CLEANTEX

Clean and Innovative Textiles Strategy for Circular Economy

MODULE 5
Sustainable Yarn, Fabric and Garment/Assembly Production

Unit 5.2
Knitting and Weaving Processes in Circular Economy

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In the Unit 5.2, an overview of existing knitting and weaving processes is presented. Furthermore, monitoring and control of process parameters that can reduce waste, cost and environmental impact, circular weaving in the context of waste management and production efficiency, fully-fashion and seamless/whole garments knitting in the context of waste management and production efficiency are discussed.

Woven fabrics are known since the Palaeolithic era, i.e., more than 25,000 years ago. There is no information on how these Palaeolithic fabrics were manufactured – likely they were manufactured like hand weaving without any looms. The first information which reached us from previous centuries shows that the first weaving looms were vertical as presented in a picture from ancient Egyptian civilization more than 5,000 years ago. Such weaving was really completely waste-less, as all yarns were woven into a fabric and even small ends of yarns were used for manufacture.

Unlike spinning or weaving, knitting does not figure in any ancient myths. The history of knitting is believed to have begun in Egypt in approx. four hundredths of a years of our era. Until the 16th century, knitting in Europe was exclusively male work. Men were the first official knitters, with women granted the role of spinning the yarn and attending to the postproduction process of assembling and finishing the garments. This was particularly evident during the 13th to 16th centuries when knitting guilds were conceived around Europe, particularly in the United Kingdom. Each guild established a distinctive reputation with regard to the quality of knitting it produced. By the 13th century, socks were mostly knitted, initially as flat products with a seam and from the 15th century as circular knitting using five knitting needles. The first mechanical stocking frame knitting machine was invented only in the year 1589 by William Lee (1563-1614) in Nottinghamshire, England. Its principle of operation is still used today in weft knitting machines. At the time of its invention, politicians argued that, if the machine was adopted, the art of hand knitting would be abandoned and converted to the factory system. This thinking continued into the late 18th and early 19th centuries, despite the fact that technological development promised expansion, growth, and prosperity. The stocking frame knitting machine allowed larger quantities of garments and household goods to be produced in shorter periods of time, combined with lower labour costs. Mass production technology grew with the advances of the industrial modern age, including the ongoing creation of machines and the steam engine.

Monitoring and control of process parameters can reduce waste, cost and environmental impact. One of the factors that is controlled during knitting or weaving is yarn consumption. The dimensions of a knitted garment are difficult to control because of its elastic nature. If two garment samples are knitted with the same yarn and structure but have different dimensions, it indicates a difference in the length of the loop or the density of the stitch. In this case, the knitting machine settings need to be adjusted. During the knitting process, yarn consumption can be minimized in knitting by effectively analysing the yarn feed through the computerized system of the knitting machine.

For managing time and yarn waste, it is very important to control possible knitting defects such as broken needle, yarn fly, hole, barre, and thick or thin yarn segments. Barrè means a continuous, visual barred pattern or strap lines parallel to the yarn direction in a knitted fabric. It is usually caused by different tensions of the yarn among feeds. The cause of a fabric hole is a broken needle. The defects of the thick and thin yarns segments directly depend on the quality of the yarn. Defects in a knitted fabric mean that these defected pieces of the fabric will increase the total amount of a knitting waste. In fully-fashion and seamless knitting, such defected pieces usually are disassembled and the yarn is reused for knitting. It helps to reduce the amount of knitting waste significantly.

Everyone thinks of a revolutionary method to minimize the production cost. In the existing garment production system, the cutting and sewing process is mainly labour-oriented. The sewing process may create a needle hole in the sewn product that reduces marketability, and also the stress created at the seam portion will also lead to failure in the garment. Finally, cutting and sewing is a labour-intensive processes that create human error, and then the cutting process creates more fabric wastages. In addition to offering higher comfort and better fit to consumers by eliminating seams, the innovative

seamless knitting technique creates entire garments with minimal intervention of cutting and sewing processes, leading to substantial savings in cost and time, higher productivity, quick response, and just-in-time production. Seamless garments have no waistband or side seam failures. Seamless garments take 30 to 40 % less time to produce than cut-and-sew versions, as they minimize the traditional labour-intensive steps of cutting and sewing. Seamless garment technology is an advancement in the apparel industry that eliminates the fabric laying, cutting, and sewing process. The sewing process may create a needle hole in the sewn product and also the stress created in the seam portion. Thus, seamless knitting eliminates processes that create human errors. Since each garment is produced based on digitally programmed data, item-to-item and batch-to-batch quality even for repeat orders remains consistent.

The biggest attention in weaving modernization in front of sustainability and waste-less manufacturing is given in a non-stopped procedure of weaving when one beam is changed by the similar next one and ends are tied directly in a loom. Furthermore, the ends of the yarns in the bobbins after beam formation could be used for the manufacture of woven fabric as warps. However, not all kinds of warp yarns can be used for wefts; therefore, some amount of waste usually appears in this process. In weaving, minimization of yarn consumption can be achieved by minimizing the length of side weft waste. For example, in the Picanol weaving loom, the EcoFill system is used with the main focus on applications where high-value weft yarns are used. This system helps to eliminate the catch-cord system and reduces filling waste. The next step is to recycle the weft-yarns waste. At the end of the insertion, the filling yarn can be stretched and guided into a suction mouth. The remaining ends of the filling yarn waste are then removed and ready for recycling. Eliminating catch cords, workload for the weaver is the reduced. The AirMaster system allows measurement of air consumption as well as detection of leakage and blockage. The data are measured by the electronic air consumption meter and this makes it possible the following features:

- Continuous measurement of air consumption;
- Fully automatic diagnosis for leakage and clogging detection;
- Management of the length of the filling in order to reduce waste.

Vertical type of weaving looms existed until the beginning of the Middle Ages, when a horizontal loom with warp beam was developed. Ancient vertical weaving looms were really waste-less, as warps and wefts were used up to the very end. Horizontal weaving is not fully waste-less, even in the case of hand looms, as some part of yarns from the beam are not used for fabric weaving – the beginning of warps and the end of warps on a beam cannot be used for weaving. Also, there are ends of wefts left on both sides of a woven fabric. In many cases catch-cords are used which also create additional amount of yarn waste.

The difference between high-tech weaving machines based on airjet or rapier technology in regard of reduced amount of waste is in the principle of wefts insertion. Using rapier of shuttle weaving technology, ends of wefts left on both sides of woven fabric are very short. While in airjet technology, there are relatively long ends of wefts left on both sides of woven fabric, which are cut directly in a weaving loom and it is a pure waste of yarns. Even modern technologies of classical weaving did not fully solve waste problems in weaving. Even more, in modern technologies waste rises not only in weaving looms but also in the process of beam manufacture, as not all yarns from bobbins in a creel are used for beam manufacturing. Therefore, we cannot say that modern weaving is fully waste-less and sustainable. In order to reduce the amount of warp yarn waste, bobbins of higher mass and with higher length of yarns on them are used for warp beam formation. In this way, it is possible to reduce the number of bobbins with residue of yarns left after beam formation.

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most waste-less and sustainable weaving is circular weaving when woven fabric is manufactured like a circle tube directly from a creel, that is, a warp beam is not used, and it helps to reduce waste of yarns used for warps. In addition, in this mode of weaving it is possible to avoid the waste of weft yarn ends. It is necessary to mention that such kind of looms is used only for very narrow technical application - for sacks, for tube reinforcements and other kind of technical fabrics. The amount of such kinds of fabrics is less than 1% of all woven fabrics in the world.

Knitwear can be produced using three methods:

1. Traditional: cut-and-sew;
2. Fully-fashion: knit to shape-and-sew;
3. Seamless.

Typically, a knitted garment consists of separate parts: the front and back body panels, and the sleeves, which are sewn together afterward. It requires highly skilled sewing labour. The cut-and-sew method involves knitting a panel fabric, cutting out the garment pattern, and then sewing. Cut-and-sew produces the most waste as compared to the other two. The amount of fabric waste can even be up to 30%. The knit-to-form or fully-fashion method involves knitting the garment panels to the exact shape required for construction. The highest amount of fabric waste in this case is 3 to 9 %, depending on the technical possibilities of the knitting machine and the complexity of the shape of the panel. Seamless knitting was developed to achieve more efficient and less costly production, that is, to be able to cut down on the costs for cutting and sewing when making knitted garments. It was also developed because of the functionality, no seams in small, narrow items such as gloves. Technical waste using this method is less than 3%, usually ends of yarns.

The high amount of waste in the traditional clothing industry is a big problem, and it can be solved by using fully fashion and seamless knitting technology. However, this technology requires automated and computer controlled knitting machines. The fully-fashion knitting of regular details and seamless knitting technology shortens the manufacturing process and significantly reduces material waste. A new way of making garments also opens up new ways of thinking, which may lead to new expressions. This technology allows to get fully-fashioned panels of garment that do not require cutting operations or cutting is used only for small corrections, such as shape of neckholes and armholes being taken during the knitting process. The knitted panels usually have all necessary parts – pockets, buttonholes, even collars, which are also knitted during the same knitting process. Additionally, fully-fashioned knitted panels can be unknitted if some knitting defects appear, and these yarns can be used for knitting repeatedly. However, only part of the seams is eliminated; cutting operation is still required to trim the fabric area outside of the garment panels, and sewing is needed to join components together into a garment.

Panels, knitted with fully-fashion knitting technology, commonly are connected to each other through locking courses, as the main problem in complete garment knitting is fabric take-up realization. Locking courses are knitted using different yarns from those used for the main part knitting, and they are mostly cheaper than the main yarns. The locking courses helps to avoid take-up of the first courses of each panel and, what is also very important, protect the knit from unstitching after detachment of two adjacent panels. Detachment is very easy to perform by pulling a yarn out of the locking courses, which is bent into much longer loops than the loops in the main part of the panel.

Several knitting parameters can affect the dimensions, appearance, tensile properties, and tactile comfort of a garment. These include combinations of stitch types, loop formation, yarn types, machine settings, and design processes. The shape of the fully-fashion knitted pieces can be changed in different ways. For instance, different knitting patterns can be combined in one panel. Usually such a combination includes patterns with the same number of wales but different effects on vertical and horizontal dimensions. Additionally, yarns with different linear density or yarn diameter can be used for different parts of the same knitted panel. It also can significantly change the width of the piece. Different loop lengths and different widths of a panel can be obtained by using multigauge flat weft-

knitting machines. Also, loop transfer from needles to needles allows to get interesting design as well as to change dimensions of a panel. Fully fashioned garments can be developed through knitting technology by widening or narrowing the fabric, i.e., by doing the loop transfer. In addition, the exact required shape of the knitted panel can be obtained by changing the number of knitting needles. If new needles are added to the knitting zone (i.e., for widening), a yarn can be simply laid on the newly added needle, or some group of the loops can be transferred onto the adjacent needles. To narrow the panel, one loop or group of the loops are transferred onto the adjacent needles and knitted together with the loops that were knitted on the recipient needles.

Each fully-fashioned panel of the garment can be knitted on separate knitting machines, or all panels of the garment can be knitted on the same knitting machine. However, the first method is usually used. After knitting, all panels are sewn together into one garment. Cutting operation is not needed, or it is used only for small corrections, for example, to correct the neckline. Therefore, the fully-fashion method ensures a much lower amount of fabric and yarn waste, as a well as lower energy and manpower consumption.

Seamless / whole garments knitting ensures the best waste management and production efficiency. Seemless knitwear is produced in one entire piece, three-dimensionally, directly on the knitting machine. Seamless garment technology is an advancement in the apparel industry that eliminates the fabric laying, cutting, and sewing process. Ultimately, we can minimize the production cost as well as production time by 40 % compared to the existing traditional apparel production system. In addition to that, a seamless garment gives more comfort because it does not have a seam in its structure, even though the sleeve and neckline of the garment could be joined by sewing. The dimension of seamless knitting creates clean shoulder lines and produces a garment that is better suited to the shape of the body. In addition, eliminating the seams under the arms also eliminates the bulky discomfort of typical sewn knitwear. Although knitted necklines and collars create a sophisticated look of a garment.

Seamless knitting technology brings an innovative concept in clothing manufacturing and enables to have:

- Different pattern structures in different areas. For example, a jersey knit can be placed side-by-side with a mesh knit, which can be placed side-by-side with a rib or jacquard knit, with an embroider-like logo.
- Different kind of yarns in different areas.
- Better and wider range of fit.
- Freedom of movement and comfort.
- Custom apparel at a good cost.

The fully-fashion and seamless nature of knitting also ensures continuity of the fabric, allowing functional yarns such as those made from conductive fibres to wrap around the entire body without interruption for applications in smart garments and wearable technology. Previously, seamless garment manufacturing was limited to underwear. Due to the unlimited pattern possibilities, seamless technology is now being employed to manufacture very exclusive outwear, compression garments, and garments for sportswear. Also, the seamless technology is being used for protective garments, maternity care & support care garments. Innovative warp-knitted garments can also be produced in a single sequence, without any seams. They can be used in functional sportswear, underwear, hosiery, and fashionable outerwear.

New technologies have unique advantages, both commercial and economical. Seamless knitting benefits everyone - designers, manufacturers, and consumers. It gives:

- Freedom of body movement. Generally, the seam portion of any garment does not have the same elasticity as the body fabric, so the difference in elasticity will affect the movement of the free body. Since the seamless garment does not have any seam in its structure, this problem has been eliminated.

- Inherent softness. There are no bulky and annoying stitches at the underarm, shoulders, and neck lines, which may cause irritation to the wearer, since the garment having a seam-free structure provides the soft feel only.
- Seamless garment technology creates new design possibilities and diverse design structures.

Seemless knitting caused a supply chain revolution in a knitwear manufacturing. This technology improved planning accuracy and efficiency through the use of virtual samples, minimized post-processing, and reduced lead time. Bottlenecks in the supply chain, caused by labour-intensive cutting and sewing processes, is eliminated. Seamless knitting enabled pre-sale events to forecast demand and also quick response to support mid-season production and customization. Optimized inventory prevents leftover stock. Seamless knitting ensures earth-friendly manufacturing by using minimal resources.

Beyond comfort, seamless garments are also sustainable. The following sustainable advantages we can find from seamless technology:

- Reduced labour cost: Due to the elimination of cutting and sewing processes, it is obvious that reducing more labour involvement is necessary.
- Minimum yarn consumption: Most of the fabric wastage occurs in the cutting stage. Since seamless garment excludes this process, the fabric consumption per garment is less, so the yarn consumption is also very low.
- Smaller work space: As the number of sewing operations is less, except for a few cases in the garment production system, it leads to a smaller space requirement.
- Reduced yarn and fabric inventory: The cutting and sewing process requires more fabric and yarn inventory. Due to the absence of this process, there is no need to maintain a large inventory.
- Quick sampling: Sampling is a costly and time-consuming process because a small portion of fabric and accessories must be prepared.
- Fewer product failures: Most garment failures are due to seam failure. The seamless garment does not have seams, thus garment failure is also very less.
- Less cost of production: This leads to savings in production costs of up to 40% compared to the customary garment production system.
- Just-in-time production: Just-in-time production is possible with the help of seamless technology.

Seemless knitwear, in addition to the well fit and comfort, have sustainable benefits of knitwear that consumes only the material required to produce a single garment. Since Shima Seiki developed Wholegarment® and Stoll developed Knit-and-wear technology, it is possible to start the production process with a yarn and end up with a garment without cutting or sewing. Seamless knitting can also be described as more ethical than alternative technology, as it minimizes the need for manual labour.

Looking back, when seamless knitting technology was first launched, it was mainly used on synthetic materials. With continuous upgrades to the technology, it can now be applied to an even wider range of fibres, especially expensive. With this seamless knitting technology, consumers can enjoy a more natural feeling when wearing clothing made from more expensive natural and renewable fibres.

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