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Modification of External Layers of Distance Knitted Fabrics with Elastomeric Threads and Its Effect on the Structural Parameters

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Abstract
The article presents the concept of producing distance weft-knitted fabrics of relatively high thickness in regard to the needle pitch and distance between the beds of a flat knitting machine. Such construction was obtained by linking external layers of the knitted fabric with different reports and a number of knitted-in monofilament threads, and also by the modification of external layers using elastomeric threads. Distance knitted fabrics designed for the potential use as preforms for composites and elements protecting against the impact were analised with regard to the structural parameters.

Key words: *distance weft-knitted fabrics, monofilament, elastomeric yarn, algorithm of knitting, structural parameters, flat knitting machine.*

The aim of this work was to produce, with the use of knitting machines, distance knitted fabrics which, as opposed to those produced nowadays, would be characterised by a greater thickness in regard to the needle pitch of the knitting machine. Such a construction was obtained by introducing additional elastomeric threads to the external layers of the knitted fabric (layers 1 and 2 – ***Figure 1.B***) beside the basic threads, thereby increasing the compactness of the knitted fabric and thus changing the arrangement of monofilament threads between the external layers, which increases the thickness of the knitted fabric.

A more perpendicular configuration of monofilament threads and the presence of elastomeric threads increases the transverse rigidity of the knitted fabric, thanks to which the distance knitted fabrics designed can be used as preforms of composites and elements protecting against an impact.

In its simplest form, the idea of a distance knitted stitch comprises two warp-weft knitted fabrics connected with an additional thread, keeping the fabrics at the same constant distance. The thickness of the distance knitted fabric produced according to the algorithm presented in ***Figure 1*** depends on the diameter and mechanical parameters of the thread connecting the layers, and also on the distance between the needle beds of the knitting machine. A similar rule regulating the thickness of the distance knitted fabric is described in articles [1, 2] concerning distance warp-knitted fabrics.

In order to realise the algorithm given in ***Figure 1***, the knitting machine used should have:
- a mechanism enabling to regulate the distance between the needle beds,
- the possibility to use an additional element in the knitting zone helping to hold the joining monofilament fed on the needles (in 3rd system).

Such conditions are fulfilled only by cylindrical knitting machines, with the mechanism regulating the distance between the disk and cylinder. However, the range of such regulation is not sufficient to obtain distance knitted fabrics of greater thickness. Flat knitting machines cannot regulate the distance between the needle beds.

Realising the algorithm presented, without any additional elements supporting the monofilament thread (introduced in system 3) in systems 1 and 2, leads to the lifting up of the thread connecting the layers together with the needles. As a result, the stitch is not formed properly and the knitting process is disturbed. The use of an additional element is easy for a cylindrical knitting machine [2], while introducing an additional supporting element to the knitting zone in the case of a flat knitting machine means redesigning the whole machine.

Numerous literature concerning distance knitted fabrics [6 - 13] describes different aspects of their production and application.

These short considerations and literature analysis show the following:
- regulation of the thickness of the distance knitted fabric only by changing the distance between the needle beds is not sufficient; it is not possible to obtain such stitches with a thickness greater than 2 needle pitches,
- in the case of flat knitting machines, monofilament threads have to be introduced in a way in which other threads forming the external layers support them in the courses where the needles in which the monofilament threads were fed are acting.

In this work we elaborated an algorithm for producing distance knitted fabrics which enable to produce a knitted fabric of relatively great thickness using a flat or cylindrical knitting machine, without the need of regulating the distance between the needle beds.

Distance knitted fabrics were produced on flat knitting machines controlled numerically, made by STOLL, using a CAD/CAM studio cooperating with these knitting machines.

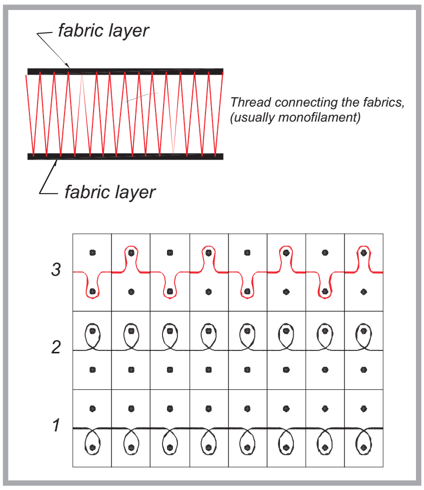

Figure 1. *Idea and algorithm of the distance knitted stitch. A – stitch, B – basic algorithm of knitting.*

An advantage of such machines is the electronic selection of needles, which enables to realize simply the algorithms determined. The machine applied was a flat knitting machine of CMS 530HP, E5 type made by STOLL, designed for producing knitted fabrics for technical applications.

Technological assumptions for the algorithms of knitting determined

Yarns made of Kevlar 49 filament fibres of 158 tex linear density were used in the experiments. A polyamide monofilament of 0.25 mm diameter was used as a thread linking the external layers, keeping the distance between the layers, thereby shaping the thickness of the knitted fabric. The number of monofilament threads in one course was the same in each variant. ULTRALASTIC elastomeric threads of 152 tex linear density were introduced to the external layers of the knitted fabric. Elastomeric thread was fed with 100% draft, together with kevlar yarn. All variants of the knitted fabric were produced using the same parameters of the knitting machine.

Elastomeric thread was used in order to increase the thickness of the knitted fabric by decreasing the distance between the loops. As the experiments showed, the introduction of elastomeric thread to the external layers of knitted fabric increases its thickness by bringing the wales closer to each other and, consequently, leads to a perpendicular arrangement of the monofilament threads with regard to the external layers (***Figure 3.C***). Distance knitted fabric with additional elastomeric thread is more resistant to compressive forces, acting perpendicularly to the stitch surface, which corresponds to the theoretical considerations of the authors of articles [3 - 5].

A basic assumption in determining the algorithms of knitting for the distance knitted fabrics was the diversification, in each variant, of knitting monofilament threads into a course of fabric, maintaining the distance. It should be mentioned that the algorithm and its principles of elaborating given in ***Figures 2*** and ***3*** are of a general character, as they concern the process of knitting using flat and cylindrical knitting machines. The variants were the following: 0tu, 1tu, 2tu, 3tu, 4tu, 5tu & 6tu, where tu stands for the needle pitch, while the digit represents the number of needle pairs omitted between subsequent needle pairs knitting-in the monofilament with the interlock arrangement of needles.

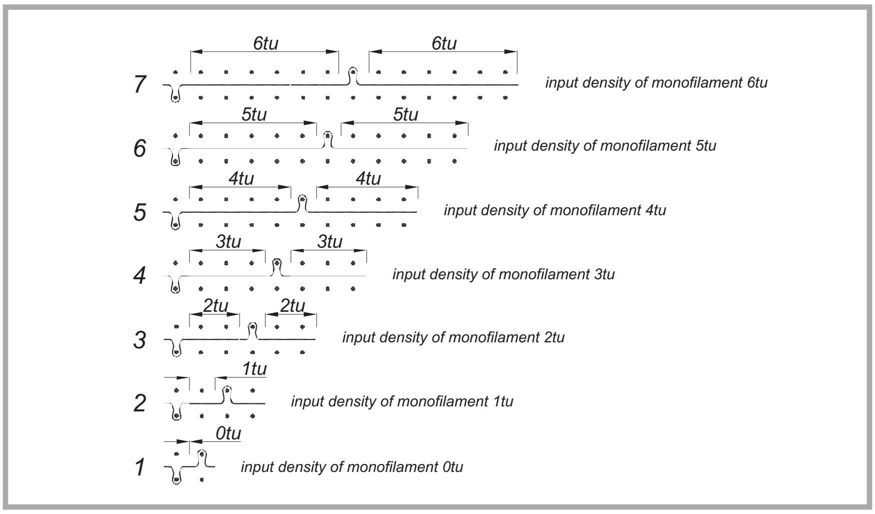

Figure 2. *Principle of knitting-in and labelling variants of distance knitted fabrics.*

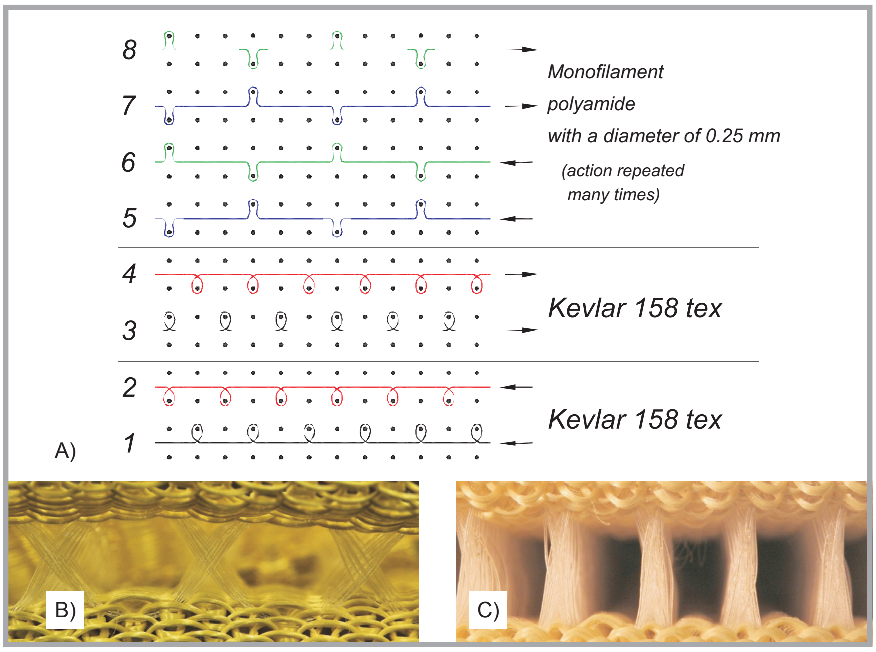

Figure 3. *Variant 3tu of a distance knitted stitch with Kevlar filament yarn. A – algorithm of knitting, B – cross-section of the stitch created using kevlar only, C – cross-section of the stitch created using kevlar and elastomeric thread.*

The principle of knitting-in the monofilament and determination of variants of distance knitted fabrics are illustrated in ***Figure 2.***

A report of introducing a monofilament included a work of four systems, which was repeated three times, giving 12 monofilament threads in each course of stitch. It means that in the hook of one needle knitting-in the monofilament, besides the basic thread, there are also 6 monofilament threads at the end of the report. The variants from 0tu to 6tu are characterised by the following similar arrangement of monofilament threads with and without elastomeric threads, which is presented as an exemplary variant - 3tu, with a schematic configuration of threads on the needles (***Figure 3***).

The interlock method of introducing monofilament leads to the grouping of monofilaments introduced in the same place inside the stitch. In order to check the possibility of compacting and dispersing monofilament threads in one course, two additional variants of knitted fabric were formed, extending variant 5tu.

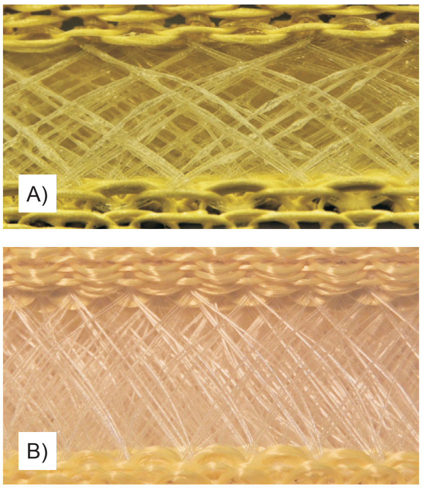

Figure 4. Variant 5tu -A of a distance knitted stitch with Kevlar filament yarn, A– cross-section of the stitch created using kevlar only, B – cross-section of the stitch created using kevlar and rubber thread.

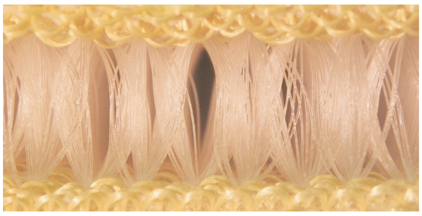

Figure 5. Variant 5tu – B, cross-section of the stitch created using kavlar and elastomeric thread.

These two additional variants were marked as 5tu – A and 5tu – B, in which the way of knitting-in the monofilament was modified.

Variant 5tu – A (***Figure 4***) is characterised by a large number of monofilaments incorporated. Subsequent pairs of monofilament threads were introduced with a displacement of two needle pitches. As a result, the whole inner space of the stitch was filled with monofilaments. At each course of the stitch, 24 monofilaments were introduced with a single realisation of the algorithm introducing the monofilament. The attempt presented in this paper contained 48 monofilaments in one course, as the part of the knitting algorithm introducing the monofilament was repeated only twice. The number of monofilament threads in the hook of a needle at the end of knitting one row of loops was only 2. Repetition of the part of the algorithm introducing the monofilament increased the number of monofilaments in one row of the stitch. Such an introduction of a monofilament limits the thickness of the fabric but increases its compression rigidity. A disadvantage of such a thickening of the internal space of the distance with a monofilament is a decrease in the efficiency of the machine and an increase in the surface mass.

Variant 5tu – B (***Figure 5***) differs from the basic variant 5tu only in the density of the monofilament arrangement in the internal layer.

Summing up, the variants of distance knitted of the knitted fabric and influencing their mechanical properties.

A combination of feeding monofilaments in variant 5tu – A allows to decrease and disperse empty spaces inside the stitch, obtaining:
- an increase in compression rigidity (positive),
- a decrease in the thickness of the stitch for basic variant 5tu,
- an increase in the surface mass,
- a decrease in efficiency.

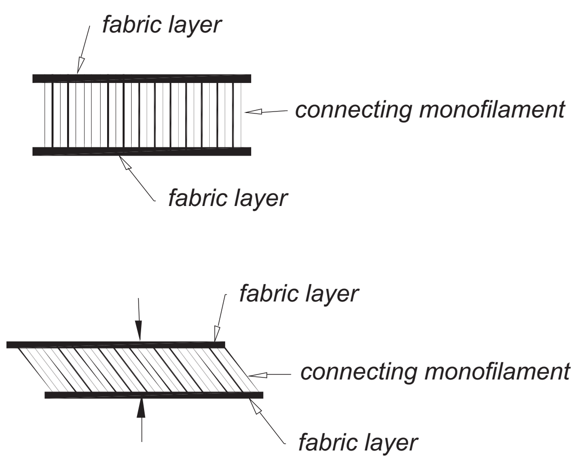

Figure 6. Behaviour of distance knitted fabrics produced using algorithm I during the process of compression.

Analysis of structural parameters of distance knitted fabrics

16 variants of knitted fabrics were analysed with regard to their structural parameters. Moreover, two additional variants, 5tu – A and 5tu – B, described in the previous chapter, were formed.

All variants of distance stitches were designed in two versions – with and without elastomeric thread. Those made without elastomeric thread were characterised by a smaller surface mass, lower thickness and lower compression rigidity.

The algorithm of introducing monofilaments was repeated several times, allowing to introduce 12 to 48 monofilaments into one course of loops. Three different algorithms of knitting-in a monofilament were applied:
- algorithm I - basic interlock (variants 0tu, 1tu, 2tu, 3tu, 4tu, 5tu & 6tu),
- algorithm II - interlock for both threads, but subsequent knitting-in of monofilaments was performed with a displacement of ½ knitting-in report (variant 5tu – B),
- algorithm III - interlock for both threads, but subsequent knitting-in of monofilaments was performed with a displacement of one pitch (variant 5tu - A).

Algorithm I gives the greatest thickness; the knitted fabric contains empty channels inside its structure, which during application can be easily filled with a resin, obtaining a composite. However, algorithm I gives a fabric whose external layers are displaced in the compressing process with forces acting perpendicularly. Therefore, the thickness of the knitted fabric decreases, which is presented in ***Figure 6***.

Variant 5tu – B limits this effect, while variant 5tu – A completely eliminates it (***Figures 4 and 5***). Variant 5tu – A is characterised by:
- lower thickness than the basic variant 5tu,
- a large number of monofilament threads in one course (higher compression rigidity),
- a great filling of the stitch by the monofilaments,

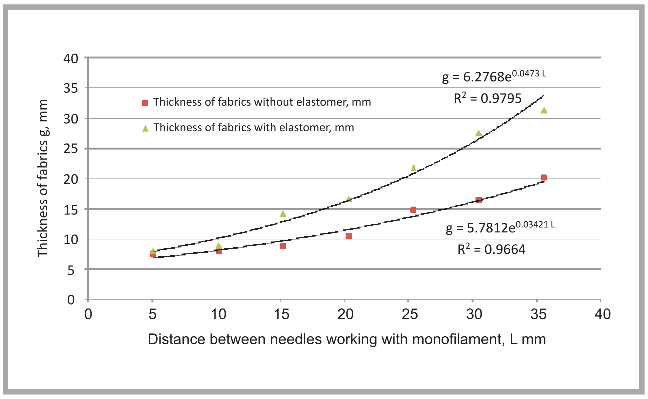

Figure 7. *Thickness of distance knitted fabrics made of 158 tex Kevlar.*

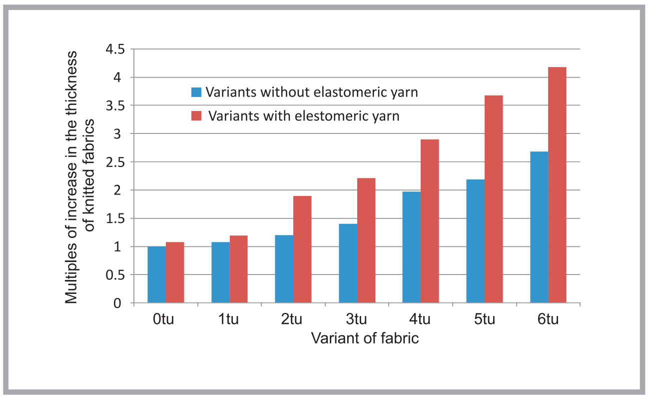

Figure 8. *Multiples of increase in thickness of knitted fabrics in relation to 0tu variant made without the elastomer.*

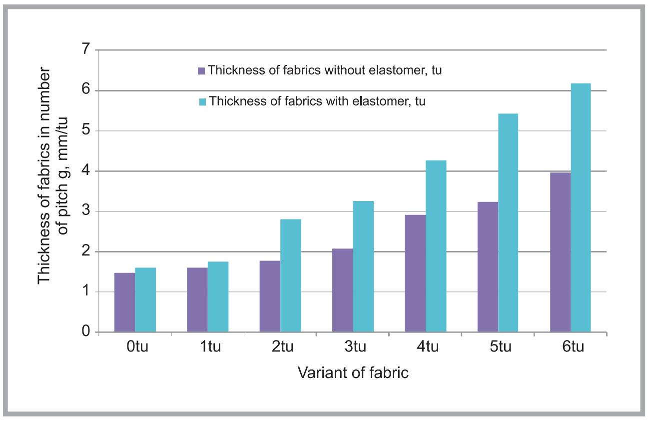

Figure 9. *Thickness of distance knitted fabrics expressed by the number of needle pitches.*

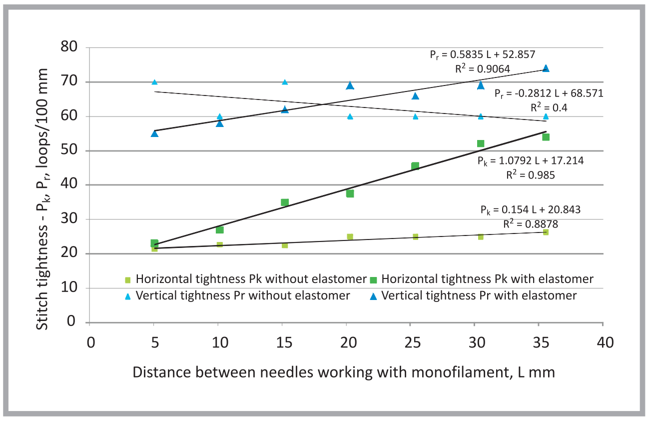

Figure 10. *Influence of elastomeric thread on the stich density of distance knitted fabric.*

- a limited number of monofilament threads fed to the hook of the same needle,
- a lack of horizontal displacement of the knitted fabric's external layer in relation to that adhering to the background during the compressing process,
- possible regulation of transverse rigidity by:
  - changing the number of monofilaments in one course of loops,
  - using a monofilament of a different diameter of the cross-section.

Main disadvantages of variant 5tu – A are the following:
- an increase in the surface mass of the knitted fabric
- a decrease in the efficiency of the knitting machine.

Thickness of distance knitted fabrics

Distance knitted fabrics made of elastomeric yarns in the external layers are characterised by higher thickness values than those made without those yarns. According to the results presented in ***Figure 7***, the thickness of the knitted fabrics increases with an increase in the length of the underlaps of monofilament threads (***Figure 2***) (referring to distance knitted fabrics made with and without elastomeric threads), while the intensity of the increase in the knitted fabric's thickness is higher for those made of elastomeric threads (***Figure 7***).

The increase in the thickness of a knitted fabric obtained by adding elastomeric threads is presented in ***Figure 8***.

The introduction of elastomeric thread to the distance knitted fabric increases the thickness thereof, up to 4 times (e.g. for 6tu variant).

In order to enable to predict the thickness of distance knitted fabric regardless of the needle pitch of the knitting machine used, the thickness of the knitted fabrics was defined by the number of needle pitches, which is presented in ***Figure 9***.

There are no significant differences in the values of thickness between variants 0tu, 1tu and 2tu without elastomeric thread, its value being near that for 1.5tu (***Figure 9***).

An increase in the thickness of knitted fabric after the introduction of elastomeric threads depends on the length of the underlaps of monofilament threads, and it increases with an increase in the length of the underlaps. The introduction of elastomeric thread to the structure of the knitted fabric enables an increase in the thickness of knitted fabric of two needle pitches in comparison to that without such threads.

Stich density of distance knitted fabric

According to expectations, the introduction of elastomeric threads to the external layers of distance knitted fabric increases the thickness thereof, while an increase in the thickness of wales is bigger than that in the thickness of courses (***Figure 10***), due to the knitting-in of the elastomeric thread stretched along the courses.

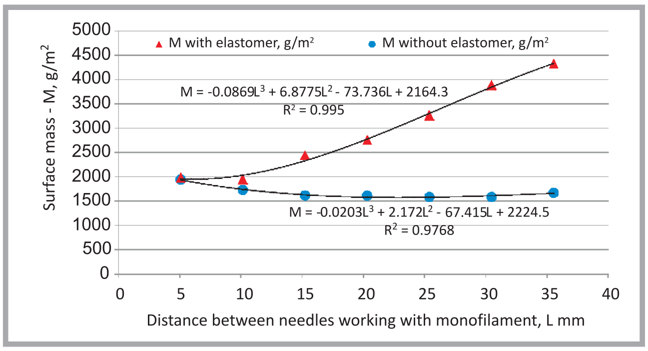

Figure 11. *Surface mass of distance knitted fabrics made of 158 tex Kevlar.*

Surface mass

The modification of external layers of distance knitted fabric with elastomeric threads leads to an increase in the surface mass due to an increase in the surface stich density, which is the main factor influencing its value. For the extreme variants of knitted fabrics with elastomeric threads, a more than double increase in the surface mass was noted, from 1980 to 4322 g/m^2 (***Figure 11***).

However, for variants without elastomeric threads, a decrease in the values of surface mass was noted, when comparing to the initial variant 0tu - 14%.

Conclusions

As the experiments show, it is possible to increase the thickness of distance knitted fabrics without changing the distance between the needle beds of the knitting machine.

The thickness of the distance knitted fabric can be shaped by changing the distance between subsequent needles knitting-in the monofilament thread. With an increase in the distance between the needles knitting-in the monofilament, the thickness of distance knitted fabrics also increases.

The possibilities of increasing the distance between the needles knitting-in monofilament threads are limited by the geometry of the knitting machine. In the case of flat knitting machines, the maximum value of such a distance equals 6 needle pitches, while for cylindrical knitting machines the maximum value of this distance can be higher.

Dispersed knitting-in (variant 5tu – A) of monofilament threads leads to the following:

- the possibility of a significant increase in the number of monofilament threads in one course of knitted fabric,
- a decrease in the thickness of the knitted fabric,
- an increase in the compression rigidity,
- a decrease or even disappearance of the phenomenon of mutual displacement of the external layers of knitted fabric during compression,
- an increase in the surface mass,
- a decrease in efficiency.

The introduction of elastomeric yarn to the structure of knitted fabrics composed of distance knitted stitch leads to the following:

- an increase in the stich density of the knitted fabric,
- an increase in the thickness of the knitted fabric up to 4 times, when compared to variant 0tu made without elastomer.
- an increase in the surface mass.

In the case of fabrics knitted without elastomeric yarns, the surface mass decreases, while the thickness of the knitted fabric increases with an increase in the length of the underlaps of monofilament threads.

The algorithms of knitting developed can be applied to warp knitting machines controlled numerically, which have optional electronic selection of needles.

The algorithms of knitting presented in the article can be applied to knitting machines controlled mechanically only in the case of a technique of knitting with at least four channels, in both needle beds. However, the preparation for working in the case of such knitting machines is very labour-intensive.

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References

1. Pieklak K, Mikołajczyk Z. Spatial Model of the Structure of Warp – Knitted 3D Distance Fabrics. *Fibres &Textiles in Eastern Europe* 2008; 16, 5(70): 83-89.
2. Kowalski K, Bednarski G. Struktur und Eigenschaften einer neuen Gruppe gestrickter Abstandstextilien. *Melliand Textilberichte* 1998; 5: 384-386.
3. Supeł B, Mikołajczyk Z. Model of the 3D Distance Knitted Fabric's Connector Fastened by Articulated Joints. *Fibres &Textiles in Eastern Europe* 2008; 16, 5(70): 77-82.
4. Supeł B, Mikołajczyk Z. Model of the Compressing Process of a One- and Two-Side Fastened Connector of a 3D Distance Knitted Fabricxcel. *Fibres &Textiles in Eastern Europe* 2008; 16, 6(71): 44-48.
5. Supeł B, Mikołajczyk Z. Modelling the Process of the Compression of Distance Knitted Fabrics in the Aspect of 'Elastica Curves. *Fibres &Textiles in Eastern Europe* 2010; 18, 4(81): 52-55.
6. Penciuc M, Blaga M, Ciobanu R. Principle of creating 3D effects on knitted fabrics developed on electronic flat knitting machines. Buletinul Institutului Politechnic DIN IASI Publicat de Universitatea Tehnică „Gheorghe Asachi" din Iasi Tomul LVI (LX), Fasc. 4, 2010 SecŃia TEXTILE. PIELĂRIE,
7. Bruer S. Three-Dimensionally Knit Spacer Fabrics: a Review of Production Techniques and Applications. *Journal of Textile and Apparel, Technology and Management* 2005; 4.
8. Araujo M. Modelling and Simulation of the Mechanical Behaviour of Weft Knitted Fabrics for Technical Applications. *Autex Research Journal* 2004; 4; 2.
9. Lam JKC, Zhou JY. Principle on 3D Knitted Fabrics, a Knitter's Perspective. In: *1st World Conference on 3D Fabrics and their Applications*. 10-11 April 2008, Manchester, UK.
10. Blaga M, Penciuc M. 3D Applications Produced on Knitted Fabrics. In: *44 Congress IFKT Knitting round the clock*, Knitting Technology Saint-Petersburg, 23-27 September 2008.
11. Penciuc M, Blaga M, Radu CD. Manufacturing of 3D Complex Knitted Shapes. In: *45th International Congress IFKT;* 2010: 1000−1005.
12. Abounaim M. 3D Spacer Fabric as Sandwich Structure by Flat Knitting for Composite Using Hybrid Yarn. In: *Autex 2009 World Textile Conference*. , Kadoglu H. (Ed.), Izmir, 2009, 675−681.
13. Abounaim M. *Process development for the manufacturing of at knitted innovative 3D spacer fabrics for high performance composite applications*. Ph.D. Dissertation, Technischen Universitat Dresden, Fakultat Maschinenwesen, 2010.

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