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Skewness and Spirality of Knitted Structures
Poševnost in spiralnost pletiv

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Abstract
Weft knitted structures are affected by various forms of dimensional distortion. Inclination and distortion of loops within knitted structures are commonly known as skewness and spirality, respectfuly. Causes of skewness and spirality have been thoroughly investigated, analyzed and classified. They can basically be divided into two groups: material causes and process causes. One of the material causes is yarn related and is caused by residual torque in the yarn shown by its twist-liveliness. One of the more important process causes is machine related and is connected to knitting with multiple feeders on the circular knitting machine. Skewness and spirality have been subjects of research for almost a century. Models have been developed for understanding and predicting the loop distortion phenomena. Procedures for reduction or even elimination of the skewness/spirality have continuously been developed and improved. Some of them include changes in raw material, the others in mechanical processes and/or equipment while the other again concentrate on after-treatments. Many standards and other testing methods for measuring the skewness and spirality have been used in research and industrial practice. The uses of many terms describing this phenomenon have shown the continuous importance of the skewness/spirality problem on the one hand and the inconsistency of the terminology on the other.
Keywords: knitting, knitted fabric, skewness, spirality, loop inclination, yarn liveliness, residual torque

Izvleček
Na votkovne pletene strukture vplivajo različne deformacije zanke. Nagnjenost in izkrivljenost zank v pleteni strukturi sta poznani kot poševnost oz. spiralnost pletiva. Vzroki za poševnost in spiralnost so podrobno preiskani, analizirani in ocenjeni. Na splošno jih je mogoče razdeliti v dve skupini: v materialne in procesne. Eden od materialnih vzrokov je povezan s prejo; poševnost/spiralnost pletiva povzroča preostali vrtilni moment preje, ki se odraža v neumirjenosti preje. Med najpomembnejšimi procesnimi vzroki je povezanost s pletilnikom, ki se nanaša na večsistemsko krožno pletenje. Raziskave poševnosti in spiralnosti pletiva potekajo že skoraj sto let. Razviti so bili modeli za razumevanje in predvidevanje deformacije zanke. Ves čas razvijajo in izboljšujejo postopke za zmanjšanje ali celo odstranitev poševnosti/spiralnosti. Nekateri vključujejo spremembe surovin, drugi spremembe mehanskih postopkov in/ali opreme, medtem ko se preostali usmerjajo v plemenitenje. V raziskavah in industrijski praksi so bili za merjenje poševnosti in spiralnosti uporabljeni številni standardi in druge preskuševalne metode. Uporaba številnih izrazov, ki opisujejo pojav poševnosti/spiralnosti, kaže na trajen pomen problema na eni strani in na nedoslednost terminologije na drugi.
Ključne besede: pletenje, pletivo, poševnost, spiralnost, nagnjenost zanke, neumirjenost preje, preostali vrtilni moment

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1 Introduction: skewness and spirality as a constant problem

Knitted fabrics are complex and dimensionally sensitive structures. Variations in material, structural, process and environmental parameters significantly influence the performances and comfort properties of knitted fabrics, as well as their qualities. Inclination and distortion of loops within knitted structures are commonly known as skewnes and spirality, respectfully. They affect both the aesthetic and functional performances of knitted fabrics and knitwear. They are reflected in an inclination of the lower edge of the knitted garment and/or the displacement of the side seams to the back and front, mismatched patterns, assymetrical necklines, inclined slits, cutting and sewing difficulties, etc [1].
If the distortion exceeds 5° it is considered an important problem [2]. Nevertheless, Brackenburry [3] stated that fabrics of around 10° spirality are commonly processed.
Single knitted structures are the most affected by various forms of dimensional distortion. Double knitted structures like rib, interlock and purl are less sensitive in this respect. One of the more investigated distortions within the knitted structure is the asymmetrical shape of the loop which is reflected in loop inclinaton.

2 Terms and definitions referring to knitted loop inclination: non-standardized terminology

In ISO 16322 standard, Part 1 [4], distortion of a knitted fabric in which the wales follow a spiral path around the axis of a tube is termed *wale spirality*. In ISO 16322 standard, Part 2 [5], *spirality or torque in fabrics* are defined as fabric conditions, wherein filling yarns or knitted courses are angularly displaced from a line perpendicular to the edge or side of a fabric or garment. In ISO 16322 standard, Part 3 [6], *spirality and torque in garments* are defined as rotation, usually lateral, between different panels of a garment resulting from the release of latent stresses during laundering of the knitted fabric forming the garment.
In AATCC 179-2004 standard [7], *gament twist* is defined as a rotation, usually lateral, between different panels of a garment resulting from the release of latent stresses during laundering of the knitted fabric forming the garment. Further, it is indicated in the standard that *twist* may also be referred to as *torque* or *spirality*. On the other hand, *skewness* is defined as a fabric condition resulting when filling yarns or knitted courses are angularly displaced from a line perpendicular to the edge or side of the fabric. In this connection, the reference to the ASTM Standard Terminology D 123-92 is given [8].
In standard ASTM D 3882 [9], *skew* is defined as a fabric condition resulting when filling yarns or knitted courses are angularly displaced from a line perpendicular to the edge or side of the fabric.
Smirfitt [10] used the term *spirality* and indicated that it appears when all the loops in the fabric take up inclined positions, thus giving the fabric a skewed or spiral appearance.
Brackenburry [3] used the term *spirality* as well. It was described as a fabric distortion which arises from twist stress within the constituent yarns of plain fabrics, causing all loops to distort and throwing the fabric wales and courses into an angular relationship other than 90°. In the chapter on spirality, it was also stated that if the fabric is retained as a tube, the spirality throws the vertical alignment of the fabric awry so that the wales lie at an angle to the edges of the fabric and slowly spiral around the fabric.
Lau et al [11] noted in their paper that in flat knitted fabrics, an inherent inclination occurs of the courses to the wales : the wales are not perpendicular to the courses. This phenomenon was referred to as *wale-spirality*. They pointed out that it should not be confused with *spirality* which is defined by Textile Terms and Definitions as a distortion of a circular-knitted fabric in which the wales follow a spiral path round the axis of the knitted fabric tube [11, 12].
Primentas [13, 14] distinguished spirality from drop. *Spirality* or *wale skew* in a knitted fabric is described as configurations of the wales which are skewed from the vertical, whereas the *drop* or *course skew* concerns the course skewness from the horizontal and is due to the helical dispositions of the courses.
Shahid et al [15] as well as Abdel-Megied and Ahmed [16] used the term *wale skew* for the wales skewed from the vertical, and conversely, *course skew* for the courses skewed from the horizontal. The same terminology was used in the Technical Bulletin published by Cotton Incorporated [17].

There are another terms often used to refer to the same phenomena like: *bias* and *shear* [18] and *bow* [19].
It can be seen from the above-stated definitions and descriptions that various terms are used when referring to the fabric dimensional distortion induced by the loop inclination in knitted structures. Moreover, the same description is attributed to various terms. For example: »a fabric condition, wherein filling yarns or knitted courses are angularly displaced from a line perpendicular to the edge or side of a fabric«, is defined as *spirality or torque in fabric* in ISO 16322 standard, Part 2 [5]; *skewness* in AATCC 179-2004 standard [7], and *skew* in ASTM D 3882 standard [9]. In another case, the same term has been used for different concepts. For example: *wale spirality* is defined as »distortion of a knitted fabric in which the wales follow a spiral path around the axis of a tube« in ISO 16322 standard, Part 1 [4], which clearly means that it refers to circular knitted fabrics, while Lau et al [11] used the same term for the phenomenn which appears in flat knitted fabrics where inclinations occur of the courses towards the wales.
In order to avoid misunderstandings and misinterpretations related to the loop inclinations and distortions in knitted fabrics, the terminology concerning this phenomenon should be redefined and standardized.

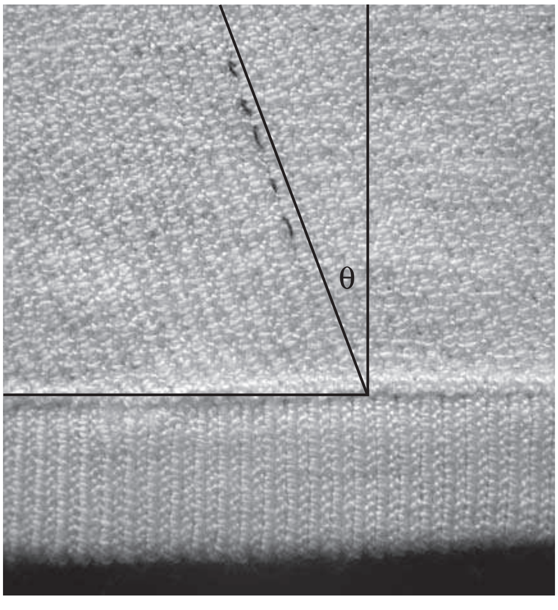

Figure 1. Skewness in single flat-knitted structures with tubular welt. The wales are not perpendicular to the courses (θ = skewness angle)

Basically, two terms should be applied. The term *skewness* (Figure 1) should be used for the loop inclinaton/distortion caused by the yarn twist-liveliness which mainly occurs in flat-knitted fabrics. The term *spirality* (Figure 2) should be assigned to loop inclinations/distortions in tubular knitted fabrics produced by multi-feeder circular knitting machines leading to the formation of spiral knitting courses.

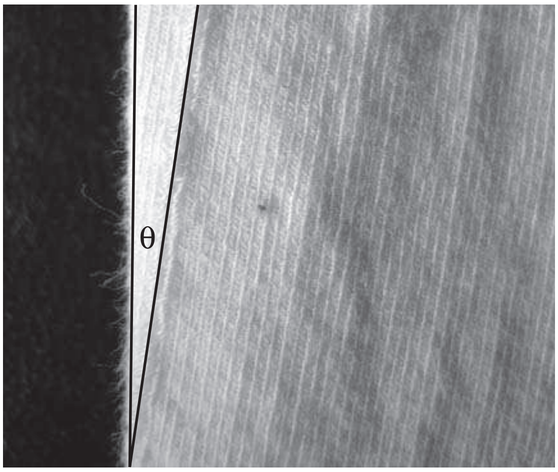

Figure 2. Spirality in single circular-knitted structures. The wales lie at an angle θ to the edges of the fabric and slowly spiral around the fabric (θ = skewness angle)

3 Early observations: rather reduction than prevention of the problem

Early studies by Woods [20] emphasized the relationship between the structure and the mechanical properties of single yarns. The theory of twist was studied for ideal yarns. Nevertheless, the variability of yarn diameter, shrinking due to change of twist, radial compression of the yarn and fiber slippage were also noted as influencing the yarn properties. Later studies by Baker [21] stressed the importance of bending in yarn geometry and in connection with the mechanical properties of textiles made from these yarns. In his paper, Baker [21] outlined the results of a geometric analysis of the idealized structure of a bent yarn. The importance was stressed of such knowledge in problems dealing with the mechanical properties of twisted woven and knitted textile structures. Specific attention was given to computations of local and average fiber strains which occur in highly twisted dense structures.

Studies conducted by Woods represented the basis for further practical and experimental investigation into yarn torque.

The spirality was studied by Davis and Edwards as early as in the 30s of the 20th century. In addition to wollen, cotton knitted fabrics were also investigated [22, 23]. The authors observed that various methods had been adopted for overcoming this defect but they had all been directed towards removing the spiral efect from the fabric rather than preventing its formation. Further, they commented that as a result of prolongued investigations, it could be stated that the spirality was caused mainly by the amount of twist in the yarn. Nevertheless, in their research the impact of yarn feeding, loop forming, machine type and machine gauge on the knitted fabric spirality was also investigated.

In their general review of the methods of manufacturing and physical properties of various types of hosiery stretch yarns, Munden and Fletcher [24] commented on the tendency of twist-lively yarns to form a spiral knitted fabric as well as to snarl when released, causing faults within the knitted structure. In order to overcome these difficuties, doubling two single yarns of opposite twist-liveliness was proposed with just sufficient turns to keep the single yarns together. Moreover, additional machine settings and the uses of anti-snarl devices were indicated.

Smirfitt [10] indicated that loop formation involves both twisting and bending, resulting in twist redistribution in the arms of the loop. If the yarn is twist-lively so that it tends to snarl upon itself, then the loop shape will be affected as the yarn in the fabric is prevented from snarling by its contact with adjacent loops. The result is that all the loops in the fabric take up inclined positions giving the fabric a skewed or spiral appearance.

Kliment [25] cited a force couple system to explain the torsional moment applied on the loop arms. Kliment stated that because of this moment, which is effective towards the front of the fabric in one arm while it is effective towards the back of the fabric for the other arm, causes the arms to slide over the surfaces of interlocking arms of the adjacent loops. The yarn lengths of the arms differ and loop leans on the arm that has shorter yarn length. Kliment also discussed other factors influencing loop inclination: yarn twist direction, rotational direction of knitting machine, yarn tension, number of feeders on circular knitting machines, etc.

4 Complexities of skewness and spirality: advanced investigations

In general, there are two main reasons for knitted loop distortion. One of them is yarn related and is caused by residual torque in the yarn shown by its twist-liveliness. The other is machine related and is connected to knitting with multiple feeders on the circular knitting machine [2]. If the twist-lively yarn is used for knitting, the resultant loop is no longer symmetrical because of the induced torsional strain in the yarn. The twisted yarn has a tendency to untwist and release the torisonal strain inside it, in order to acquire the natural configuration of a minimum energy state. The yarn attempts to rotate inside the fabric, thus lifting one side of the loop out of the surface while the other side stays inside the fabric. This distortion of loop symmetry induces an inclination towards loops and rib-like effect on the fabric. A small amount of fabric distortion can also be observed in fabrics produced from non-twist lively yarns when knitted on a multi-feeder circular machine. This loop distortion is caused by unbalanced tension in the two legs of the loop. However, the loop distortion effect in such cases is much smaller than that generated by the residual torque in the yarn [11].

Beside the two above-mentioned reasons, there are also other factors influencing knitted loop distortion that have been investigated by many researchers from both fundamental and practical viewpoints [26, 27]. Several theoretical approaches were taken to analyze the spirality phenomenon, yet because of its complexity, each study focused on a limited number of factors, either for the sake of simplifying the analysis or due to limited ability to verify the theory using experimental approaches. Other studies have dealt with the analysis of spirality from the strictly experimental view by examining the effects of a number of factors, some of which were machine-related and others fabric-related, on the extent of spirality of knit structures [18].

It has to be noted that researchers have mainly used the term spirality in their publications, therefore the same term is mainly used in the following review.

Banjeree and Alaiban [28] found out on the basis of their experimental work that the knitted fabric should be knitted on a machine with the finest possible gauge at a tightness factor value ≥14.0 to minimize the spirality in the finished fabric. They also stated that fabric mercerization causes a larger reduction in loop assymetry than yarn mercerization, though the treatment remains the same.

Tao et al. [26] determined empirical relationships between the spirality of cotton single jersey fabrics and yarn linear density, twist factor, fabric tightness factor and loop shape factor, using statistical techniques. They confirmed that the yarn twist and fabric tightness are the most predominant factors contributing to fabric spirality. The experimental results also demonstrated the importance of relaxation treatment on fabric spirality.

Similarly, Chen et al. [29] used regression techniques to determine empirical relationships between the spirality of plain knitted wool fabrics and the parameters of plied yarns and fabrics including the twist factor of plied yarn, loop length and fiber diameter in both dry relaxed and simulated industrial relaxed states. Their experimental results showed that the twist factor of two-ply wool yarn is the most important factor influencing fabric spirality. Loop length and fiber diameter also show significant effects. In general, increasing the twist factor of two-ply yarn, loop length, and fiber diameter increases the angle of spirality. The experimental results demonstrated that relaxation treatment of fabrics in water decreased the angle of spirality.

Marmarali [30] performed research on the dimensional and physical properties of cotton and cotton/spandex single jersey fabrics. In her research, three different types tightness and two different types of cotton/elastane fabrics were used. It was found that the spirality is more distinctive in loose fabrics than in non-elastane fabrics. Along with the fact that the spirality values of cotton/elastane fabrics are lower than 5° as an acceptable level, cotton/elastane fabrics which have elastane thread knitted in every course have considerably lower spirality values than fabrics with elastane thread incorporated within alternating courses.

Degirmenci and Topalbekiroglu [31] systematically investigated the effect of fabric weight, yarn production technologies, the yarn twist direction and dyeing on the spirality of knitted fabrics. Plain fabrics were investigated made from cotton ring-spun yarns. The results showed that increasing the fabric weight decreases spirality; however, the decrease does not have the same reverse proportionality for all yarn types. It was established that the dyeing process decreases spirality.

Ceken [1] investigated the effects of various finishing-dyeing processes on the wale spirality of single circular knitted fabrics and seam distortion. Single jersey samples for T-shirts were prepared. Higher spirality angles were observed in the fabrics treated with open-width finishing-dyeing processes in comparison to tubular form, however the seam distortion degrees of the T-shrts sewn from these fabrics were minor which showed that fabrics in open-width form are more relaxed.

Kothari [14] performed a study on the effects of various yarns and machine parameters on the spirality of cotton tubular single knitted fabrics. The experimental results showed that repeated washings and tumble drying caused an increase in spirality depending on the level of twist presented in the consistent yarns as well as the amount of tightness present in the fabric structure. Lower loop length, higher machine gauge and higher yarn linear density reduce the spirality, as tightness of fabric construction imposes restrictions on loops getting distorted. Increasing twist factor increases twist-liveliness in yarns leading to large spirality angles. This effect is further faciliated in those fabrics with larger loop lengths, made from finer yarn and knitted on coarser knitting machines.

Zaman & Weber [32] examined the effect on knitted fabric spirality of feeding speeds of elastomeric yarns with 100% cotton yarns. The reuslts of the research showed that with increasing speed of elastomeric yarn feeding, the spirality angle starts to reduce.

5 Causes of knitted fabric skewness and spirality

On the grounds of a thorough review of the theoretical and experimental research into the skewness/spirality phenmenon, the various causes of fabric spirality can basically be divided into two groups: material causes and process causes. More precisely, they can be classified into four main categories: fiber causes and yarn causes within the frameworks of material causes and knitting causes, and finishing causes within the framework of process causes [18, 33].

Fiber causes include fiber type, fiber quality, fiber torsional rigidity, fiber flexural rigidity, fiber blend, fiber finess, and fiber length [18].

Yarn causes include yarn voluminosity, yarn spinning process, fiber arrangement, twist level, twist direction, yarn linear density, yarn plying, yarn preconditioning and mechanical properties [18].

As regards material causes, many authors have studied the nature, origins and characteristics of the spirality of knitted fabrics [11, 13, 22, 34–37]. They concluded that the main factor for the spirality is the yarn twist-liveliness, denoting the active torsional energy present in the yarn. Its magnitude depends primariliy on the torque inserted within the yarn by means of twist [13]. When a twistless yarn was bent by forces and couples to form a two-dimensional loop, a perfectly symmetrical (to the central axis) loop configuration would emerge [11].

Knitting causes can be further classified into two main gropus: fabric parameters and machine parameters. They include fabric density, tightness factor, loop length, fabric structure, knitting machine gauge, needle type, number of feeders, yarn input tension, fabric take-down tension, etc. [18].

Skewness/spirality increases with the loop length which is connected to the tightness of a knitted structure. The yarn in an open knitted structure has a higher tendency to rotate inside the fabric after relaxation while in a closed knitted structure the movement of a knitted loop is restricted, and thus the spirality is reduced [18].

Skewness and spirality are more distinctive in single knitted structures while in double structures the effect of spirality is nullified. Nevertheless, spirality can be noticed in certain jacquard structures. Rib and interlock structures do not exhibit the skewness/spirality problem [18].

The number of active feeders in a circular knitting machine influences the angle of spirality which depends on the number of feeders per machine diameter. With a multi-feeder machine, the fabric is created in helix. The rotational direction of a knitting machine has an influence on spirality as well. Z-twisted yarns induce clockwise spirality while S-twisted yarns induce counterclockwise spirality [18].

Finishing causes include stentering, calandering, softner, mercerizing, resins, enzymes [18].

6 Theoretical skewness and spirality analyses

Hepworth [38, 39] theoretically investigated the mechanism by which the use of twist-lively yarns leads to spirality in a fabric. Through a computer simulation (which was in accordance with the technical possibilities at the time of investigation), the shape of a loop within the fabric could be calculated from consideration of the inter-yarn pressures exerted on a loop by its neighbors. According to the tightness of the knitted fabric, other contacts than interlacing between neighboring loops were also anticipated. Adjacent wales were presumed to be so close together as to touch and a condition known as »jamming« was assumed. The presence of residual torque in the yarn was simulated by introducing a twisting couple acting on the yarn in a loop. Since the spirality had been previoously proven to be affected by both yarn twist-liveliness and fabric tightness, the calculation was caried out for a range of values of these variables. Such an analysis yielded information about the theoretical interactions between yarn residual torque and fabric spirality. However, practical applications were limited because of its complexities. Murriells [40] commented on Hepworth's research that it had been based on certain assumptions and the results would have been determined by the validity of these assumptions, which did not appear to be fully verified in the Hepworth's study [40]. Kurbak et Kayacan [2] considered the Hepworth's model too complicated to apply. Further, they noted that it only treated spirality angles of up to 15°, while in practice the spirality sometimes exceeds 30°.

A new knitted fabric mechanical model was developed by Choi and Lo on the basis of the prevously described energy model [41, 42]. It was assumed that the shape of the yam after knitting was curved and had non-linear mechanical properties. In the new model, considerations of the loop shape changes due to twist-liveliness of the yam were made and the improved model allowed skewing of the loop and hence an asymmetric loop shape as viewed from the front. Minimum energy consideration of the fabric structure also led to the inclusion of the freedom for the loop to bend out of the fabric plane. Namely, in a loose fabric the loops have more freedom to move about. They can rotate in both the directions of the z-axis and y-axis. The rotation in the z-direction is the well-known phenomenon of fabric spirality. The loop rotation in the y-direction does not affect the overall dimensions of the fabric but it has a localized effect of making one arm of a knitted loop become more prominent than the other. For a Z-twist yarn, the right arm would rotate out of the fabric plane. The rotation of the loop about its own axis in the y-direction due to the effect of twist-liveliness then results in a so-called *wavy loop* seen from the top. The new mechanical loop model allows a more precise description of the loop shape especially in the case of fabric knitted with natural fiber spun yarns. With the new model, fabric dimensions can be predicted more accurately and the skewness problem may also be anticipated. This model was tested on real wool knitted fabrics. Experimental results showed that there was excellent agreement between the calculated and measured values for both course spacing and skewness.

Kurbak and Kayacan [2] developed a theoretical model for the spirality of plain knitted fabrics by modifying the plain knitted loop model [43]. The model was drawn to scale by using the 3DS-MAX computer graphics program. The loop shapes obtained were exactly the same loop shapes as observed on the real fabrics knitted with compressible yarns. The proposed model is thought to be applicable not only for studying the spirality of classical textiles but also for modeling small diameter tubular technical textile fabrics. In Kurbak‘s study, it was suggested that because of the three-dimensional nature of the plain loop, the yarn part at the left arm of the loop and the yarn part at the right arm of the loop have torsions in opposite directions. If the yarn used was twist-lively, the potential twist applied in the same direction for both of the arms. Therefore, the total twist decreased in one arm and increased in the other. In order to equalize their total twists, the curves of the yarn axis in the arms differ from each other. The loop head and legs are arranged by replacing the elliptical upper and lower curves of Kurbak‘s plain knit model with parametric curves. In order to obtain a simple model, it was assumed that the fabric dimensions, the average course spacing and the average wale spacing do not change with fabric spirality. Another method of twist redistribution in the fabric which differentiates the wrapping angles of the helices on two arms of a loop has been defined as *the second kind of spirality*. Kurbak noted that *the second kind of spirality* can mainly be observed in rib structures as well as in some of the technical textile plain knitted fabrics. In their further studies, Kurbak and Soydan [44] invstigated twist-liveliness and the *second kind of spirality* effect on the rib knitted structures in which the rib components at the right side and at the left side of a plain stitch component are different in construction.

Murells et al [40] proposed an artificial neural network (ANN) model based on experimental results for predicting the degrees of spirality of single jersey fabrics made from 100% cotton conventional and modified ring spun yarns. The factors investigated were the yarn residual torque i.e. the measured twist-liveliness, yarn type, yarn linear density, fabric tightness factor, the number of feeders, rotational direction and gauge of the knitting machine, and the dyeing method. The ANN model was compared with a multiple regression model, demonstrating that the ANN model produced superior results for predicting the degree of fabric spirality after three washing and drying cycles. A relatively good agreement between the predictions and actual measured values of fabric spirality was achieved with a correlation coefficient, R, of 0.976 in out-of-sample testing. The relative importance of the investigated factors influencing the spirality of the fabric was also investigated. Both the ANN and the regression approach showed that twist-liveliness, tightness factor and yarn linear density were the more important factors in predicting fabric spirality, with the other factors having a minor influence. This confirmed the generally held view that twist-liveliness is the major contributor to spirality.

7 Methods for determining skewness and spirality

Several standard and other methods are available for determining the skewness and spiraity of knitted fabrics.

7.1 IWS Test Method No. 276: Method of Test for the Measurement of the Angle of Spirality in Knitted Fabrics

With the IWS method, the spirality is determined by placing a protractor on the fat smooth fabric surface with its base-line along the course and reading the angle between the wale line and a line 90°perpendicular to the course line [11, 45].

A modified IWS test method TM 276 was used to measure the fabric spirality both before and after the relaxation treatment [40]. The angle was measured between the wale line and the line parallel to the machine running direction which in this case was the edge of the circular fabric.

7.2 ISO 16322 standard Textiles – Determination of spirality after laundering

This standard has been published in three parts:

- Part 1: Percentage of wale spirality change in knitted garments [4]
- Part 2: Woven and knitted fabrics [5]
- Part 3: Woven and knitted garments [6].

In Part 1 [4], a method of measuring the percentage of wale spirality change in weft-knitted jersey garments produced on knitting machines is specified following laundering. During the testing procedure, the welt or hem of the body of a garment prior to laundering is tensioned until the top edge of the welt or hem is straight. The angle subtended by the wales with a line perpendicular to the top edge of the welt or hem is measured by a protractor. This measurement is repeated after laundering and the change in spirality is computed from the differences in the results. In recent times, the spirality angle has been measured from knitted fabric images by using computer graphic tools.

In Part 2 [5], three procedures: diagonal marking, inverted T-marking and mock-garment marking are specified for measuring the spirality or torque of woven and knitted fabrics after laundering. For the diagonal marking, square single-layer fabric specimens aligned with the selvedge or tubular fold line of the fabrics are prepared and the corners of the marked square are labeled. The Inverted T-marking procedure using a T-marking device is particularly suited to narrow-width fabrics. Mock-garment marking includes an over-edged seam along each long direction and one short direction of the specimen, forming an open-ended bag or pillowcase-type specimen to simulate a garment panel. Spirality is measured in millimeters, percentage of a marked distance, or angle of non-verticality. Similarily to part 1, this part of ISO 16322 is not intended to measure the spirality of fabrics as manufactured but rather the spirality after laundering.

Part 3 [6] specifies the procedures for measuring the spirality or torques of woven and knitted garments after laundering. Similarily to parts 1 and 2, this part of ISO 16322 is not intended for measuring the spirality of garments as manufactured but rather the spirality after laundering. When measuring, a horizontal reference line across the width of the garment panel is marked above the bottom edge or hem. A benchmark is placed midway along the horizontal reference line. A line parallel to the horizontal reference line is drawn at an appointed distance above the benchmark. Another benchmark in placed on the parallel line directly above the first benchmark. After the laundering, the displacement is measured and spirality calculated. There is a note in the standard pointing out that some fabric constructions, like denim, may have spirality intentionally introduced during manufacturing. Another note states that garments made of fabrics from circular knitting machines may have inherent non-verticality of wale alignment.

7.3 AATCC Test Method 179-2004 Skewness Change in Fabric and Garment Twist Resulting from Automatic Home laundering

The AATCC test method [7] determines the changes in skewness in woven and knitted fabrics or twist i.e. spirality in garments when subjected to repeated automatic laundering procedures commonly used in the home. The changes in skewness in fabric or spirality in garment specimens are measured using benchmarks applied to the specimens before laundering. The paths of the course lines and the wale lines in the examined knitted structure are determined accurately by either placing the protractor or a ruler along the path or drawing a line with a fine tip pen. The procedures of samples' markings are similar to those described in the ISO 16322 standard while the laundering and drying procedures are specified in more detail. There are also additional explanations regarding the marking, laundering and measuring procedures. The standard points out that for some fabrics, the skewness of the fabric in a garment is not solely dependent on its behavior in the unsewn state; it may also be dependent on the manner of garment assembly. The standard allows a digital imaging system to be used as a measuring device in place of the prescribed manual measurement devices if it is established that its accuracy is equivalent to the manual devices.

7.4 ASTM D 3882-2006 standard: Bow and skew in woven and knitted fabrics

The ASTM test method [9] covers the measurement of distortion regarding courses in knitted fabrics from the normal path perpendicular to the fabric length [46]. The straight line distortion of a marked knitting course is measured from its normal perpendicular to the selvage or edge. The measurements are performed in three places spaced as widely as possible along the length of the fabric; the minimum examined length is 1m. If possible, no measurements are to be made closer to the ends of the roll or piece of fabric than 1m. A distinctive color yarn or pattern line across the with of the fabric can be incorporated within the knitted structure or a suitable marker should be used to trace the knitting course path. The distance along the straight edge between the two selvedges is measured to the nearest 1mm and recorded as the fabric width. The distance parallel to the selvadeges between the straight edge and the distinctive color yarn or marked line is measured to the nearest 1mm and recorded as the skew distance. The skew distance should be recorded including the skew direction, right hand »Z« and left hand »S« and whether evident on the face or back of the fabric. The skew (%) is then calculated from the ratio between the skew distance and the fabric width. The ASTM 3882-2006 standard [9] notes that skew can be induced during fabric manufacturing, dyeing, tentering, finishing, or other operations where a potential exists for uneven distribution of tensions across the fabric width. Futher, it comments that skew is more visually displeasing in colored and patterned fabrics rather than in solid colors because the contrast makes the distortion more prominent. The defect may cause sewing problems in such fabrics and draping problems in finished products.

7.5 Other methods for determining skewness and spirality

The spirality can also be measured on the basis of a quick dimensional stability test method [47–49], using a microwave oven for drying. Square samples of the knitted fabrics 30 x 30cm are cut and marked approximately 25cm apart in both wale and course directions. After a sample has been dried for 10min in a microwave oven equipped with a turntable and having a 600watt output capacity, the spirality is measured by a protractor. The sample is then soaked in lukewarm water containing a little non-ionic wetting agent for 30min. The exact concentration and water temperature are not critical. After the excess water is removed by blotting the sample with a towel, the sipralitv of the wet, relaxed sample is measured. The sample is then dried again in the microwave oven for 15min and the dry relaxed spirality is measured. The procedure can be repeated to simulate repeating cycles of laundering and drying.

Celik et al [50] developed an algorithm for determining the angle of spirality using image analyses. The method was based on image-processing techniques, specifically the Fast Fourier Transform, for obtaining the directions of the wale and the course in order to measure the angle of spirality. Namely, the most visible peaks (white regions) lie in the horizontal direction carrying information about the periodicity of the wales. Similarly, the more visible peaks which lie in the vertical direction carry the information about the periodicity of the courses. Thus, the lines in the horizontal and vertical directions passing through the more visible peaks and intersecting at the center have to be determined or defining the angle of spirality. The proposed algorithm has yielded fast and accurate results.

Semnani and Sheikhzadeh [51] developed a new intelligent method for evaluating the deformations of loops in various weft-knitted fabrics based on an ideal shape of loops and angle of direction of loops in a knitting machine. In order to measure deviation of loop direction against internal stresses, an image analysis technique was applied to images taken from different fabrics using constant front light. Evaluation of fabric regularity with emphasis on the deformations of loops was based on analyzing the fabric images using Radon transformation analysis. The index of fabric regularity was obtained from the deviations of loops from the original direction of the ideal regular fabric.

8 Reduction and elimination of skewness and spirality

The acceptability of the skewness/spirality extent varies with the quality, price and the use of the knitted fabrics. There are many techniques adopted for overcoming i.e. reduce or eliminate skewness/spirality [3, 52,]. Some of them include changes in raw material, the other in mechanical processes and/or equipment while the other again concentrate on after-treatments. The more suitable method for producing spirality-free single jersey is by knitting two-folded yarns but this increases the price [3, 22, 34, 52]. The opposing torsional forces in the single yarns and the resulting folded yarn are counterbalanced. Garments, knitted from folded yarns like T-shrts become heavier. The use of two-folded yarns requires the production of finer single yarns to produce lighter fabrics, resulting in a dramatic increase in their production cost [52]. Low twisted yarns can also be used for spirality-free knitted fabrics but their apllication can cause other

production and quality problems like pilling, low tenacity, etc.
Reduction or elimination of skewness and spirality can be achieved by setting, i.e. using resins, heat, steam or mercerization, depending on the material compostition of the knitted structure. Setting by resins, steam, or dry heat is often slightly unstable and after repeated washings, skewing of the wales normally reoccurs. Therefore, spirality can be eliminated by setting the residual twist in the yarn. In single yarns from natural fibers, where the problem usually occurs, the set is not generally permanent to washing [10]. Twist setting or relaxation relieves the stresses set up in textile fibers by twisting. It ensures the standstill of the twist-liveliness of even highly twisted yarns while retaining their twist level [52]. Setting processes can include storing yarn packages at high temperatures and relative humidity, or steaming.
Primentas [53] reported that partial detwisting reduces significantly and in some cases eliminates the spiraliy of weft knitted fabrics produced from single ring-spun yarns. Highly twisted yarns were steam-set and counterbalancing torsional force was introduced by partially detwisting the steam-set yarns to a level of 15–30% of their initially intrdouced twist.
Araujo and Smith [54] studied the effects of yam spinning technology on the spirality of jersey fabrics in the dry and fully relaxed states for 100% cotton and 50/50 cotton/PES blend yarns. The 100% cotton yarns showed a greater angle of spirality than the 50/50 blend in the fully relaxed state. For 100% cotton, for both dry relaxed and fully relaxed states, the angle of spirality decreased as follows; friction > ring > rotor > air-jet yarns. 50/50 blend yarns, both the air-jet and the rotor spun, which had the lowest tendency to snarl, the lowest angles of spirality were observed in both the dry relaxed and fully relaxed states.
Open width finishing with the fabric passing through a stenter corrects the spirality while finishing the fabric in tubular form does not [3].
Higgins et al [55], investigated the effects of different tumble drying temperatures on the shrinkage, skewness and spirality properties of 100% cotton plain, interlock and lacoste fabrics. They observed the lowest spirality for plain and lacoste knitted fabrics' structures at 65–75°C tumble drying and 65–75°C flat drying processes. For interlock structures, the spirality was the lowest for both 22°C and 65–75°C tumble drying processes.
The blending of a small percentage of low-melt PES with cotton and heat treatment resulted in a reduced spirality [34], however the texture of the fabric was rather unpleasant due to the stiffness of the fabric.
Park et al. [56] investigated spirality-related mechanical properties such as torque, the tensile and torque tendencies of single knit fabrics made of LincLITE® and conventional yarns, respectively. They concluded that twist liveliness, snarling tendency, torque and residual torque, and the assymetry of torque and tightness significantly effect the spiralities and skewness of single jersey fabrics. They assumed that the remedy for spirality should basically be achieved by the modification of the knitting yarn itself. They discovered that by replacing 100% Merino wool with special LincLITE® yarns (soft and bulkier yarns, developed by the Wool Research Organization of New Zeland, now known as Canesis Network Limited) provides less spirality to the single knitted structure. On the other hand, some researchers found out that knitting with elastane can also reduce the spirality [57, 32, 30].
Spirality can be eliminated or reduced by replacing single knitted structure with one of the spirality resistant structures. Spirality does not occur in 1x1 rib and interlock fabrics. The loops formed in oposite directions cancell out the distortions [3]. Cross-tuck and double lacoste structures produced on circular knitting machine from cotton, polyester and cotton/polyester and cotton/viscose blended yarns performed lower spirality as well [57]. When comparing plain jersey, single lacoste and double lacoste cotton knitted fabrics, it was discovered that with the increase of tuck loop real density and spirality decrease [58].
Knitting alternate Z- and S- twisted with equivalent twist-liveliness produces an overall spiralty-free fabric with an irregular and uneven texture, presenting a cockling or a herring-bone effect on the fabric surface. In this way, spirality can be turned to a pattern which in addition, gives the fabric a greater potential for lengthwise stretch [52, 10].
Mercerizaion treatment of cotton yarns showed substantial reduction in yarn twist-liveliness and therefore also the reduction in spirality. Although mercerization is an efficient wet-relaxation process it is not a complete solution fort the spirality of knitted fabrics [52, 28].
Resin treatments known as cross linking is sometimes used to reduce the degree of distorion due to spirality.

The resin is applied to the fabric in aqueous solution and is set by passing the fabric once through a high temperature stenter. Beside eliminating some or all of the spirality, improved dimensional stability, appearance and handle are claimed for the process [3].
Mavruz Mezarcioz and Ogulata [59] proposed a more systematic approach for dealing with spirality. They investigated the use of the Taguchi parameter design and concluded that it provides simple and efficient methodology that requires only a few well-defined experimental sets and offers a simple approach for optimising preformance, quality and the costs of single jersey knitted fabrics.

9 Conclusions

The main comparative advantage of knitted fabric in relation to other flat textile structures is their comfort due to their handle, permeability, stretchability and elastic recovery. However, some of these properties are not always just an advantage; they induce deformations among which so called skewness and spirality are ones the most problematic from the performance as well as the aesthetic point of view. The skewness/spirality problem may seem bizzare as it is often connected to low-cost knitted fabrics and knitwear, while on the other hand its complexity impedes a simple and ultimate solution or even elimination. Therefore, further investigation of the problem is anticipated by focusing on conventional as well as novel materials, knitting techniques and structures.
Skewness and spirality have been subjects of research for almost a century. Causes for skewness and spirality have been thoroughly investigated, analyzed and classified. Models for understanding and predicting the loop distortion phenomena have been developed. Procedures for reduction or even elimination of the skewness/spirality have continuously been developed and improved. Many standards and other testing methods for measuring the skewness and spirality have been used in research and industrial practice. The presented review on one site discusses various standard and non-standard methods for determining skewness and spirality.
The use of many terms describing the phenomenon have shown the constinuous importance of the skewness/spirality problem on one hand and the unconsstency of the terminology on the other. In order to avoid misunderstandings and misinterpretations related to the loop inclination and distortion in knitted fabrics, only two basic terms should be standardised: skewness and spirality.
The presented review aims to expose the paradox of seemingly simple phenomenon which has continuously required a universal solution. It also points out the main problems associated with the skewness/spirality phenomenon and seeks to induce further reflection leading to a more systematic approach to problem solving. From the review of the sicentific and professional literature, it can be concluded that the research has mostly been focused on cotton knitted fabrics. Some researchers have investigated polyester and cotton/polyester knits and knits with added elastane threads, whilst only a few have analysed woolen knits. Although cotton is more commonly used for knitted goods, the research should be oriented towards other raw materials as well, including regenerated cellulose fibres and synthetic fibres other than polyester. Furthermore, besides elastane added to the knitted structure in the form of bare threads, the research should also be focused on core-spun elasticised yarns.
As plain single structures have mostly been investigated and only a few researchers have investigated rib, interlock and basic single tuck and miss knitted structure, a more systematic approach is expected to emerge regarding spirality and skewness in other knitted structures.
The investigated knitted structures were mostly produced on circular knitting machines. Although the loop inclination is mostly a problem in knitting with multiple feeders on circular knitting machines, in depth research is expected of those parameters influencing skewness in flat-knitted structures including 3D and whole garment structures.

References

1. CEKEN, Fatma. The effect of spirality of single jersey circular knit fabrics on seam distortions. *Tekstil,* 2010, **59**(5), 186–192.
2. KURBAK, Arif, KAYACAN, Özlem. Basic studies for modeling complex weft knitted fabric structures. Part II: A geometrical model for plain knitted fabric spirality. *Textile Research Journal*, 2008, **78**(4), 279–288, doi: 10.1177/0040517507082351.
3. BRACKENBURRY, Terry. *Knitted Clothing Technology*. Oxford: Wiley-Blackwell, 1992, 49–50.
4. *Textiles – determination of spirality after laundering. Percentage of wale spirality change in knitted garments*. *Part 1.* ISO 1332:2005. 4p.

5. *Textiles – determination of spirality after laundering. Woven and knitted fabrics*. Part 2. ISO 1332:2005. 21 p.
6. *Textiles – determination of spirality after laundering. Woven and knitted garmen*ts. Part 3. ISO 1332:2005. 8 p.
7. *Skewness change in fabric and garment twist resulting from automatic home laundering*. AATCC Test method 179:2004. AATCC Technical Manual 2010, 311–314.
8. *Standard teminology relating to textiles*. ASTM 123–92, 68 p.
9. *Standard test method for bow and skew in woven and knitted fabrics*. ASTM D 3882:2012. 5p.
10. SMIRFITT, John Arthur. *An introduction to weft knitting*. Watford: Merrow, 1975, 15–16.
11. LAU, Y.M., TAO, X., DHINGRA, R.C. Spirality in single-jersey fabrics. *Textile Asia*, 1995, **8**, 95–102.
12. WITHERS, J.C. *Textile terms and definitions*. Manchester: The Textile Institute, 8th Edition, 1986.
13. PRIMENTAS, A. Spirality of weft knitted fabrics: Part I – Descriptive approach to the effect. *Indian Journal of Fbre & Textile Research*, 2003, **28**, 55–59.
14. KOTHARI, V. K. Spirality of cotton plain knitted farics with respect to variation in yarn and machine parameters. *Indian Journal of Fibre & Textile Research*, 2011, **36**, 227–233.
15. SHAHID, M.A., AHMED, F., MAHABUBUZZAMAN, A. K. M., HANNAN, M. A. and KHAN, A. N. Spirality in cotton knit fabrics before and after compacting using selected yarn count and stitch length. *Journal of Innovation and Development Strategy*, 2010, **4**(2), 11–17.
16. ABDEL-MEGIED, Z.M., AHMED, E.L.B. The effect of machine setting on weft- knitted fabric properties. *Journal of Applied Sciences Research*, 2008, **4**(11), 1371–1379.
17. Knit fabrics and the reduction of torque. *Technical bullletin*, Cotton incorporated, Cary North Carlolina, 2002, 13 p.
18. HASSAN, N. A. E. An investigation about spirality angle of cotton single jersey knitted fabrics made from conventional ring and compact spun yarn. *Journal of American Science*, 2013, **9**(11), 402–416.
19. DHINAKARAN, M. Bow, skewness and spirality in knitted fabrics. *Textile Magazine*, 2006, **47**(7), 69.
20. WOODS, H. J. The kinematics of twist. *Journal of the Textile Institute*, 1933, **24**, T317–32.
21. BACKER, S. The mechanics of bent yarns. *Textile Research Journal*, 1952, **22**(10), 668–681.
22. DAVIS, W., EDWARDS, C.H., Spirality in knitted fabrics. *Journal of the Textile Institute*, 1934, **25**(3), T122–132.
23. DAVIS, W., EDWARDS, C.H., Spirality in knitted fabrics: II Cotton. *Journal of the Textile Institute*, 1935, **26**(3), T103–110.
24. MUNDEN D. L., FlETCHER, M. W. A. Processing and properties of knitted stretch fabrics. General description of stretch yarns and fabrics. *Journal of the Textile Institute proceedings*, 1956, **4**(8), P638–P669.
25. KLIMENT, L. Maschenverschiebung in Gestricken. *Wirkerei und Strickerei Technik*, 1977, **8**, 394–397.
26. TAO, J., DHINGRA R.C., CHAN, C.K., ABBAS, M.S. Effects of yarn and fabric construction of spirality of cottong single jersey farbic. *Textile Reserach Journal*, 1997, **67**(1), 57–68.
27. FATKIĆ, E., Spiralty of plain jerseys. *Tekstil*, 2005, **54**(4), 153–159.
28. BANERJEE, P.K., ALAIBAN, T.S. Geometry and dimensional properties of plain loops made of rotor spun cotton yarns. Part III: Spirality of the wale line. *Textile Research Journal,* 1988, **58**(5), 287–290.
29. CHEN, Q. H., AU, K. F., YUEN, C. W. M., YEUNG, K. W. Effects on yarn and knitting parameters on the spirality of plain knitted wool fabrics. *Textile Research Journal*, 2003, **73**(5), 421–426, doi: 10.1177/004051750307300508.
30. MARMARALI, A. B. Dimensional and physical properties of cotton/spandex single jersey fabrics. *Textile Research Journal*. 2003, **73**(1), 11–14, doi: 10.1177/004051750307300102.
31. DEGIRMENCI, Z., TOPALBEKIROGLU, M. Effects of weight, dyeing and the twist direction on the spirality of single jersey fabrics. *Fibres & Textiles Eastern Europe*, 2010, **18**(3), 81–85.
32. ZAMAN, M., WEBER, M. Efect of feeding speeds of elastomeric yarn with 100% cotton yarn on knit fabric spirality. In Proceedings of 46th Interantional Congress IFKT, Sinaia, 2012, 903–909.
33. DESALE, V., RAICHURKAR, P.P., SHUKLA, A., YADAV, R. A. Study on Spirality of Single Jersey Knitted fabric. [dostopno na daljavo]. [citirano 14. 5. 2015]. Dostopno na svetovnem spletu: www.fibre2fashion.com.
34. De ARAUJO, M.D., SMITH, G.W. Spirality of knitted fabrics, Part 1: The nature of spirality. *Textile Research Journal*, 1989, **59**(5), 247–256, doi: 10.1177/004051758905900501.
35. De ARAUJO, M.D., The spirality of knitted fabrics. *Tekstilec*, 1990, **33**(5), 157–167.

36. HAIGH, J. Loop distortion in plain knitted fabrics. *Wool Scientific Rewiew*, 1987, **64**, 84–119.
37. NUTTING, T.S. Spirality in weft knitted fabrics. *Hosiery Research Bulletin*, 1960, **4**, 18–31.
38. HEPWORTH, B. Spirality in knitted fabrics caused by twist-likely yarns: a theoretical investigation. *Melliand Textilberichte*, 1993, **74**, 515–520 (E212–E213).
39. HEPWORTH, B. Spirality in knitted fabrics caused by twist-likely yarns: a theoretical investigation. In *Proceedings of the 34. Congress IFKT*. Brno, 1992, 140–148.
40. MURRELLS, C. M., TAO, X. M., XU, B. G., CHENG, K. P. S. An artificial neural network model for the prediction of spirality of fully relaxed single jersey fabrics. *Textile Research Journal*, 2009, **79**(3), 227–234. doi: 10.1177/0040517508094091.
41. CHOI, K.F., LO, T.Y. An energy model of plain knitted fabric. *Textile Research Journal*, 2003, **73**(8), 739–748, doi: 10.1177/004051750307300813.
42. CHOI, K.F., LO, T.Y. The shape and dimensions of plain knitted fabric: A fabric mechanical mode. *Textile Research Journal*, 2007, **76**(1), 777–786, doi: 10.1177/0040517507069030.
43. KURBAK, A. Plain knitted fabric dimensions. Part II. *Textile Asia*, 1998, April, 36–44.
44. KURBAK, A., SOYDAN, A.S. Geometrical models for balanced rib knitted fabrics. Part III: 2 × 2, 3 × 3, 4 × 4, and 5 × 5 rib fabrics. *Textile Research Journal*, 2009, **79**(7), 618–625. doi: 10.1177/0040517508096218.
45. *Spirality of plain knitted fabrics. Test Method for the Angle of Spirality (in Plain Knitted Garments)*. Woolmark Test Method TM 276, 2000.
46. Standard test method for bow and skew in woven and knitted fabrics [online], [accessed 14. 5. 2015]. Available on World Wide Web: <http://www.astm.org/Standards/D3882.htm>.
47. LY, N. G., DENBY, E. F., HOSCKE, B., N. A Quick test for measuring fabric Dimensional Stability. *Textile Research Journal*, 1988, **58**(8), 463–468.
48. PAVKO-ČUDEN, Alenka. Primerjava laboratorijskih preiskav in poskusnega nošenja pletenin različne surovinske sestave. Magistrsko delo, Ljubljana: Univerza v Ljubljani, Oddelek za tekstilstvo, 1993.
49. PAVKO-ČUDEN, Alenka and MALEJ-KVEDER, Sonja. Primerjava poskusnega nošenja ter laboratorijskega preskušanja stabilnosti dimenzij in poševnosti pletenin (Comparison of wear trials and laboratory testing of knitwear dimensional stability and spirality). *Tekstilec*, 1994, **37**(10), 293–300.
50. CELIK, O., UCAR, N., ERTUHRUL, S. Determination of spirality in knitted fabrics by image analysis. *Fibres & Textiles in Eastern Europe*, 2005, **13**(3), 47–49.
51. SEMNANI, D., SHEIKHZADEH, M. New intelligent method of evaluating the regularity of weft-knitted fabrics by computer vision and grading development. *Textile Research Journal*, 2009, **79**(17), 1578–1587, doi: 10.1177/0040517509104753.
52. PRIMENTAS, A. Spirality of weft knitted fabrics: Part II – Methods fort the reduction of the effect. *Indian Journal of Fbre & Textile Research*, 2003, **28**, 60–64.
53. PRIMENTAS, A., IYPE C. Spirality of weft knitted fabrics: Part III – An innovative method fort the reduction of the effect. *Indian Journal of Fbre & Textile Research*, 2003, **28**, 202–208.
54. De ARAUJO, M.D., SMITH, G.W. Spirality of knitted fabrics. Part II: The effect of yarn spinning technology on spirality. *Textile Research Journal*, 1989, **59**(6), 350 – 356, doi: 10.1177/004051758905900607.
55. HIGGINS, L., ANAND, S. C., HALL, M. E., HOLMES D. A. Factors during tumble drying that infuence dimensional stability and distortion of cotton knitted fabrics. *International Journal of Clothing Science and Technology*, 2003, **15**(2), 126–139, doi: 10.1108/09556220310470132, doi.org/10.1108/09556220310470132.
56. PARK, S.W., COLLIE, S., HERATH, C.N., KANG, B.C. and FUJIMOTO, T. Spirality related mechanical properties of single knit fabrics of linc LITE® and conventional yarns. *Fibers and Polymers*, 2008, **9**(4), 467–475, doi.org/10.1007/s12221-008-0075-4.
57. HOSSAIN, Md. Milon, JALIL, Mohamed Abdul, SAHA, Joykrishna, MIA, Md. Moznu, RAHMAN, Md. Mizanur. Impact of various yarn of different fiber composition on the dimensional properties of different structure of weft knitted fabric. *International Journal of Textile and Fashion Technology*, 2012, **2**(1), 34–44.
58. ASIF, A., RAHMAN, M., FARHA, F.I. Effect of knitted structure on the properties of knitted fabric. *International Journal of Science and Research*, 2015, **4**(1), 1231–1235.
59. MAVRUZ MEZARCIÖZ, Serin, OĞULATA, R. Tuğrul. The use of the Taguchi design of experiment method in optimizing spirality angle of single jersey fabrics. *Tekstil ve Konfeksiyon*, 2011, **21**(4), 374–380.