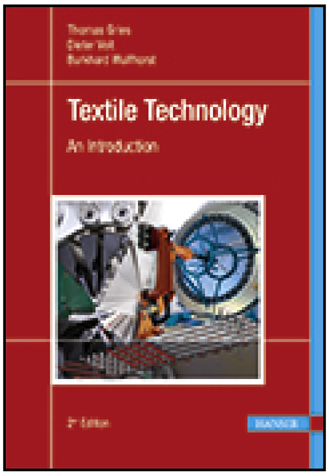

Sample Pages

Thomas Gries, Dieter Veit

Textile Technology

An Introduction

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Preface to the Second Edition

Since the publication of the first edition of this book in 2006, there have been numerous new developments in the textile industry. Therefore, we decided to create a new edition of this proven standard work. All chapters have been extensively updated and rewritten and some new topics have been added, such as measuring and testing techniques, and simulation. This new 2nd edition is the most comprehensive and current state-of-the-art guide to the textile manufacturing procedure.

Aachen, 2014 *Thomas Gries, Dieter Veit*

Preface to the First Edition

Due to the demand for an English edition of this book, the text was revised and new references added.

Dipl.-Ing. I. Parker PhD and Mrs. A. Itterbeck translated the German version of the book into English.

Aachen, 2006 *Burkhard Wulfhorst, Thomas Gries*

Preface to the First German Edition

This first part of this book is based on the lecture "Textiltechnik 1" that I have given at the RWTH Aachen for students of textile engineering, trade school teacher students, and students of economics with a minor in textile technology.

It covers all processing steps for the manufacturing of textiles. The book starts with an overview of the textile industry, its history, and the current market. This is followed by a description of the various raw materials, the different methods of yarn and fabric manufacturing and an introduction to knitting technology, nonwovens, finishing, and ready-made garment production. As technical textiles are becoming more and more important, one chapter is focused on their production as well as on typical applications. The book concludes with a discussion of current recycling processes.

To provide a better understanding of the individual textile processes, an example is given at the end of each chapter that describes the respective processing step with regard to a particular textile product.

In addition, current and future development trends are discussed at the end of each chapter.

An extensive references list at the end of each chapter can be used for further studies.

I would like to express my gratitude towards the following former and current scientific employees of the Institut für Textiltechnik der RWTH Aachen who contributed to this book: Dipl.-Ing. E. Berndt, Dr.-Ing. Th. Bischoff, Dr.-Ing. Dipl.-Wirt. Ing. C. Cherif, Dr.-Ing. E. de Weldige, Dr.-Ing. R. Knein-Linz, Dr.-Ing. N. Elsasser, Dr.-Ing. R. Kaldenhoff, Dr.-Ing. M. Leifeld, Dr.-Ing. O. Maetschke, Dr.-Ing. K.-U. Moll, Dr.-Ing. M. Osterloh, Dipl.-Ing. M. Pasuch, Dipl.-Ing. M. Reintjes, Dipl.-Ing. G. Satlow, Dr.-Ing. M. Schneider, Dipl.-Ing. P. Sommer, Dr.-Ing. D. Veit, Dipl.-Ing. St. Zaremba.

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Univ.-Prof. Dr.-Ing. Dipl.-Wirt. Ing. Th. Gries edited the chapter on chemical fibers. Mr. Ph. Moll and Dr.-Ing. G. Tetzlaff read the chapter on processes and machines for making-up proofs.

Our special gratitude goes to the Carl Hanser Verlag for their excellent cooperation and the production of this book.

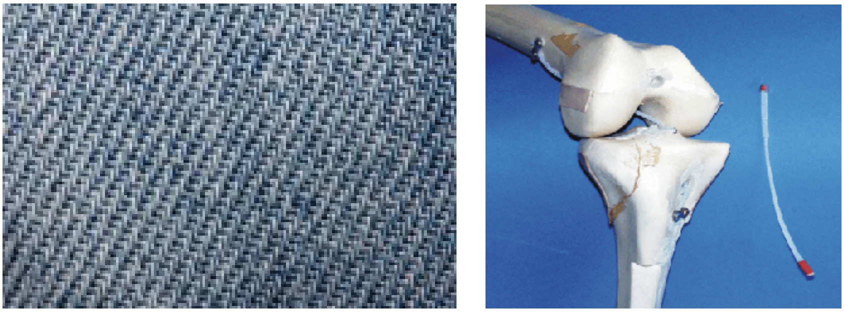
Aachen, 1998 *Burkhard Wulfhorst*

1 Introduction

1.1 Why Are There Fibers and Yarns?

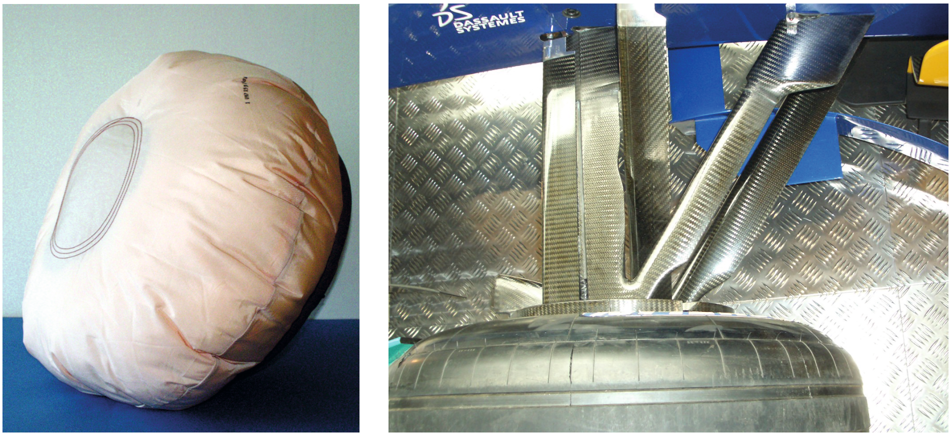
For millennia, humans have been using fibers and textiles. The most common product is clothing, which is also the most important in terms of amount of production. Textiles were and still are being used for medical applications, such as a wound dressing made from silk in Roman times. Today, parts of organs, blood vessels, and ligaments are produced using textile structures. Without fiber-reinforced composites, modern aircraft production would not be possible, and in the house and road building industries, fibers and textiles are increasingly being used (Fig. 1.1). Filters are made from textile structures using a wide range of textile materials ranging from polymers (like polyester) to steel.

For this wide range of products, fibers and textiles are used for three reasons: their mechanical properties, such as tenacity, elongation, shrinkage, and E-modulus, can be adjusted, their unique high ratio of surface to mass, and their variable porosity.



Jeans fabric

Textile implant



Airbag

Wheel suspension made from CFC (carbon fiber composite) (photo by Julian Eichhoff)

Figure 1.1 Typical textile products

1.1.1 Tenacity and Elongation

Along their axis, fibers exhibit a very high tenacity. When fibers are combined into a yarn, this value is increased many times, for example by way of an additional twist. Textiles made from fibers and yarns also show a high tenacity in each direction in which the fibers or yarns are placed. This property allows the tailored design of textiles according to the expected loads and load directions. Thus the amount used can be reduced to a minimum by having fibers and yarns located only in those places and directions where forces and momentums are applied to the final product. Textile products thus require much less material than classical materials such as metal. Hence, textile structures are predestined for lightweight applications, such as in automotive, space and aircraft, building, medical, and sports applications. Besides their tenacity, their elongation, shrinkage, and E-modulus can also be set to the required values. This is not possible with any other currently existing material. Figure 1.2 shows selected tenacity-at-break and elongation-at-break values for a range of materials. The mechanical properties of most textile materials are within these values. Elastane with an elongation exceeding 700% is an exception.

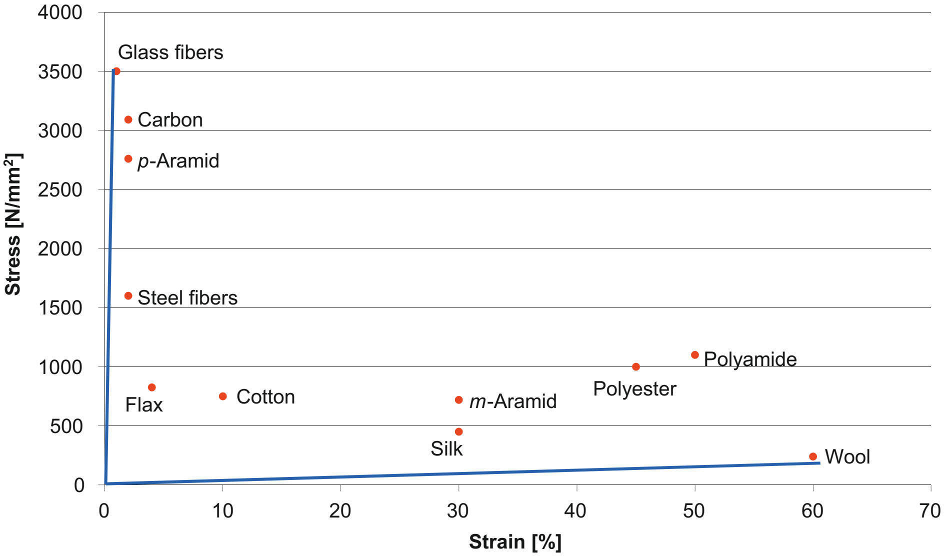
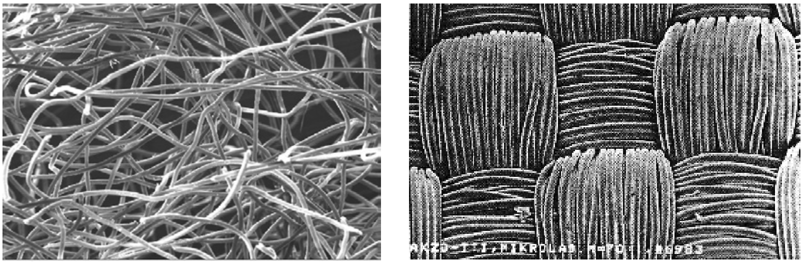


Figure 1.2 Typical values for tenacity-at-break and elongation-at-break for fibers

1.1.2 Surface and Porosity

The geometrical dimensions of a textile structure can also be varied within a wide range. This allows the production of very dense as well as very open structures. Open structures in addition have an excellent surface-to-mass-ratio, which makes them an excellent material for application where a high surface area combined with little mass is required. Typical applications of this kind are filters and diapers and medical implants. In the latter, apart from a load-adjusted structure, a defined and in most cases large surface area is required in order for the body's own cells to grow on them. The variable adjustability of both surface and porosity makes fibers and textiles unique compared to all other materials. Figure 1.3 shows a typical nonwoven fabric where all fibers contact each other only at very few crossing points. Hence, the free surface area of such a structure is huge. In contrast, the woven fabric on the right shows yarns densely packed, resulting in very little free surface area and very low porosity.



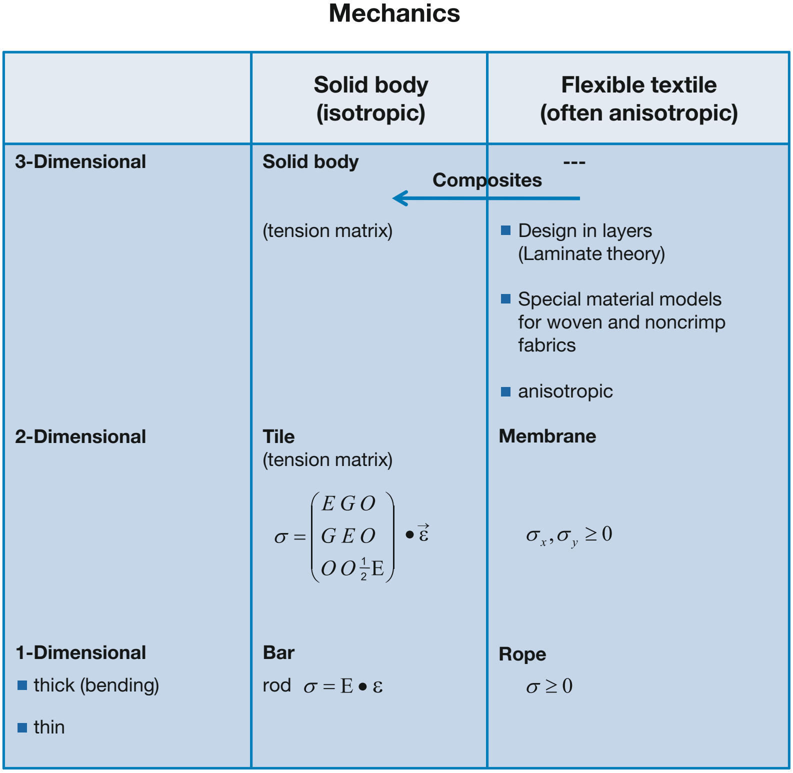
Nonwoven

Woven fabric

Figure 1.3 SEM picture of a nonwoven (left) and a woven fabric (right)

1.1.3 Mechanics of Solid Bodies and Textile Structures

The mechanics of textile structures are very complex compared to those of solid bodies, as can be seen in Fig. 1.4. In many cases though, it is possible to make certain assumptions and hence simplify the respective equations so that they can be solved either manually or by using computer simulations.



Mechanics

	Solid body (isotropic)	**Flexible textile (often anisotropic)**
3-Dimensional	**Solid body** (tension matrix)	--- ← **Composites** ■ Design in layers (Laminate theory) ■ Special material models for woven and noncrimp fabrics ■ anisotropic
2-Dimensional	**Tile** (tension matrix) $\sigma = \begin{pmatrix} E\,G\,O \\ G\,E\,O \\ O\,O\,\frac{1}{2}E \end{pmatrix} \bullet \vec{\varepsilon}$	**Membrane** $\sigma_x, \sigma_y \geq 0$
1-Dimensional ■ thick (bending) ■ thin	**Bar** rod $\sigma = E \bullet \varepsilon$	**Rope** $\sigma \geq 0$

Figure 1.4 Mechanics of solid bodies and textiles

1.2 Evolution of Textile Technology

Food, housing, and clothing are fundamental human physical needs. Clothes both serve a utilitarian function and express personality and living standard.

The evolution of apparel manufacture can be traced back to the Neolithic Age. As early as 4000 B.C., the hand-operated spindle and the loom were the most important tools for the production of textiles in central Europe. The materials used were wool and flax (linen). In 2000 B.C., there was a flax minister in Egypt and woven silk was produced in China.

Table 1.1 Evolution of Textile Technology (Wulfhorst, 1998)

Dates	Evolution	Raw materials	Spinning	Weaving	Knitting
Stone age	Animal skins	●			
4000 BC	Wool, flax (linen)	●	●		
	Hand-operated spindle				
	Loom			●	
1350 AD	Cotton in Central Europe	●	●		
	Manual spinning wheel				
	Treadle loom			●	
1530	Flyer spinning wheel of Leonardo da Vinci		●		
	Narrow fabric loom			●	
1589	Manual knitting loom of W. Lee				●
Around 1750	Start of industrialization				
1764	Cotton, wool, flax	●			
	First spinning machine “Spinning Jenny”		●		
1768	James Watt’s steam engine				
1769	Flyer spinning machine “Water Frame,” continuous fine spinning		●		
1775	Manual warp knitting loom of J. Crane				●
1785	First use of steam engines		●		
	Mechanical weaving loom			●	
1793	Cotton gin	●			
1795	“Jacquard machine”			●	
1830	“Self-acting mule”		●		
1844	“Ring spinning machine”		●		
1846	Production of guncotton	●			
Around 1855	Circular knitting machine				●

Table 1.1 Evolution of Textile Technology (Wulfhorst, 1998) *(continuation)*

Dates	Evolution	Raw materials	Spinning	Weaving	Knitting
1863	Flat knitting machine of J. W. Lamb				●
1892	Viscose fiber; Cupro fiber	●			
1899	Acetate	●			
1900	Weaving loom with automated weft change and electrical drive			●	
1914	Weft insertion with air jets			●	
1935	Polyamide PA 6.6	●			
1937	Polyurethane	●			
1938	Polyamide PA 6	●			
1939	Polyester (PES)	●			
1942	Polyacrylonitrile (PAN)	●			
1955	Open-end spinning technology		●		
	Water-jet weaving machine			●	
1960	Projectile shuttle and rapier loom			●	
1965	OE-rotor spinning machine		●		
1974	OE-friction spinning machine		●		
1992	Air-jet weaving machine			●	
	Lyocell	●			
1994	Compact spinning		●		
2003	Air-jet spinning		●		
2011	Open reed weaving			●	

At the turn of the first to the second millennium, the spinning and weaving processes changed considerably. During the crusades, European knights for the first time saw cotton textiles. By the middle of the 14th century, the new fiber material was introduced in central Europe (Table 1.1).

Increasing urbanization in Europe combined with a growing demand for textiles gradually led to a mechanization of textile production. Yarn spinning was mainly a women's chore whereas weaving was a craft for men and already highly specialized with silk, wool, and linen weavers. The invention of the flying shuttle by John Kay in 1733 doubled the productivity of a loom and led to a sharp increase in yarn demand ("yarn hunger"). This in turn led to further developments in mechanized yarn spinning (for example, the spinning jenny by James Hargreaves in 1764). The newly introduced steam engine quickly led to the establishment of large textile mills suitable for mass production. This was the start of a new era we today know as industrialization.

From the beginning of industrialization, textile technology had to satisfy two demands: the growing need for textiles caused by population growth and textiles that everyone could afford. The spinning and weaving machines that until then had been operated manually or with water power could no longer meet these requirements. Thus, it was necessary to mechanize the current machinery or to build new machines so as to use the new power potentials (steam, electricity) effectively. An outstanding example is the development of the first mechanical weaving looms, which were used at a weaving mill in England and driven by a steam engine.

For the next 180 years, development was continuous. An innovative peak was reached in the 1960s with the introduction of nonconventional spinning techniques and a weaving loom without shuttles. With these new techniques, production could be increased almost fivefold, while the need for manpower was reduced drastically.

In step with development of machines for spinning, weaving, and knitting technology, raw materials had to be made available at a reasonable price. A successful example is the cotton gin invented in 1793 by Eli Whitney, which for the first time allowed the industrialization of cotton production by increasing productivity from 500 g to 500 kg per day for one worker. In contrast to wool and linen, cotton could then be produced in large quantities, thus satisfying the hunger for textiles. Cotton production was established in the southern United States within a few years and dominated world production within a couple of decades.

By the end of the 19th century, important advances in the area of cellulose chemistry led to the development of chemical fibers from natural polymers. A first major step was the development of artificial silk made from nitrocellulose by Count Hilaire de Chardonnet and presented at the world exhibition in Paris in 1894. Alas, some unfortunate women wearing his new garments went up in flames when they accidentally came to close to open fire because nitrocellulose also makes an excellent explosive. Despite these initial difficulties, other inventions in the early 20th century in macromolecular chemistry, namely viscose production by Urban, Fremery, and Bronnert in 1901 and the discovery of macromolecules by H. Staudinger, initiated the development of chemical fibers from synthetic polymers, such as polyamide (PA), polyester (PES), polyacrylonitrile (PAN), and polyurethane (PUR). It took another 60 years until in 1993, the overall production of man-made fibers for the first time exceeded that of natural fibers.

The introduction of nonconventional spinning technologies in the 1970s, such as open-end rotor and friction spinning and air-jet spinning in recent years, led to a 10- to 15-fold increase in yarn production speed over the last four decades.

In the area of weaving, the speed of weft insertion was increased further. Novel nonconventional weft insertion techniques using projectile, gripper, water, and air started replacing the shuttle. The currently realized insertion speed of about 2500 $\mathrm{m} \cdot \mathrm{min}^{-1}$ may still be increased. Multiphase weaving is another step toward increasing production speed; however, in spite of the serious efforts of several weaving loom producers, the so-called wave-shed weaving, which is a multiphase weaving process, has not become successful due to technology-specific disadvantages. A new technology is open-shed weaving, which allows one to add additional patterns or to reinforce a woven fabric in certain spots for say technical applications.

1.3 Production Stages

Multiple production stages are necessary for the manufacture of fibers, yarns, and textiles. Figure 1.5 gives an overview of raw materials and processing steps.

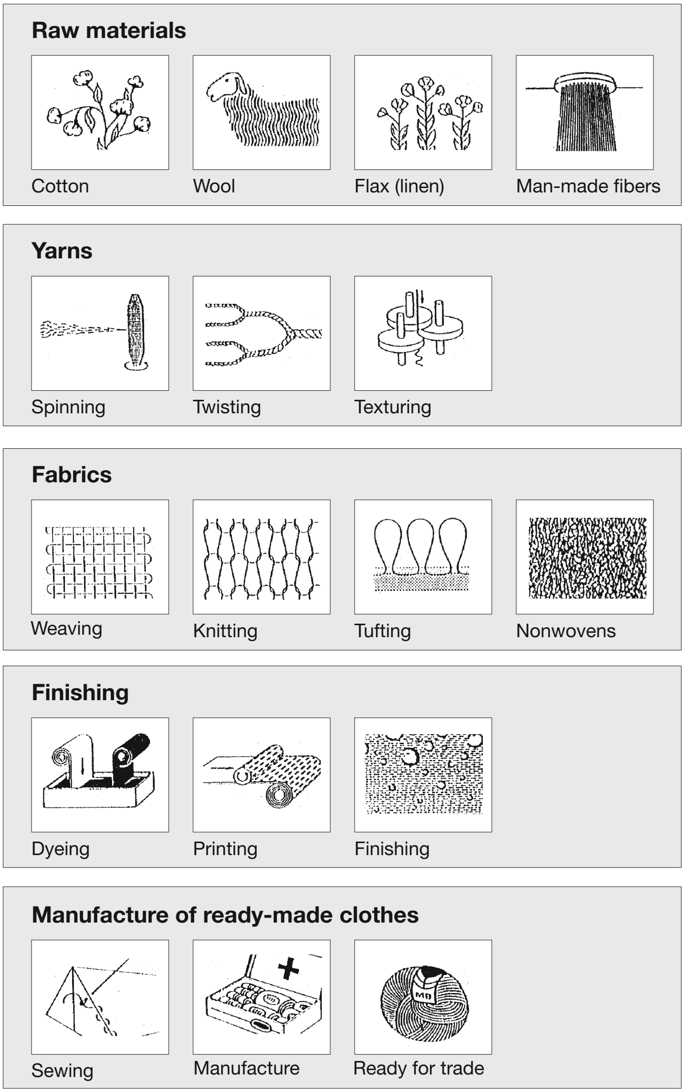


Figure 1.5 Raw materials and processing steps (Arbeitgeberkreis Gesamttextil, 1988)

The production chain from raw material to waste disposal is often called the "textile pipeline" or "value-added chain" (Fig. 1.6). The expression "value-added chain" can be derived from Fig. 1.7, where the increase in added value for the manufacture of a three-piece suit is illustrated.

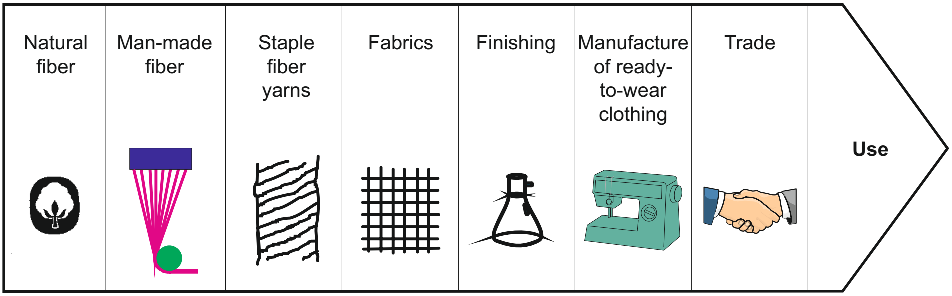


Figure 1.6 "Textile pipeline" or "value-added chain"

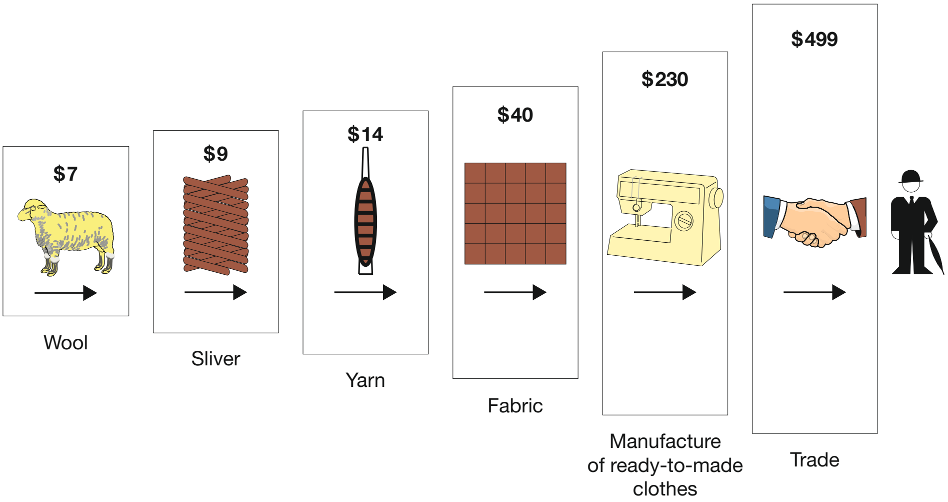


Figure 1.7 Added value for a three-piece suit (jacket, pants, vest) in US dollars

Raw materials for the manufacture of textile products are fibers, both natural and man-made. The choice of material—natural or man-made fibers or even blends—depends on the field of application and the desired properties of the product.

The technological properties of natural fibers—for example, length, fineness, strength—may vary. For cotton, the properties listed above depend mainly on the growing area and the growth conditions. For wool, these properties are essentially influenced by the breed of sheep and by the animals' environment (food, diseases). The listed criteria are crucial to the quality, produced amount, and price of natural fibers.

In contrast to natural fibers, the properties of man-made fibers can be designed depending on the chemical constitution and the conditions of polymer synthesis. In addition to fineness and strength, the fiber length can be adjusted as required. Chemical fibers are produced and processed as filament fibers or as staple fibers (with continuous yarn cut or broken into pieces of defined length).

Natural and man-made fibers are initially processed in different production steps as follows.

After harvest and ginning, cotton fibers are pressed into bales. The bales are delivered to the spinning mill and first enter the spinning preparation (Chapter 3). Here, the pressed and condensed fiber material is resolved into flocks. This separation into individual fibers is accompanied by an intense cleaning and parallelization. Subsequently, the fibers are reunited into a band of fibers, called a web. This fiber web is evened out and reduced in weight in several steps and then produced into the roving (product). Further increase in fineness (by drafting) and subsequent introduction of a twist (strengthening) leads to the yarn. The final yarn is wound onto cops (tubes) or cross-wound bobbins. Other natural fibers are processed in different production steps (Chapter 3).

Processing of chemical fibers is completely different. Many chemical fibers are spun from a spinning solution or a polymer melt (Chapter 2), resulting in a single primary thread (monofilament) or a smooth filament yarn of multiple single fibers (multifilament). Smooth filament yarns are textured to add bulk and crimp. In the so-called converter process, large cables of filament yarns can be torn or cut to staple length. Accordingly, the procedure is called “ripping” or “cutting conversion.” The resulting staple fibers may be processed into staple yarns in combination with natural fibers.

The next processing step is weaving preparation, where the system of warp ends necessary for woven production is built. This is a system of threads in the longitudinal direction, which is combined into an assembly of parallel threads and wound onto the warp beam. The warp beam is inserted in the loom. During weaving (Chapter 4), the subsequent manufacturing step, a textile fabric, the woven fabric, is produced. A woven fabric is characterized by the rectangular crossing of two systems of threads (warp and weft yarn). The way in which warp and weft yarn is crossed is called the woven structure or weave pattern.

An alternative method of producing textile fabrics is the manufacture of knit fabrics (Chapter 5). As a result of the way the stitches are constructed, knitted structures are rather loose and voluminous. Characteristics for knit fabrics are a soft handle, high porosity, thermal isolation, and good drapeability.

Textile fabrics may also be produced as what are known as nonwovens (Chapter 6). The production process can be divided into

- manufacture of the fiber web,
- stabilization of the fiber web resulting in the nonwoven, and
- finishing of the nonwoven.

A fiber web is a coherent assembly of fibers. It may be constructed from several layers of fiber webs on top of each other or from several layers of nonwovens. According to the different directions of fiber orientation, isotropic webs and webs nonisotropic in the cross and machine directions are distinguished. Fiber webs can be produced mechanically, aerodynamically, or hydrodynamically.

After the production of wovens, knits, or nonwovens, the fabrics are finished (Chapter 9). Finishing may also be done earlier during the production process as fiber or yarn finishing.

The main purposes of finishing are

- removal of dirt and contamination,
- dyeing or printing, and
- surface modifications in order to improve product properties and wear comfort.

The last step in the manufacture of a textile product is the production of ready-to-wear clothing (Chapter 10), a process in which the textile fabrics are put together by mass production according to their application: apparel, home and furnishing textiles, or technical textiles. Processing steps for this step are separation, assembly, and shaping.

The individual processing stages in the chain of Fig. 1.7 are explained in Chapters 2 through 10. To relate these stages to each other, the process engineering of each stage is illustrated with examples at the end of each section, including jeans, rugs, carpets, and airbags.

1.4 Typical Products Made from Natural and Man-Made Fibers

The following overviews show typical examples of intermediate products made from natural and man-made fibers and filament yarns, see Fig 1.8.

Typical Products

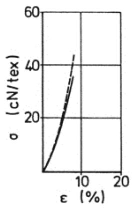
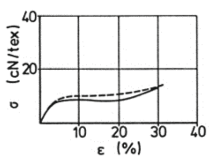
Staple fibers	Natural fibers	Man-made fibers
Short staple  	■ Cotton - Fineness 1,5–3 dtex - Cross-section kidney shaped – circular - Crimp, low - Fiber length (max.) 25–35 mm (statistic. distributed)	■ Cotton type - Cross-section circular - Crimp, low - Fiber length 35–40 mm (uniform fiber length = rectangle-shaped staple) delustered (dull) (approx. 0.3% TiO_2)
Long staple  	■ Wool – fine wool - Fineness 3–5 dtex - Cross-section circular - Crimp, high - Fiber length < 80 mm ■ Wool – coarse wool - Fineness 20 dtex - Cross-section circular - Crimp, low - Fiber length < 200 mm	■ Wool type - Fiber length uniform - Rectangular-shaped staple cutting converter - Combed yarn similar to breaking converter ■ Carpet type - Fiber length uniform (rectangular-shaped staple)
Filament	■ Silk - Fineness 5 dtex - Cross-section triblobal - Crimp - Fiber length (tech.) endless (~ 1000 m)	■ Filament yarn - Fineness 3–5 dtex - Cross-section circular (rarely trilobal)

Figure 1.8 Typical products made of natural and man-made fibers

Man-made fibers can be classified according to fiber length, their mechanical properties, and the material of which they are composed. The following overview (Fig. 1.9) shows the most important types, sorted according to length.

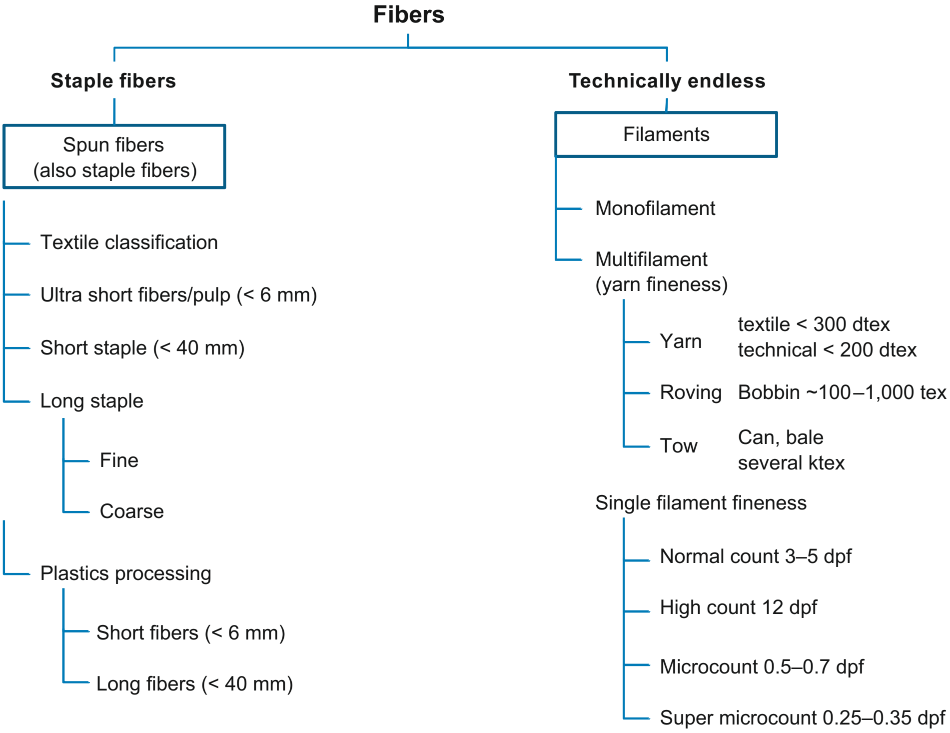
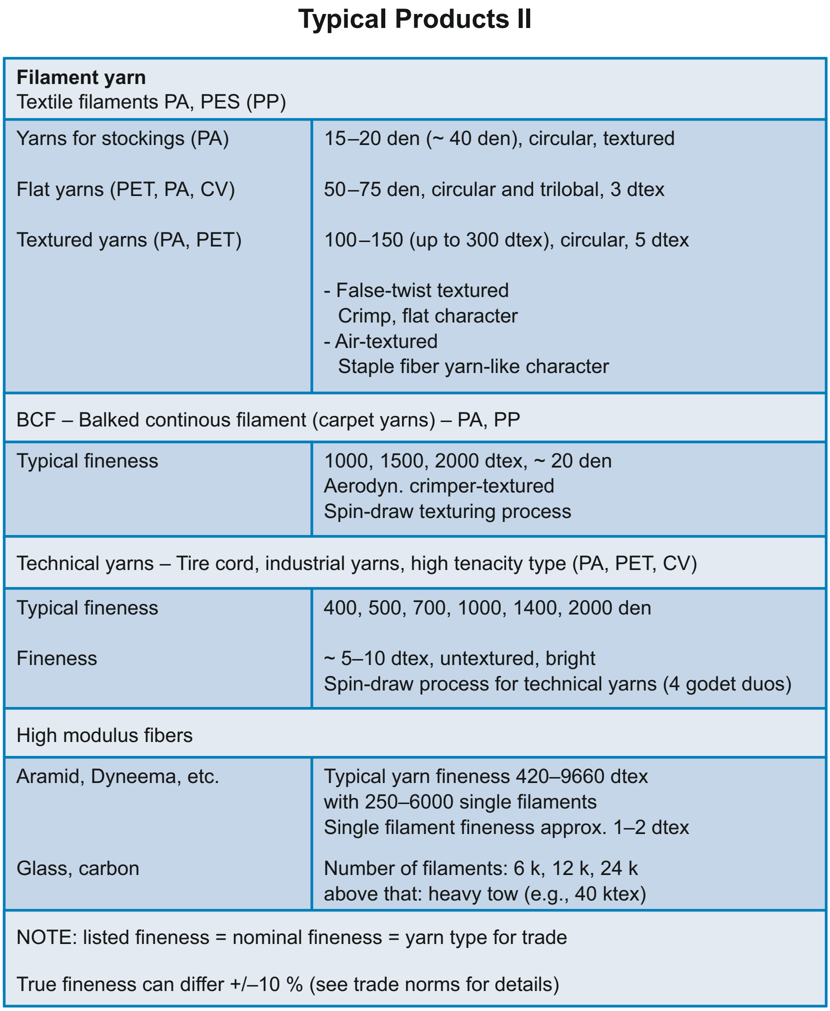


Figure 1.9 Classification of man-made fibers according to length

Filament yarns can be classified by the products into which they are converted as seen in Fig. 1.10.



Typical Products II

Filament yarn Textile filaments PA, PES (PP)	
Yarns for stockings (PA)	15–20 den (~ 40 den), circular, textured
Flat yarns (PET, PA, CV)	50–75 den, circular and trilobal, 3 dtex
Textured yarns (PA, PET)	100–150 (up to 300 dtex), circular, 5 dtex - False-twist textured Crimp, flat character - Air-textured Staple fiber yarn-like character
BCF – Balked continous filament (carpet yarns) – PA, PP	
Typical fineness	1000, 1500, 2000 dtex, ~ 20 den Aerodyn. crimper-textured Spin-draw texturing process
Technical yarns – Tire cord, industrial yarns, high tenacity type (PA, PET, CV)	
Typical fineness	400, 500, 700, 1000, 1400, 2000 den
Fineness	~ 5–10 dtex, untextured, bright Spin-draw process for technical yarns (4 godet duos)
High modulus fibers	
Aramid, Dyneema, etc.	Typical yarn fineness 420–9660 dtex with 250–6000 single filaments Single filament fineness approx. 1–2 dtex
Glass, carbon	Number of filaments: 6 k, 12 k, 24 k above that: heavy tow (e.g., 40 ktex)
NOTE: listed fineness = nominal fineness = yarn type for trade True fineness can differ +/–10 % (see trade norms for details)	

Figure 1.10 Typical filament yarn products

1.5 Yarns

Fibers are normally spun into yarns with the exception of nonwovens (Chapter 6). A selection of typical yarn structures is shown in Fig. 1.11. The so-called “spun yarns” are yarns made from staple fibers (for example cotton and cut man-made fibers). All other yarns are made from man-made fibers. Plied yarns consist of two or more parallel oriented yarns; twisted yarns consist of at least two twisted yarns.

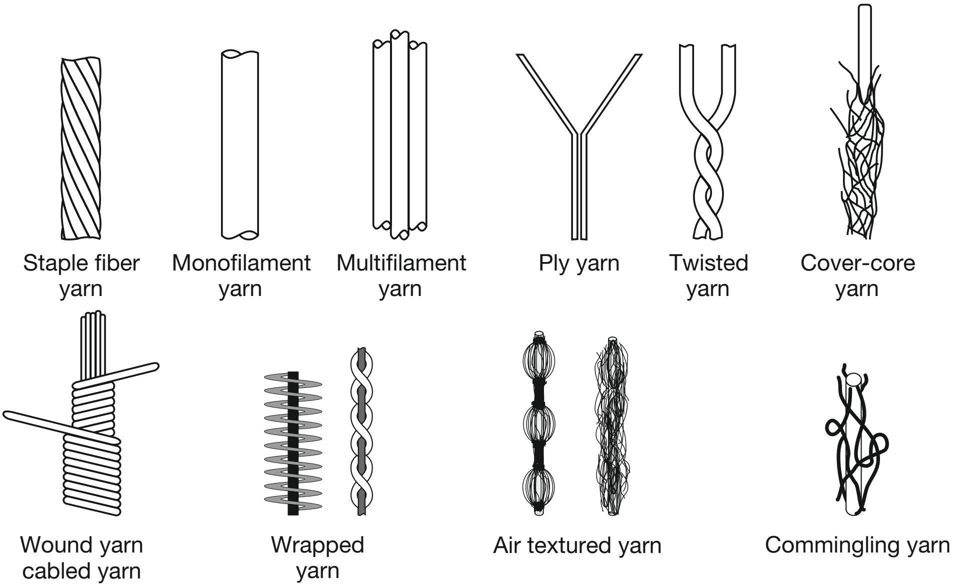


Figure 1.11 Selected yarn structures

1.6 Textiles

Textile structures are available in a large range of different types. Figure 1.12 shows the classification of textiles into fiber- and yarn-based structures and their subgroups.

Textiles are used for many different applications. The major areas of application are clothing and accessories (approximately 50% market share). This includes very different products, ranging from jeans to shoelaces, from bulletproof vests to firefighter clothing and space suits. A large amount of textiles is used for home and furnishing, for example carpets, upholstery, and fireproof tapestry made of glass fabrics. They make up around 40% of the market. A fast-growing sector is reinforcement textiles made from high-performance fibers (carbon, glass aramid). They are used in car tires for Formula 1 racing cars as well as in high-end automobiles as car body parts. These kinds of textile applications are also known as fiber-reinforced composites. The textile's main task here is to ensure a sufficient tenacity of the product combined with low weight. This requires, in a literal sense, tailored textiles produced on automated machines. Artificial blood vessels and parts of organs are typical examples for medical textiles. In recent years, smart textiles were developed that combine or integrate electronics and textiles. A typical example is a mobile phone application in a shirt sleeve. All of these applications, ranging from composites to smart textiles and from airbags to fish nets, are summed up in the term "technical textiles." They make up about 10% of the overall textile market with a much higher growth rate (around 5–10% annually) than the other sectors.

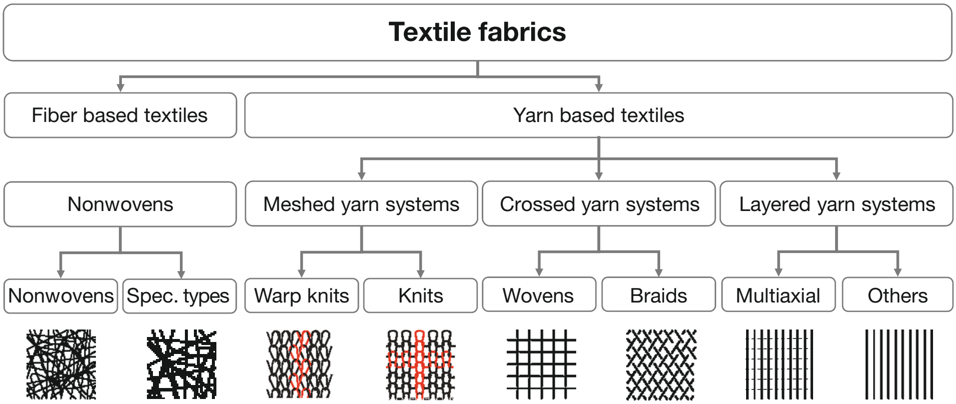


Figure 1.12 Classification of textile structures

Textile structures can be divided into two- and three-dimensional structures. Most woven fabrics and knits as well as noncrimp fabrics, braids, and nonwovens belong in the first group (Fig. 1.13). For complex, mainly technical products, three-dimensional structures are an interesting alternative to conventional products, namely 3-D wovens, knits, and braids.

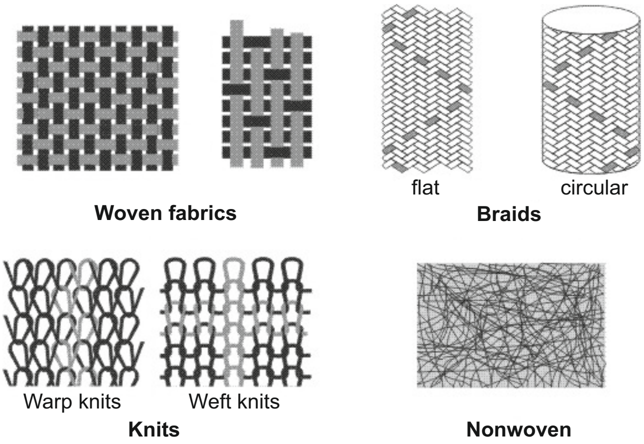


Figure 1.13 Conventional textile structures

Apart from conventional textile structures that are predominantly used in clothing and hygiene products, there is a large variety of considerably more complex textile structures used in technical applications, as shown in Fig. 1.14.

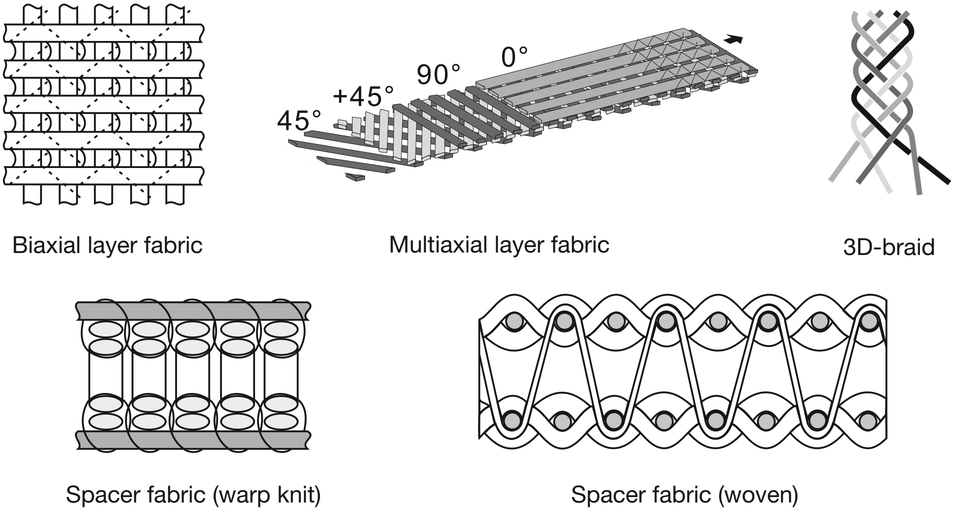


Figure 1.14 Complex textile structures for technical applications

5

Processes and Machines for Knitwear Production

Coauthors: V. Schrank, A. Hehl, K.-P. Weber

Several thousand years ago, knitwear was manually produced by means of small sticks (knitting needles). In 1589 the English Reverend William Lee invented the manual weft-knitting machine with a 16-fold greater productivity than a manual knitter. It was the first mechanized stitch-formation process. Modern developments of knitting machines led to very high production outputs together with a high variety of patterns. The production of these machines is 500,000 times higher than that of a manual knitter.

According to the German Industrial Standard DIN 60000, knits are “fabrics, made of one or several threads or one or several thread systems by stitch formation.” It should read “The respective terminology can be found in (DIN 62050, 1990). For further explanations of knitwear production see Au (2011), Ray (2011), and Spencer (2001).

Besides the classic fields of application of clothing (pullover, underwear, stockings, sportswear, bathing suit fashions) and home textiles (net curtains, bedspreads, awnings, tablecloths, covers for furniture), knitwear is also used for technical textiles, including for helmet structures, medical textiles, geotextiles for dike and road construction, filter materials, material for insulation, and nets.

Depending on the movement of the needles, knitting machines can be distinguished between knitting machines (circular, flat), warp-knitting machines (flat), and weft-knitting machines (flat), as shown in Fig. 5.1. The needles can be moved individually (knitting) or in groups (warp knitting, weft knitting). The loop formation occurs in either the production direction (warp and weft knitting) or perpendicular to the production direction (knitting). During knitting, the threads are fed to a single needle, whereas in weft and warp knitting the threads are fed to a number of needles simultaneously before the loop is formed. In weft and warp knitting, the threads are often taken from warp beams.

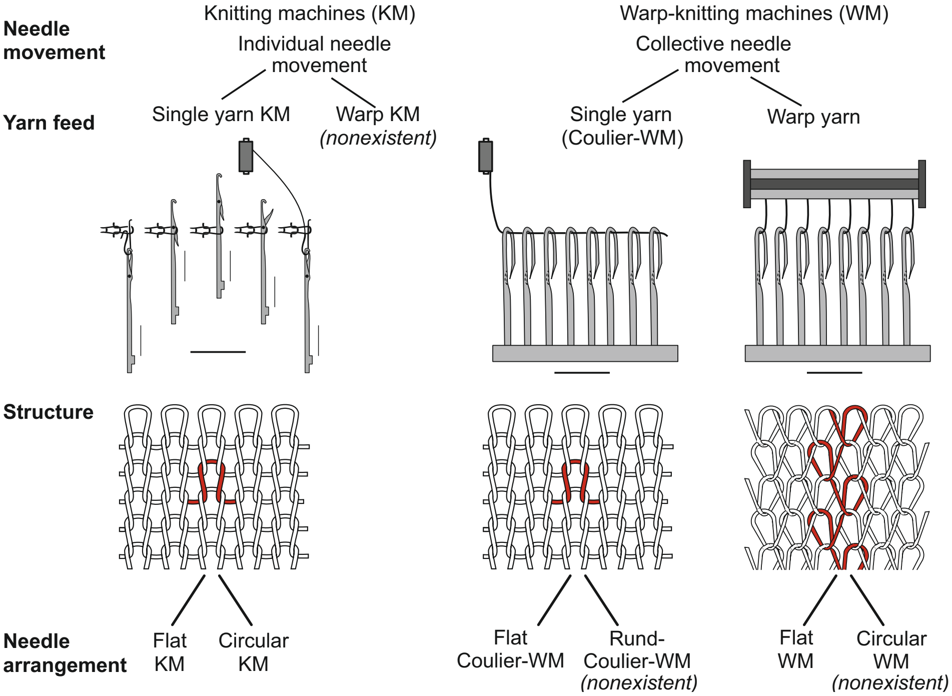


Figure 5.1 Classification of knitting machines (Weber, 2001)

In order to form the actual loop and to interconnect the loops, different types of needles are used, as shown in Fig. 5.2.

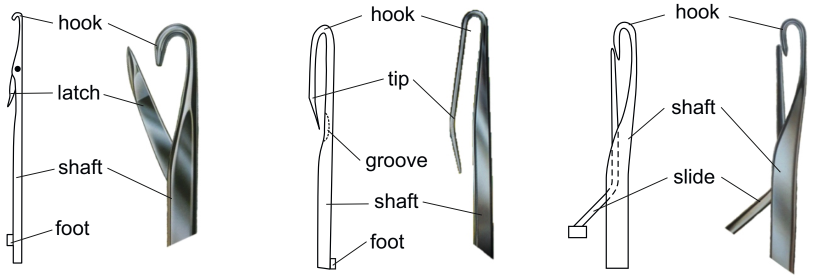


Figure 5.2 Needle types: latch needle (left), spring needle (middle), slide needle (right)

For knitting, mostly latch needles are used, whereas in warp knitting, slide needles are predominant. The advantage of latch needles is their flexibility regarding thread material and that there is no additional component needed to close the needle as is the case for slide and spring needles. However, slide and spring needles are cheaper to manufacture.

5.1 Knitting

5.1.1 Design and Structure

Knittings consist of interlocked meshes that are produced perpendicular to the production direction. A loop that is connected to other loops is called a "mesh." Meshes possess a head, a foot, and two legs. They are connected via two upper and two lower crossing points, as shown in Fig. 5.3. The meshes perpendicular to the production direction are called "course"; those meshed in the production direction are called "wales."

According to the position of the bottom crossing points, one distinguishes between purl and plain stitches. A plain stitch has its feet under and its legs over the head of the previous stitch (Fig. 5.3(a)). A purl stitch has its feet over and its legs under the head of the previous stitch, see Fig. 5.3(b).

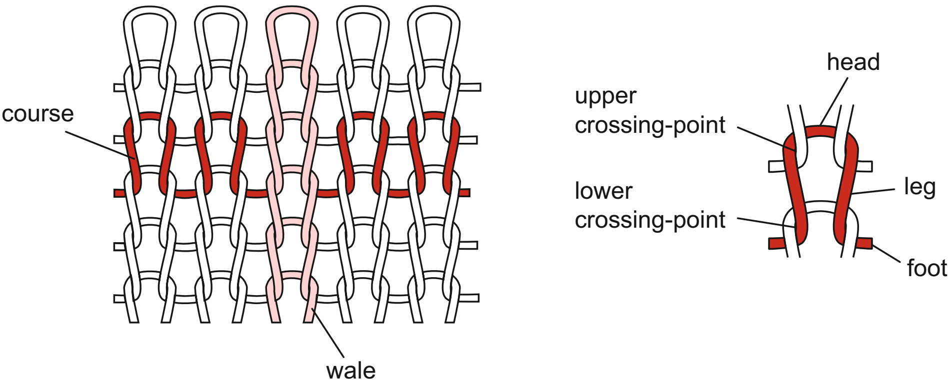
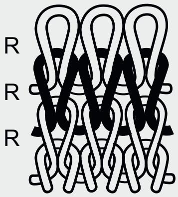
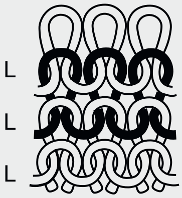
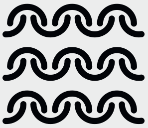
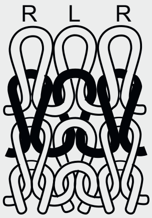
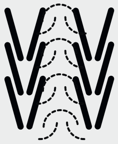
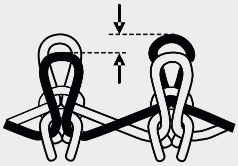
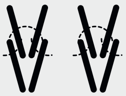
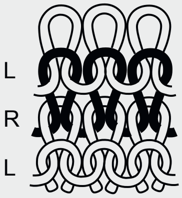
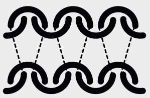


Figure 5.3 Structure of a knitted fabric: courses, wales, and crossing points

According to the arrangement of right and left stitch sides in knitwear, these can be distinguished by their binding group: back and face, double jersey, and left–left knitwear. Back-and-face knitwear has only plain stitches on one side and purl stitches on the other. Double-jersey knitwear shows plain stitches on each stitch side. Plain and purl stitch sides alternate in the direction of one stitch row (basic double jersey). Left–left knitwear shows purl stitches on each side. Plain and purl stitches alternate in the direction of a stitch wale (basic left–left). See Table 5.1 for information on mesh structure and formation.

Table 5.1 Mesh Structure and Formation

R: plain mesh L: purl mesh	Mesh structure	Fabric appearance	Realization
Plain fabric			- Structure different on each side - Face: only plain meshes, “V structure” - Back: only purl meshes (“wave structure”) - 1 needle system
			
One-by-one rib knitted fabric			- Structure identical on both sides - Alternating plain- and purl-mesh wales - Plain-mesh wales on the face appear as purl-mesh wales on the back - 2 needle systems
One-by-one rib knitted fabric (interlock)			- Structure identical on both sides - Face and back: only plain meshes - Arrow: adjacent meshes offset by half the mesh height - 2 needle systems
Purl knitted fabric			- Structure identical on both sides - Alternating plain- and purl-mesh courses - 2 needle systems

5.1.2 Loop Formation

Stitch formation will be explained using tongue needles as an example (Fig. 5.4, 1). The needle moves out of its position so that the stitch loop at the hook of the needle glides over the latch on the shaft (2). The thread is then put into the open hook (3), and the needle moves back to its original position. The stitch loop closes the hook by turning the latch, gliding on the latch (4), and moving over the hook (5, "knocking over"). Sinkers support the needle function by holding and guiding the stitches.

Stitch formation with slide and spring needles is similar, the main difference being that the hook of the compound needle has to be closed with a separate slide. The hook of the spring needle is closed by pressing the spring of the hook into the slot in the shaft.

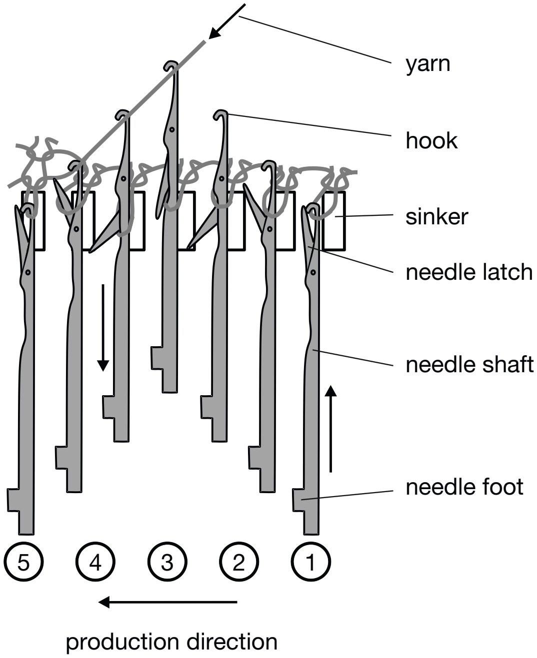
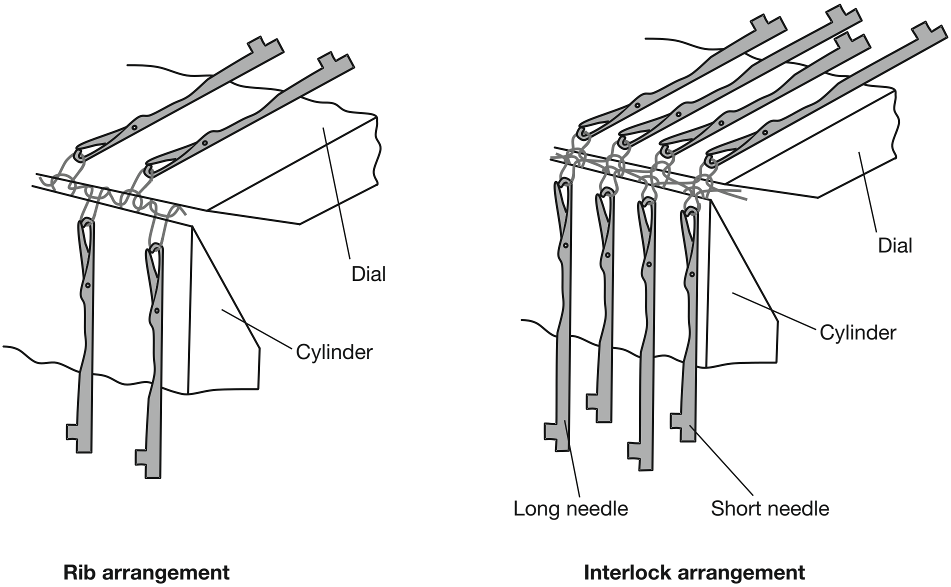


Figure 5.4 Loop formation with latch needle

For the production of plain or purl fabrics, a second needle system is required. Loop formation for one-by-one rib and interlock knittings is shown in Fig. 5.5.



Rib arrangement

Interlock arrangement

Figure 5.5 Needle arrangement and loop formation for plain fabrics

To raise the needles, special parts in the cam box are required. The needle feet are guided in channels inside the cam parts. There are three different cam part types used for forming loops, as shown in Fig. 5.6.

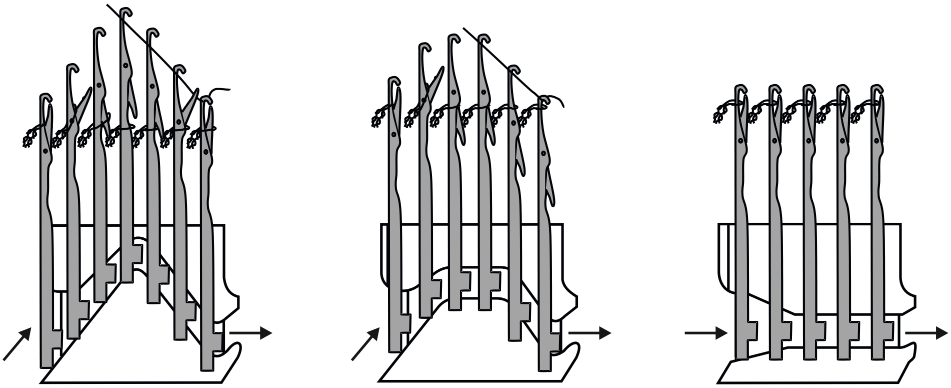
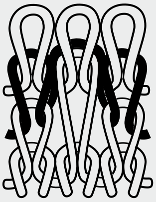
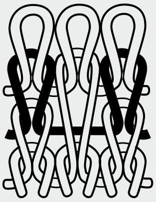
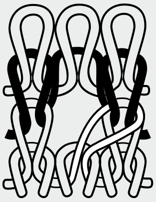
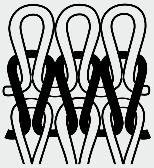


Figure 5.6 Cam part types used to form loops: knit (mesh) (left), tuck (loop) (middle), no knit (float stitch) (right)

In order to produce a simple mesh, cams are required that can raise the needle to its highest point where the actual mesh is formed (knitting). Other cam parts can raise the needle only to a middle position (tuck position), which results in a loop. Other cams do not raise the needle at all and create float stitches.

The main pattern elements are loops and float stitches as shown in Table 5.2.

Table 5.2 Possibilities for Pattern Design in Knitting Machines

Pattern	Realization	Structure
Loop	▪ Meshes are built across one or several courses ▪ Several meshes are close together ▪ Tuck position of the needle	
Floating stitch	▪ Meshes are not built across one or several courses ▪ Thread is floating; meshes of wales are lengthened ▪ Nonknitting position of the needles	
Inclined meshes (Hole pattern)	▪ Relocation of mesh loops within the cam, e. g., to create a hole	
Color pattern	▪ Feeding of colored threads	

5.1.2.1 Jacquard Technique

Realization of the different pattern designs described above is done by using cam parts that are mounted into the cam box. A pattern change is therefore time consuming and expensive because cam parts have to be exchanged. In the Jacquard technique, the movement of each needle is controlled individually, hence allowing an almost limitless number of different patterns. Figure 5.7 shows a typical example.

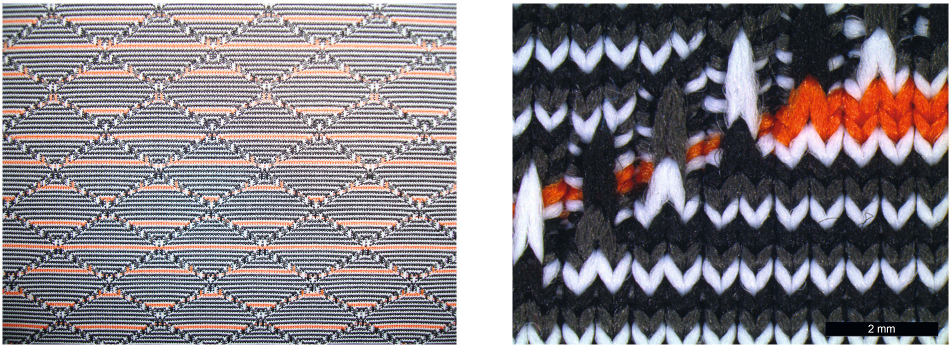


Figure 5.7 Pattern created using jacquard technique: fabric appearance (left), detail (right)

Whereas in the days before computers the patterns were read from punch cards, today the patterns are fed into the Jacquard machine directly from the computer. The information on whether the needle is supposed to pass, tuck, or knit is passed on directly to each needle. All three possibilities are combined in one cam part (Fig. 5.8). The needle foot can be moved out of the guiding channel in two places. In the position “1st selection,” the needle can either remain in the position “pass” or move into “tuck”; in the position “2nd selection,” the needle can either remain in “tuck” or move into “knit.”

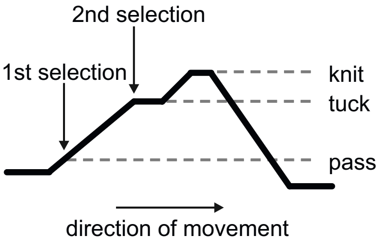
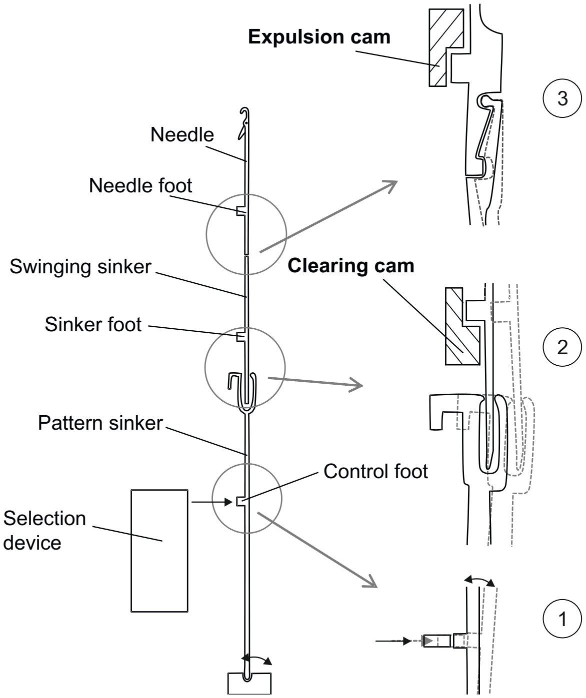


Figure 5.8 Cam part in Jacquard technique

Figure 5.9 shows the different mechanisms in the Jacquard technique. Normally, the needle is in the “knit” position unless its sinker foot is expelled from the cam groove, which causes the needle to either “tuck” or “pass.”



- No expulsion:
  Needle is in knit position
- Cam moves needle back into the circular movement position

- No expulsion:
  Sinker foot is expelled by cam
- If expulsion:
  Sinker foot is in the cam groove and can hence not be expelled

- Presetting of pattern element by selection device
- Depending on pattern:
  Expulsion of control foot by selection device
- Pattern sinker tilts sidewise

Figure 5.9 Needle control in Jacquard technique

5.1.3 Knitting Machines

Knitting machines can be classified into flat-bed and circular machines. They differ in the arrangement of the needles. Whereas in flat-bed knitting machines, the knitting process moves sideways (left to right to left…), in circular knitting machines the knitting process is rotational.

5.1.3.1 Flat-Bed Knitting Machines

Flat-bed knitting machines have four cams in a carriage. During knitting the carriages move over the fixed needle beds. They move the needles back and forth. Thread guides, adjusted to the carriages, provide the thread for the needles. Pairs of rollers pull the finished knit fabric downward to wind up the cloth or to fold it.

The two needle beds of the double-jersey flat-bed machine are arranged at an angle of about 90° to one another (Fig. 5.10, left). The needle beds are arranged horizontally to one another on purl-stitch flat-bed knitting machines so that the cams are directly opposite to one another. This allows the transfer of the double-tongue needles from one needle bed to the other (Fig. 5.10, right). Purl or plain stitches appear in the knit fabric according to the movement direction of the needle. Because double-latch needles do not have a foot, jack selectors move them. Cams in turn move the jack selectors.

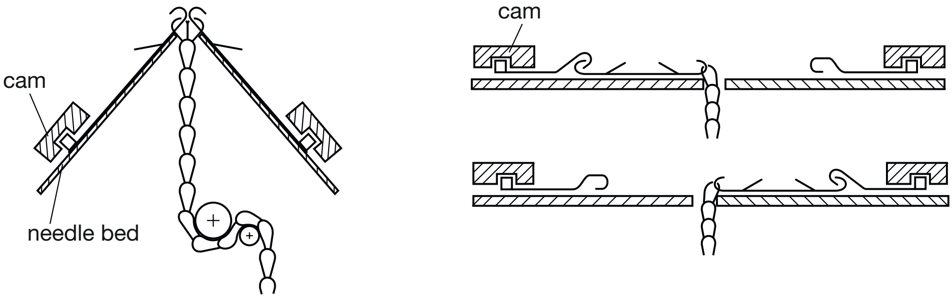


Figure 5.10 Double-jersey (left) and purl-stitch (right) flat-bed knitting (Weber, 2001)

5.1.3.2 Circular Knitting Machines

With circular knitting machines, the knits are always tubular. Depending on the diameter of the knit, small and large circular knitting machines are distinguished. Large circular knitting machines are mainly used to produce flat goods, such as T-shirts and underwear, whereas on small circular knitting machines mainly socks and stockings are manufactured.

In contrast to flat-bed knitting where the needles are raised by movable cams, in circular knitting the cams stand still and the needles move around. The threads are fed through tensioners (“fournisseur”) to keep yarn tension constant. The produced fabric is taken up inside the needle bed cylinder, where the take-up also rotates together with the needle bed (Fig. 5.11).

Circular knitting machines can produce one-by-one knits as well as purl knits (Fig. 5.12). Plain-knitting machines, in addition to the cylinder with the needle beds, have a rib disk, as seen in Fig. 5.5. In this disc, the needles can move radially. During knitting, the disc rotates and the needles then pass along the stationary rip cams.

Machines for purl knits have two rotating cylinders on top of each other. When the needle channels are aligned, needles can change from one cylinder to the other.

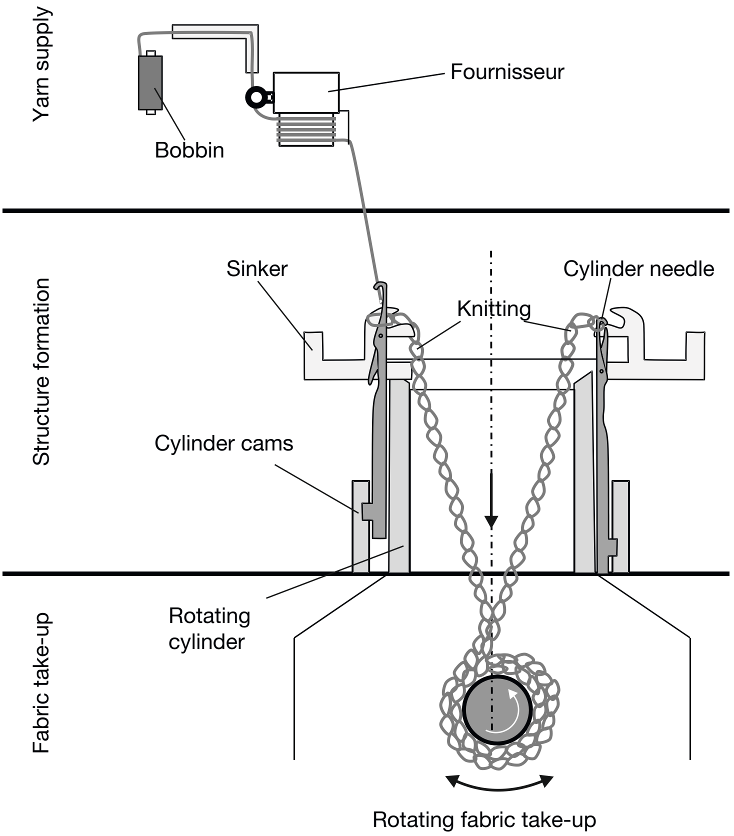


Figure 5.11 Design principle of a circular knitting machine

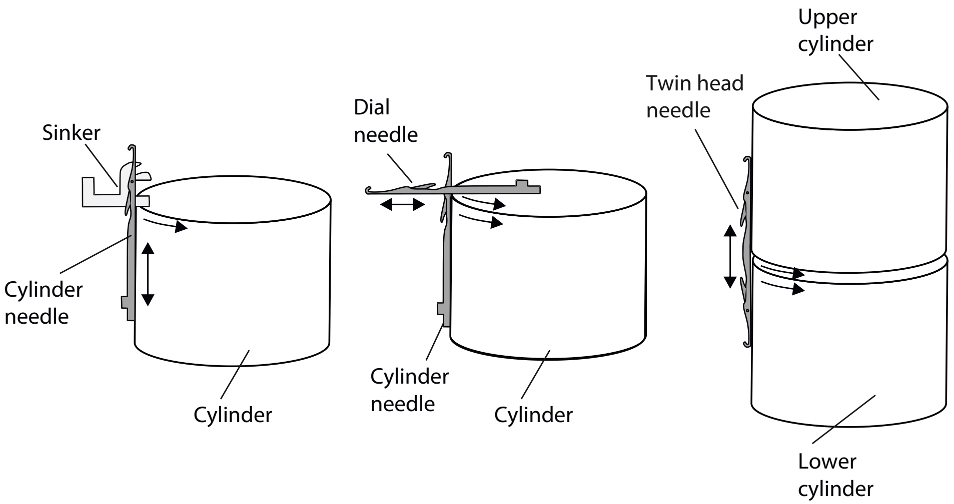


Figure 5.12 Plain, one-by-one, and purl knitting machines

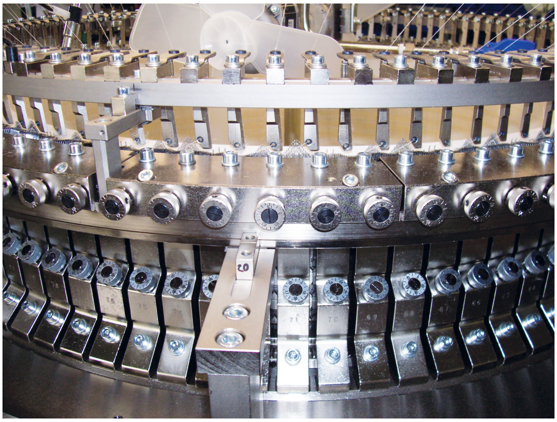


Figure 5.13
Cylinder or a circular knitting machine (Courtesy of Beck)

The threads are fed via a creel that normally is located on top of the machine (Fig. 5.14).

Figure 5.14
Circular knitting machine (Courtesy of Beck)

5.1.3.3 Spacer Knitting Machines

Knitted spacer fabrics are derived from one-by-one knits. They consist of two flat fabrics that are connected via pile yarns. These yarns are elastic to pressure and keep the flat fabrics at a constant distance (Fig. 5.15).

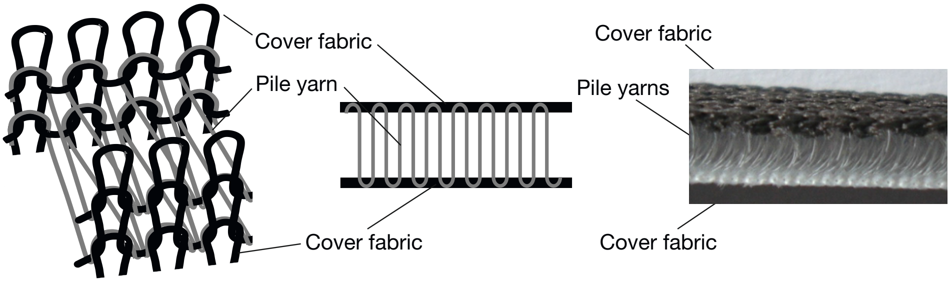


Figure 5.15 Spacer knit fabric from above (left), side view (right) (Sun et al, 2010)

Spacer fabrics can be produced on both flat-bed and circular knitting machines. Between the needle beds (cylinder and rib disc, respectively.), there is a small gap. For the manufacturing of such a structure, three thread systems are required: one for each cover fabric and the pile yarn that connects the fabrics (Fig. 5.16).

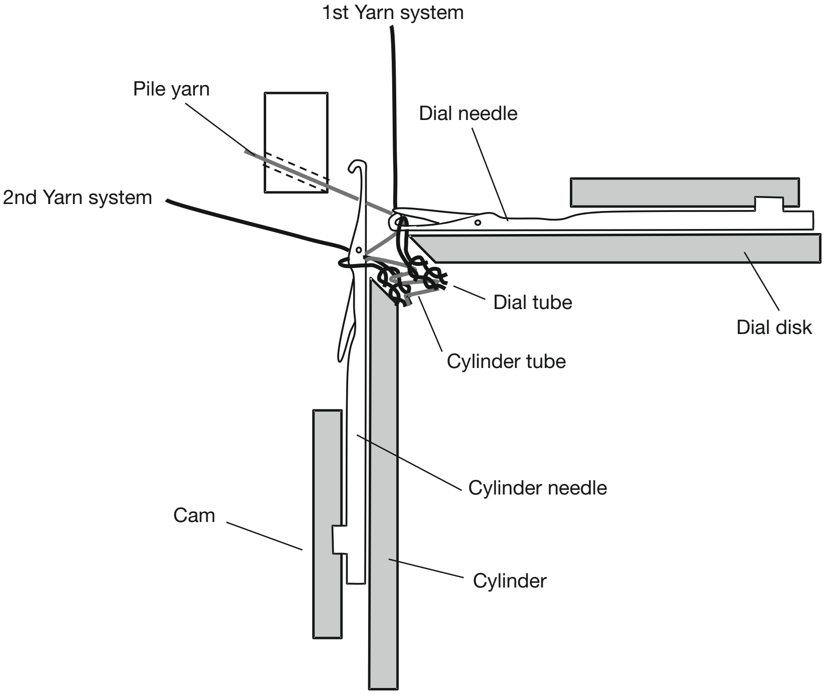


Figure 5.16 Production of a knit spacer fabric on a circular knitting machine

The cover fabrics are knitted independently on separate systems. The pile yarns connect the fabrics via loops and are fully integrated into both structures. The loop formation itself occurs alternatingly via cylinder and rib disc, similar to plain fabrics as described above.

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