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Research Article

Evolution of Weft Knitted Fabric Design: Seamless Knitwear Production Technology

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Abstract

In the present scenario, it is essential to develop new products and alter the existing ones to meet the often-changing requirements of consumer. New product development is the replacement that is significantly different from existing product in terms of forms, function and most important- benefits provided. In this direction, seamless knitted garments and its products contributes significantly by increasing the functional suitability by eliminating the additional processes. The most flexible 3D fabric and garment production technology is knitting, because of principle, needle/stitch selection and control of individual yarn feed the entire garment is produced from knitting machine without seam. These seamless garments have manufactured in basic knitting machine with and without changes in normal knitting cycle. The principle adopted for development of 3D concepts evolved from 2D fabric manufacturing techniques in weft knitting. The technology adopted for the manufacturing of seamless garments considered as sustainable practice due to the reduction of time consumption, waste generation through various process and man power cost involved per garment. Virtual simulation of knit samples integrated in advanced knitting machine reduces the production and displaying of actual samples. Through the patterning techniques adopted in weft knitting machine, the developed flat patterns are used to construct the 3D shaped products.

Keywords

Seamless knitwear, Fabric design, Weft knitting, Circular knitting, Flat knitting, shaping techniques, 3D knitting

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Introduction

The intermeshing of loops of yarn referred to as knitting, the number of loops or stitches counted in horizontal direction in the fabric swatch, which are formed by individual needle in a machine, is wales. The number of loops or stitches counted in vertical direction in the fabric swatch, which are formed by the individual feeder in a machine, is course. Based on the principle of loop formation the knitting has categorized in to weft knitting and warp knitting. The knitted fabric properties and its flexibility of the nature, knitted fabric are mostly used for the outerwear and intimate wear application. The various production methods of knitted products from the fabric are discussed in this chapter. There are special techniques, which reduce the yarn consumption per garment, waste reduction and less production time compared to other manufacturing techniques. The special kinds of knitted garments that are nor sewing for the assembly of the garment components but produced by "one step molding garment' called as seamless garments. The knitted socks, hoses, gloves, berets are produced without any seams to form the shape of the wearer contour by satisfying the comfort to the human body. These seamless knitted products are produced in weft as well as warp knitting. In weft knitting different techniques are adopted for the evolution of seamless garment production by reducing the resources such as raw materials and production time. The Table 1 shows the step-by-step historic development in seamless knitting.

Table 1
Historical developments for the contribution of seamless knitting (Choi & Powell, 2005)

S. No.	Year	Historical Developments in Knitting
1.	1589	The first flat-bed frame invented by William Lee in England to create hosiery.
2.	1800	The tubular single jersey knitted products such as socks, gloves etc., produced in sinker fitted flat knitting machine.
3.	1863	The first operational flat knitting machine (V-bed) was invented by Issac W. Lamb.
4.	1864	William cotton of Loughborough secured a patented for his rotary-driven machine. The fully-fashioned garments produced from this steam-powered knitting machine.
5.	1940	The shaped knitted skirts manufactured using "flechage" technique. This technique was patented in USA.
6.	1955	The traditional berets knitted automatically based on shaped sections, reported by The Hoisery Trade Journal
7.	1955	The entire- seamless garment knitting introduced by Shima Seki at ITMA
8.	1960	Further Shima seiki explored knitted product- gloves (tubular type) commercially.
9.	1960	British patent established by Courtaulds on the idea of joining tubular knitting for the production of knitted garment.
10.	1995	The introduction of Seamless garment knitting machine by Shima seiki at ITMA.

Weft Knitting

There are two types of knitting recognized within the weft knitting such as circular knitting and flat knitting. In each of the knitting, the required feed material such as yarn package and sheet of yarn in beam consists of less preparatory processes as compared to woven fabric manufacturing principle. The both knitting machine produces verity of fabrics that can be used for wider applications. There is very less preparatory processes required for weft knitting. The most common base structures produced in weft knitting are single jersey, rib, interlock and purl. The fabrics produced from these machines are in open width form or tubular form, which can be used for further processes to make clothing and other fashion products (Power, 2008)

Circular Knitting Technology

The circular knitting machine produces a continuous knitted fabric in tubular form. If the fabric

produced from the machine wants to be not tubular, the fabric may be cut during take down from the knitting zone and wind the fabric in open width form. So, the reduction of process time leads higher productivity. However, most of the knitting machine winds the tubular form fabrics. The circular knitting machine runs at high-speed, cost-effective production method for bulk production at continuous length of fabric. The patterning mechanism in the circular knitting machine diversity of structures developed from base fabrics – single jersey, rib, interlock and purl (Power, 2008)The size of the design based on capacity of the needle selection mechanism. The seamless garment produced from circular form machine has unique application. In seamless knitting the fabric can't be cut, the fabric with various diameter prepared in knitting process. The narrow width and thin knitted fabrics produced in small diameter cylinder machine, so the rate of production gets reduced and increased production cost. The seamless circular knitting machine having with fine gauge lately been manufactured, these machines are suitable for the knitted fabrics selling cost is higher (Semnani, 2011)

Flat Knitting Technology

The production of the open width knitted fabric, most versatile and efficient patterning in a fabric achieved in flat knitting techniques. The 2D and 3D shaping panels are produced for smaller scale productivity (Kovar, Sirotkin, & Lord, 2011)Due to less removal of short fibers, in yarn manufacturing process achieves coarser yarn. The coarser yarn is very much suitable for flat knitting machine. The coarser gauge of flat kitting receives lower yarn fineness when compared to circular knitting. The directionally oriented threads as in vertical and horizontal stationary thread (inlay yarn) can be integrated in to the flat knitted fabric during manufacturing in knitting. The flat bed knitting machine categorized as hand-propelled and hand-manipulated models automated, electronically- controlled, power driven machines. (Eichhoff, Hehl, Jockenhoevel, & Gries, 2013)

Knitted Garment – Production Methods

The unique feature of the knitted garments produced from knitted fabrics varies based on the production method adopted for the development of the garment. The reduction of man power, raw material, investment of time and reuse of rejected/defected material is varying for each production method, All the knitted garments can be classified as any one of following categories.

- Cut and sew/fully cut method
- Stitch shaping/stitch shaped cut
- Fully fashioned
- Integral garment and
- Seamless garment

Cut And Sew

The evolution of the seamless knitted garment production starts from the cut and sewn process. The components of a garment such as front, back, sleeve, pocket and trimmings are developed in cutting process as per the measurements with other allowances before sewn process. (Choi & Powell, 2005). The wide range of different types of garments manufactured through fully cut garments technique, the garments include underwear category from men, women and children, sportswear, swimwear and leisure wear. The figure 1 shows the layout of fully cut method of garment production.

The marker planners measure their success by the utilization of the marker plan created. The effective use of proper marker plan reduces the weight of fabric consumption per garment, at the same time increase the utilization of knitted fabric. A formula describes this: Marker Utilization = Area of patterns in the marker plan/ Total area of the marker (Han et al., 2017)

Advantages of Fully Cut And Sewn

- The fabric produced with low cost and high speed.
- Labor required for the fabric production also is less.
- Opportunity for scale of production particularly shows benefits at the time of cutting stage.

- Waste produced from cutting can used for other applications such as floor covering – floor matt etc.,
- For simple style of knitted garment, higher production can achieve.

Disadvantages of Fully Cut And Sewn

- Comparatively the waste generation is high even with garment having small components ranges between 17% to 50% occurred. This is a significant cost burden on the garment's producers.

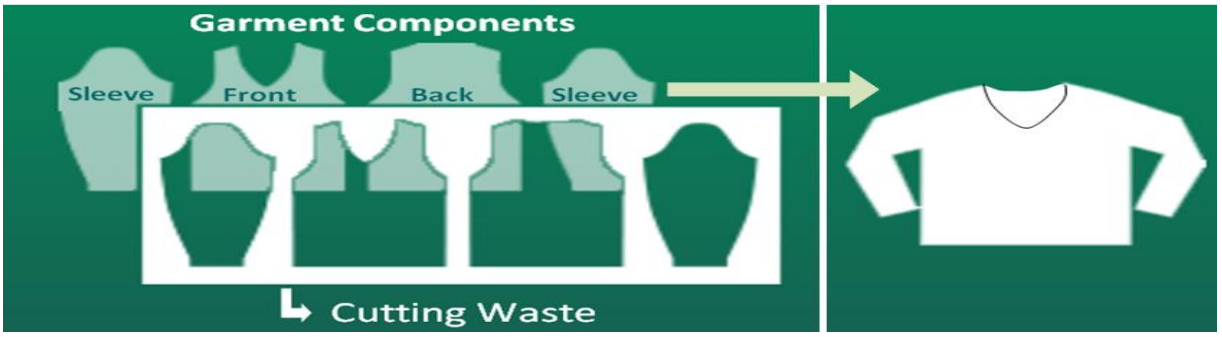


Figure 1. Cut and Sew garment production process (Source: www.shimaseiki.com)

- Higher cost incurred for labour in assembly of the garment.
- It requires longer lead time for garment production.

Stitch Shaping

The term "stitch shaped" derives from various stitches in a designed structure within the garment component length of the knitted blank that distort it from its original shape (usually rectangle) into a shape associated with the human body. The stitch shaping involves selvedge knitted fabric or tubular knitted fabric. Commonly such shaping involved in the production of rib, waistbands and sleeve cuffs that restrict the lower boundary of the garment but are extensible. These shape generation achieved without altering or distributing the total needles that present in the machine. The assembly process for these components are reduced, so this type of garment production requires less raw material, time, floor space per garment compared to fully cut production technique. The figure 2 shows the various rib structures involves for shape to the components or blank.

This technique is often used for the knitwear shaping sequences in jersey wear and underwear. This kind of shaping is simpler and faster method than fashioning. Most cut stitch shaped garments are upper body garments – men's, ladies & children's garments (Jumpers, slipovers, cardigans, jackets and waistcoats). The most popular neck opening shape for the knitted garment styles includes turtleneck, round neck, v-neck, and high/mock neck. The ribbing stripes were used for the outer garment as facing and binding to the garment like cardigans. The ribbing can be used

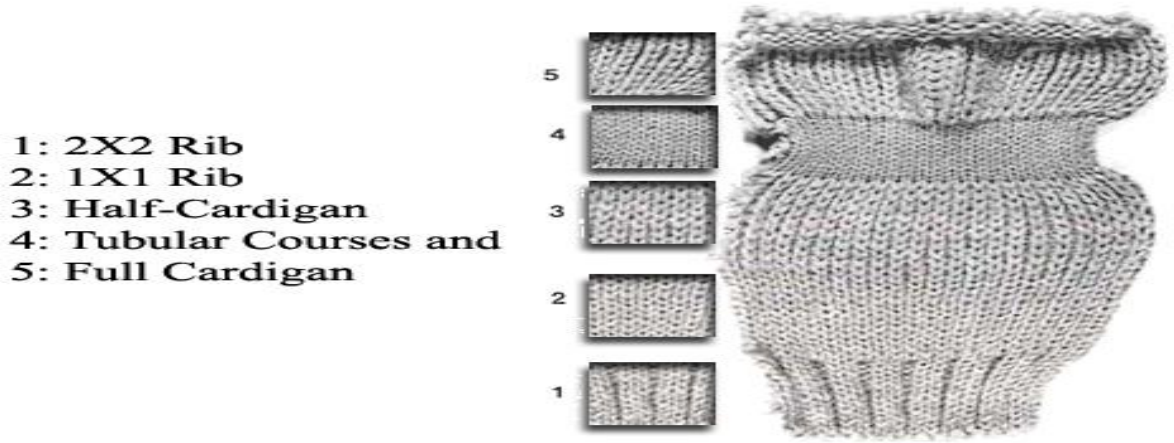


Figure 2. Stitch shaping Technique (David J Spencer: 2001)

for frills to the garment components during linking and seaming process as style required. (Spencer, 2001)

Advantages of Stitch Shaped Cut Knitting

- In stitch shaped cut technique of component production, the produced components/blanks require minimal preparation for seaming, reduces waste generation.
- The cutting of blanks involves in length and occasionally for width direction. To achieve neck holes, lower arms and for shoulder shaping minimum cutting is required.
- The process of cutting of garment components has still carried out by using hand shears as individual component or doubled or multiple component pieces.
- Cutting with standard size were done by template press cutters, in which eight blanks of knitted component can cut at a time.
- It requires less labor-intensive work in cutting process. So, labor cost per piece has reduced.
- During production low wastage of fabric is achieved about 10% to 20%.

Disadvantage of Stitch Shaped Cut Knitting

- The stitch shaped knitted blank achieved by involving of different stitches in its structure. This shaping generates definite stepped effect in its edges rather than a smooth edge shaping of fashioning.
- The linking machine required for the assembly of blank, which is with respect to gauge limitations.
- The production of each blank is based on shaping concepts, so required skilled labor.

Fully Fashioned

In working width of the knitted fabric, the progressive fashioning involves with increasing or decreasing of loops such narrowing and widening of loops in its direction produces the shape to the component of a garment that would otherwise be generated by cutting process. The figure 3 shows the progressive fashioning of panels in a garment. The production of garment components blank requires less cutting process (sometimes nil cutting based on style) due to fashioning. Some of the components knitted with fully fashioning concepts, in which single yarn is used for the formation of whole component. So, reuse of full length of yarn also possible. In fully fashioned knitwear garment manufacturing, the sequence of making up process takes place in two different stages such as rough making-up and finished/final making up.

- The fully fashioning of shaping involves the movement/displacement of a small number of loops at the selvedge of component the fabric. The selvedge in the knitted components reduces yarn fringes at the edges, so damages of yarn also reduced. Such movement of loops at the edges reduces or increases the total number of loops in its course being knitted to form a final course, in industry termed as fashioning.
- The pre-shaped custom knitted clothing produced from fully-fashioned flat or circular knitting machines. The punch card or computerized numerical data enables the selection of needles to add stitches or drop stitches to create a desired shaped knitted fabric.

Advantage of Fully-Fashioned Knitting

- Relatively no waste generation. Some garment required minimum cutting process.
- The components of garment edges knitted with sealed stitches and not liable to fraying.
- The components can be assembled by simple seam and also non-bulky seams.
- Due to fashioning number of assembly process reduced. This provides benefits to manufacturers.
- Single panel garment also produced with narrowing and widening with little assembly.
- Reuse of yarn from the whole knitted panel also possible. So reduction raw material cost.

Disadvantage of Fully-Fashioned Knitting

- The production of each panel in a garment is based on fashioning concepts, so required skilled labor. It leads more labor cost.
- The linking machine required for the assembly of garment components, which is with respect to gauge limitations.

Integral Garment

The integration of all garment components with trimmings, accessories and buttonholes for the production of garment in knitting machine termed as integral knitting. It enhances the appearance of the garment. The fully-fashioned garments were knitted as shaped components and still sewn together to make a complete garment. Whereas, integral garment knitting enables the making of 3D garment by the assembling of fully-fashioned garment components in knitting. The one piece integrally knitted garments like socks or half hose, glove, beret etc without any uncomfortable or little seam.

Advantages of Integral Knitting

- Garment components assembled in the process of knitting itself, so the garments have no joint/seam.
- The reduction of material by elimination of seam allowances. The waste generated during the production of garment is less compared to cut and sewn.
- Labor involved to make the garment also decreases the cost.
- The entire garment produced with single knitting process.
- The 3D knitted garment generated and developed with round shape.

Disadvantages of Integral Knitting

- The limited or known garments only produced from integral garment production technique without seam. The shaped garment such as swimwear and sportswear cannot make with this technique.
- The size variation with shaped garment is not possible in tubular garment production, the caps and gloves can produce with approximate shape that allows stretching to ensure required fit.
- The one size of garment only produced at a time, which cannot cut and shape in different size.

Seamless Garment Knitting

A complete garment is developed from circular or flat knitting machine with several carriers/feeders. The seamless garment knitting principle consists of no cutting or minimal cutting and sewing processes. The figure 4 represents the major steps involved in seamless garment production. The seamless garment termed as Knit and Wear® and whole garment® and complete garment. Most of the seamless garments entire components are knitted with continuous yarn, which prevents all waste generation during manufacturing such as cutting waste, allowances for cutting and ease allowances etc.,(Padaki, Alagirusamy, & Sugun, 2006)

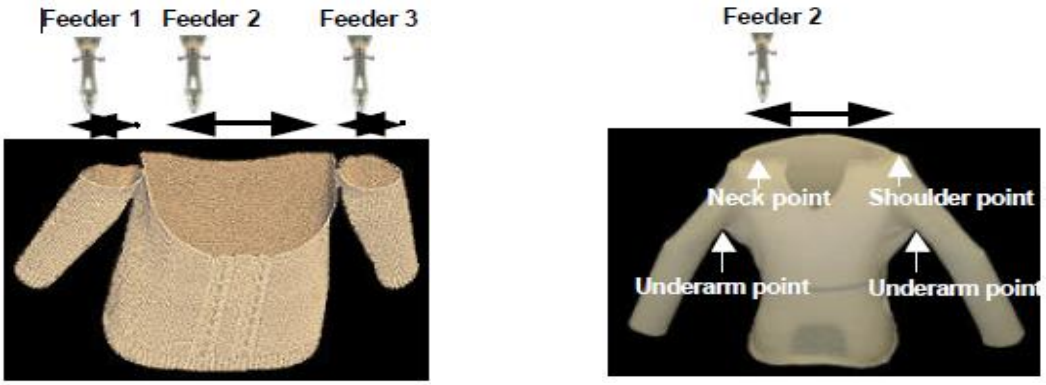
Figure 3. Fully fashioned Progressive Shaping Technique

The knitwear garment components such as front, back bodies and sleeve are produced as one complete part, as a three-dimensional garment on the knitting machine is called seamless garment. The whole garment knitwear is suitable for the applications outside the fashion field, such as sports textile, medical textile, and other examples of E-textiles as wearable smart technology. The "second skin" called as seam-free clothing has the merits of perfect fit and comfortable to the wearer,

produced as sustainable and ideal knitwear. (www.shimaseiki.com).

Advantages of Seamless Knitting

1. *Enhanced aesthetic feels and comfort:* The multi gauge gauge knitting provides more aesthetic garment. Improve aesthetic value, better look, better fit and more comfortable. As there are no bulky and irritating stitches/seams in the garment, overall, the appearance of a garment is enhanced. Also, there is no more problems developed due to making problems such as puckered seam, wrong patterns, and problems related to fitting. However, the discomfort felt due to the seam in clothing, this kind of problem is rectified in seamless garments. Seamless garments developed with limited trims and accessories interms of fasteners such as buttons, zippers and hooks. These garments have superior comfort, smoothness and sleek fit, which increase the benefit of easy wearing for the wearer. Better trimmability for the finished edge lines. There is more possibilities available for fabric design creation to knitwear designers in developing ventilated engineered fabric production. The garment produced from seamless concepts provides freedom of body movement (Nawaz & Nayak, 2015)
2. *Cost reduction:* The garment production involves many processes in other techniques like raw material inspection (fabric), spreading, cutting, assembly of components, storing etc. these processes are not there in seamless technique, there is reduction of cost incurred in labor, production per floor space, machine cost, power, etc. The time taken for making of seamless garments is less than a cut-and sew version, thus minimizing cost and time. The new kind of whole knitwear production requires highly skilled labor to operate garment machines or even be too complicated the process to sew. The seamless garment technique reduces the cost involved in these processes. No linking machine and seaming machine processes required and for the investment.
3. *Waste reduction:* The preparatory process for the manufacturing of garment such as spreading, cutting and assembly processes is not required, which shows the reduction of waste generation through saving of fabric and other raw materials. In addition to fabric saving the yarn consumption for the joining of components also saved through effective digital stitch control system (DSCS) in computerized knitting machine. So, there is quick-response production for size and pattern changes, provides higher productivity.
4. *Time saving (lower lead-time):* Just-in-time production. By elimination of various preparatory processes in garment manufacturing, leads reduction of time consumption. The manufacturer is saving time by eliminating the dependent sourcing of various accessories required for garment. As these processes are not required in seamless garment production.
5. *Flexible production:* Any type of yarn can be used in seamless knitting machine to produce garment with multi gauge concepts. The manufacturer and designer may develop the garment with the blend of the wearer shape and patterning scope. The garment produced with these blends have better design and comfort to the wearer. The concepts of multi gauge in one machine is possible in seamless knitting machine. So, there is a elimination of duplicating the same machine by investing the money. More over the versatile nature of seamless knitting



(a) Knitting three separate tubes by separate feeders

(b)Shaping of the shoulder and 3D garment

Figure 4. Steps in seamless garment production (Wonseok Choi & Nancy B Powell:2005)

wide range of apparels used in sports wear, underwear, sleepwear, ready to wear, leisure wear and shape wear are produced. It can be adopted or Mass customization.

6. *Durability:* The seamless garments manufactured without seam so, the frayed edges and breakages due to weak threads in sewing process are eliminated. Which leads long-lasting garments.
7. *Quality:* Due to reduction of preparatory processes, the defects occurred in such process and causes for the particular garment defect in preparatory process are nil. The garment produced with seamless concepts, reduces sewing defects due to process and raw materials. The garment edges are perfectly sealed. The quality of the garment maintained same for all such kind of garments. More constant apparel quality can be achieved. Generally the garments are Lightness and softness in feel.

Production Conscious of Seamless Knitting

- Some of the garment shape/style produced from seamless knitting requires partial cutting and sewing process. Fabric drawn from knitting zone has to wind in take up mechanisms with equal tension, leads reduction of fabric faults.
- Based on the garment style/trims used during production in seamless garment principle, the cost of the garment various.
- During knitting of whole garment, if any fault occurs the produced garment can be reused by unraveling of yarn because entire panel is knitting with continuous yarn. (Choi & Powell, 2005)
- In multi gauge needle selection the fabric produced with coarser gauge (alternate needle selection) appears more open and lesser elastic. According the machine can be selected for end use.
- The skilled operators required to operate the machine.

Fashioning

For developing fully-fashioned garments and seamless or integral knit garments, various shaping techniques are necessary. For fashioning in knitted components requires following fashioning elements. Based on the selection of the elements the smoothness of progressive fashioning varied. The fashioning elements are:

- Number of fashioning
- Frequency of fashioning (course)
- Number of loop fashioning (loop or needle)

To achieve a specific shaped component, the knitting technician should design the extent of the needle movement and the frequency of needle movement. The extent of needle movement and the frequency of needle movement will vary according to the shaping required. The number of loop fashioning may be the action of single-needle, two-needle, or more-needle transfer. And the frequency of needle movement is how often the action occurs, such as how many courses between one fashioning and the next.

Basic Shaping Techniques

The reduction of cutting process and assembly process in normal sequence of knitted garment manufacturing achieved due to shaping techniques. The basic shaping techniques are used for the above-mentioned garment productions. The fashioning elements involved in shaping of panels by means of various shaping techniques such as:

- Shaping by course fashioning
- Shaping by wale fashioning
- Body width/tubular knitting
- Running-on (picking up)
- Shaping by stitches (change of stitch type)
- Casting-off (knitting off).

Course Shaping

The principle of course shaping is the length of the blank is diminished or extended through successive knitted courses. The course shaping can occur on either side, both sides and indeed partial courses can be produced anywhere on the width being knitted. During course shaping process, in most of the cases the produced wales throughout the knitting is unaltered. There are two alternative methods for the construction of course shaping.

- First method (Figure 5 a) the total number of loops knitted in the sequence is diminishes in every row appears smoother unstopped line, but more than one loops diminishes in its course length develops small floats.
- Second method (Figure 5 b) the reduction/ diminishes of course in every two rows no floats occurs but the technique develops some steps and small holes can result when knitting commences on all wales.

Wale Fashioning- Shaping

The principle of wale shaping is the number of wales knitting is diminished or increased within the component internally as flat piece of fabric or a tube of knitting by keeping the constant number of courses. (Figure 6).

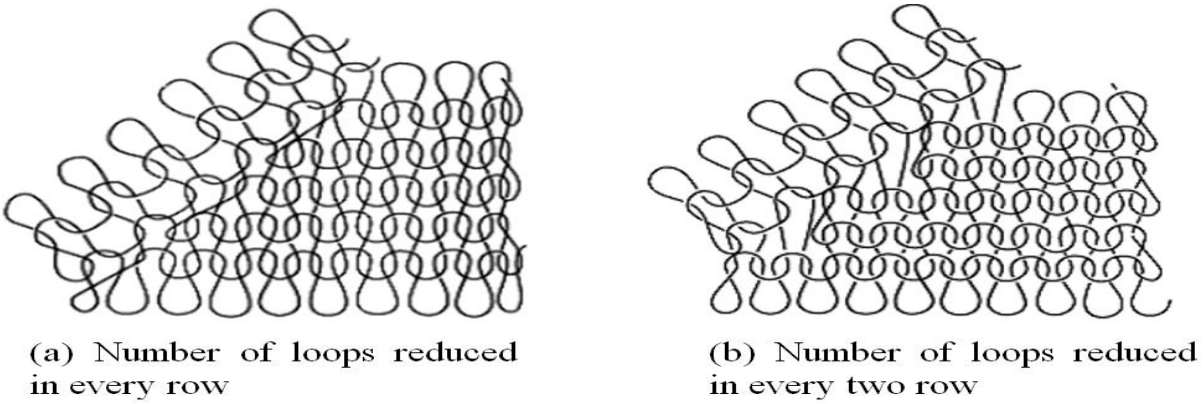


Figure 5. Course shaping (Terry Brackenbury:1992)

Tubular Knitting

The tubular form of component is created by knitting the constituent threads knit spirally. The produced tubes are useful for clothing. The human body covered by the garments produced by integrating the various knitted tubes.

Running-on/ Picking-Up

The process of placing the course loops or selvedge loops on to the needles of a knitting machine. Further continuing of new knitting is commenced on already/previously formed knitted fabric.

Change of Stitch Type

The change of fabric design type between adjacent portions of a garment component can generate shape such shape can be done in horizontally, vertically or otherwise any direction to the garment.

Castin- off/Knitting off

The process of the knitted component edges sealed at the last knitted course of a piece of fabric. This is only for hand knitting or hand operated knitting machine. Shimaseiki introduced this in their machine.

Wale Fashioning

Wale fashioning is a common manner of shaping by narrowing and widening, which involves the transfer of knitted loops from one needle in a bed to another needle within the same needle bed but with the help of the other needle bed. Wale fashioning can occur in plain structure fabrics, as well as in rib structure fabrics. First the courses are knitting at the beginning. When loops are transferred to an empty selvedge needle, they begin knitting and then, widening occurs. When loops are transferred to needles with loops, the original needles become empty and stop knitting, and narrowing occurs. The figure 7 shows the wale fashioning techniques such as widening and narrowing of wales. The following are the types of shaping (www.knittingmagic.biz).

- Three-dimensional wale fashioning,
- Needle selection shaping,
- Reciprocated knitting of pouches,
- Shaping by changing the knitted stitch structure, and shaping by altering the stitch length.

Wale Fashioning-3D

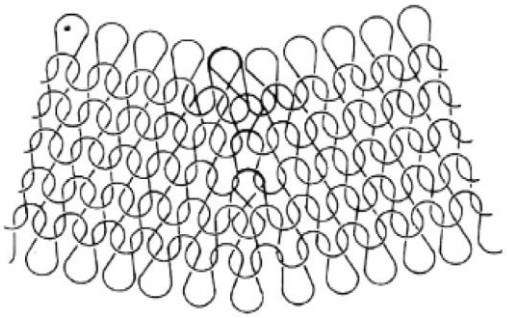


Figure 6. Wale shaping – Internal reduction within the flat fabric (Terry

The shaping of the panel occurs by the three-dimensional fashioning of panel within the width of the working needles. The use of autonomously controlled fashioning boxes is used to produce three-dimensional shape the component. The heel pouch present in the stocking knitted with plain fabric and two side of the pouches set as widening and narrowing again. The process of widening each needle present in the width is not receiving any new yarn to form a continuous loop, but it produces a new wale from consequent course. During narrowing of stocking component needle received two loops from two wales, this congregates as one wale.

Shaping Through Needle Selection

In needle selection shaping, the introduction or withdrawn of needle or more number of needles in selvedge side(s) of the knitting width. This can be done by the selection of needle, which is convenient and also automatic one. The selection of needles are done by the jacquard mechanism in flat knitting machine. The shaping of the panel edges (Table 2) is done by means of following methods.

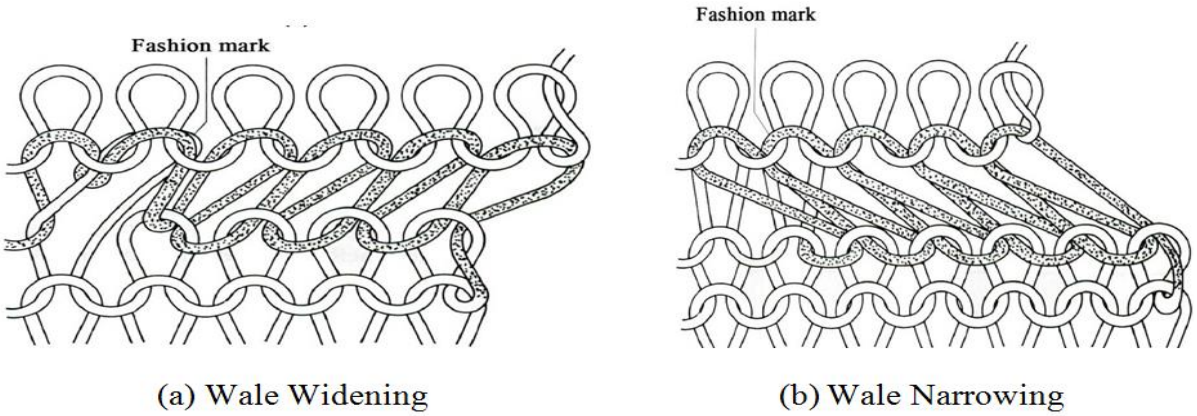


Figure 7. Wale Fashioning Technique

- By transferring & re-transferring of loops based on racking process.

- By the process of pressing of loops.
- By source of needles to hold their own loops for large number of transverse.

Reciprocated Knitting Of Pouches

In small diameter knitting machine, the three-dimensional shaping can achieve easily. The number of courses knitted by all the needles in a stocking shaping of heel and toe varies, which is based on narrowing (put the edge needles in out of action) and widening (put the needles brought into action). During shaping process, one third of needles among working needles only in action to form the pouches. The integral knitted garment components shaped in garment width machines. The shaping of the garment component field such as bust or shoulder section knitted by the principle of reciprocated pouch.

Table 2
Types of wale fashioning

Outside Widening Increasing the stitch at the edges of the blank one by one	*Split Stitch* Increasing the stitch at the edges of the blank one by one and the hole formed during widening is filled by split knit
Outside Narrowing Narrows the stitches by the movement of stitch at the edges. The stitch number between narrowing and stitch move is the same.	*Inside Narrowing* Narrows the stitches by stitch move The stitch number to be moved is larger than the stitch number to be narrowed
Interlock Increasing at the edges of the blank by	*Narrowing by Bind off* The stitches moved from the edge to subsequent loop. sequentially means of plural stitches at once

Conclusion

One among the biggest manufacturing textile sector is knitting. The knitting industry moving towards sustainability in all the phases in their process such as technology, raw materials, pre-production and postproduction, energy consumption and other investments including supply chain. Considerable developments in technology helps for the waste reduction, reduce down time of the machine, reduce raw material utilization etc., for the sustainable garment production. There are universal standards available to guide every manufacturer to step into sustainable production. The application of digital technology integrated with seamless garment technology in knitting also empowering the sustainable production of 3D knitted products for versatile application.

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