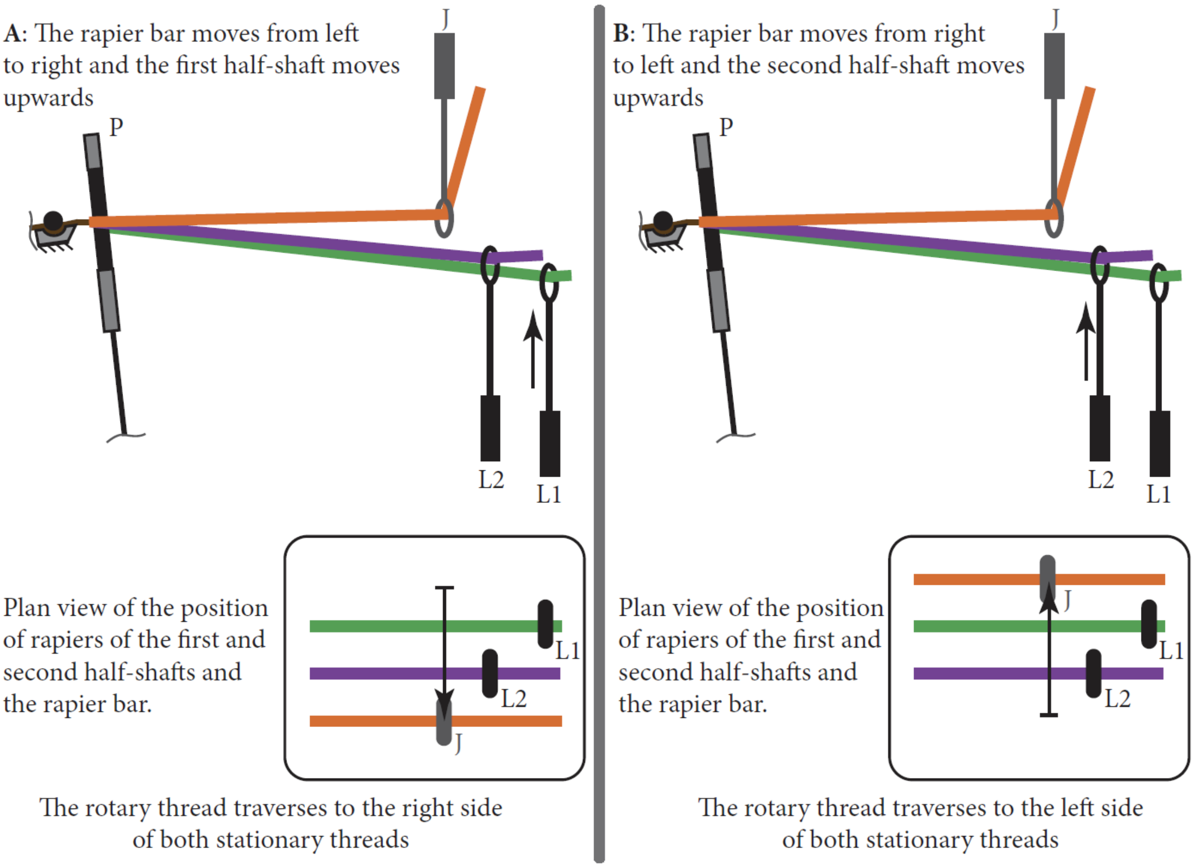


Figure 210: Rapier heald in the beat-up (reed in the front dead centre) - formation of the combined weave

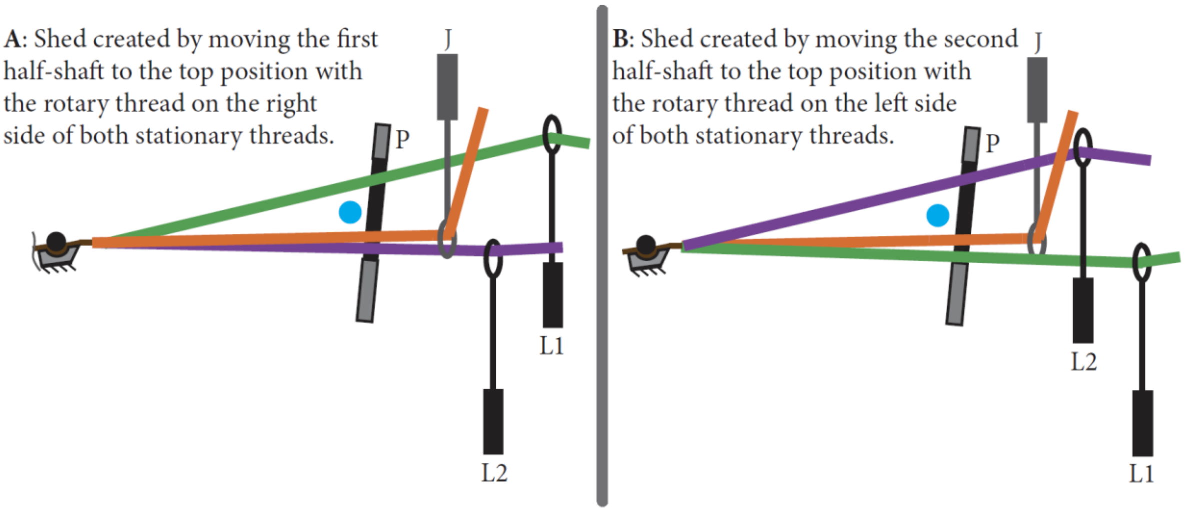


Figure 211: Rapier heald with the open shed and weft insertion - formation of the combined weave

The combined weave shown in Figure 254 will be created in the above described way. The stationary threads interlace with the wefts in the plain weave and each pair of warp threads from the plain weave pattern repeat is wrapped with the rotary thread.

Note: The half-shafts, rapier bar and the reed are driven on the Combine machine by individual motors running in the electronic cam mode (see Chapter 4.2.1 - drive type E). Therefore, the necessary lifting functions of working members of the heald may be chosen in the respective computer interface without manual operator intervention. Besides leno weave or combined weave fabrics, standard plain weave fabrics can be produced. In this case, one warp beam is used. Odd threads are threaded through the rapiers of the first half-shaft and even threads through the rapiers of the second half-shaft. The rapiers of the rapier bar remain unthreaded. The course of lifting of the double shafts then corresponds to the formation of plain weave using the double-lift shedding mechanism.

Important findings of the chapter:

1) We know what is the leno weave and the reasons for its use.
2) We can explain the method of producing leno weave fabrics on machines with heddle heald.
3) We can explain the method of producing leno weave fabrics on machines with heddle-free heald.
4) We know what is the combined weave and the method of producing it on heddle-free machines.

7 List of manufacturers of weaving machines

The following alphabetical list of the manufacturers of weaving machines is not exhaustive but includes information about the most significant products of weaving technology at the time of creation of the textbook. The list particularly includes companies whose specific design solutions are described in the textbook. The list does not include manufacturers of special weaving machines for the production of carpets or ribbon weaving machines.

Dornier company

- Address: Lindauer DORNIER GmbH, Rickenbacher Str. 119, 88129 Lindau / Germany
- Website: http://www.lindauerdornier.com/

This manufacturer, known for its production of the aircraft, started to produce textile machinery after World War II. The embargo on production of aeronautical products was imposed in Germany. The company was looking for a new production program, which found in the production of weaving technology. The Dornier company produces air-jet and rapier weaving machines (using the fixed rapier system). Both types of machines are built on the same frame and use the same electronic control system. In addition to these basic types of weaving machines, the company produces special machines to produce leno weave fabrics 1 T and 2 T with the trade name “EasyLeno”.

Itema company

- Address: ITEMA, s. p. a. - Via Cav. Gianni Radici, 4 Colzate, Italy
- Website: http://www.itemagroup.com

The ITEMA company was founded in 2012 by associating traditional Italian manufacturers of weaving machines VAMATEX and SOMET, and the Swiss company SULTEX (formerly SULZER). The Itema company produces air-jet, gripper and rapier weaving machines (using the flexible rapier system). The largest number of types is offered in the area of rapier weaving machines, followed by air-jet machines and gripper machines are represented by a single type.

Panter company

- Address: P. T.M.T. Srl, via Simone Cantoni, 4, 20064 Gorgonzola MI Italy
- Website: http://www.ptmt.it/

The company was founded in 1992 and produces rapier weaving machines. Weft insertion in all offered types is implemented by means of a pair of flexible rapiers or one flexible rapier. In the last period, the company focuses on the development of special weaving machines to produce industrial textiles of glass and carbon materials.

Picanol company

- Address: Picanol NV, Karel Steverlyncklaan 15, 8900 Ieper Belgium
- Website: http://www.picanol.be

The Picanol company has been engaged in the production of weaving machinery since 1936. The company is currently engaged in the production of air-jet and rapier weaving machines (using the flexible rapier system). The company produced more than 300,000 machines to the present. At the time of creation of the textbook, the company is the largest European manufacturer is terms of the number of produced weaving machines. Besides weaving machines, the production program of the Picanol Group includes various products from the area of textile accessories (heddles, heald shafts, relay nozzles, etc.).

Smit Textile company

- Address: Viale dell'Industria, 135 - 36015 Schio (VI) – Italy
- Website: http://www.smit-‐textile.com/

The company produces rapier weaving machines. Weft insertion is implemented by means of a pair of flexible rapiers or by means of one flexible rapier.

Toyota company

- Address: 2-1, Toyoda--cho, Kariya--shi, Aichi 448-8671, Japan
- Website: http://www.toyota-‐industries.com/

The company has been engaged in the production of the weaving machines since the late 19th century. Later, it is also engaged in the production of products for other industries (means of transport, logistics, etc.). The company produces currently air- and water-jet weaving machines.

Tsudakoma Corp.

- Address: 18-18, nomachi 5-chome, Kanazawa, 921-8650, JAPAN
- Website: http://www.tsudakoma.co.jp/textile/english/

The company has been engaged in the production of the weaving machines since the beginning of the 20th century and produced more than 180,000 machines so far. Its production program includes currently air- and water-jet machines. Besides weaving machines, the company focuses on the production of machines and equipment for making composite parts, accessories for the NC machines, etc.

VÚTS, a. s.

- Address: Svárovská 619, Liberec XI- Růžodol I, 460 01 Liberec, Czech Republic
- Website: http://www.vuts.cz/

The company VÚTS, a. s., offers jet weaving machines (air, water) designed especially to weave industrial fabrics. Machines designed to produce leno weave fabrics are dominant, which work on the self-developed and patented principle. Weaving machines are produced in limited series.

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