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Original Concept of a New Multicomb Warp-knitting Machine for Manufacturing Spatial Knitted Fabrics

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Abstract
This article presents an original concept of warp-knitting machine construction with more than two needle combs. The technical and technological parameters of the warp-knitting machine with even and odd numbers of needle combs were characterised. The geometry of mutual positions of the basic machine elements were determined including the needle combs, needle bars and the holding sinker combs in relation to the knocking-down combs. A concept of the whole structure of the machine is presented, as well as the structure of the hybrid drives of the loop forming elements, devices feeding the threads, the take–up devices and storage parts for the spatial knitted fabrics.

Key words: *warp-knitting machine, multi-comb, spatial knitted fabrics, structure concept.*

Introduction

Technologies for manufacturing spatial distance three and five layer knitted fabrics are already known. Such knitted fabrics are manufactured with the use of warp-knitting machines equipped with two frontal and two back needle combs which are placed mutually parallel in such a way that the needles are positioned opposite each other and their hooks directed outwards. Changes in the distance x between the needle combs determines the thickness of the knitted fabric manufactured. In most cases two-comb warp-knitting machines are used with six needle bars, four of which form external layers (two on each side) and two needle combs form one or two internal layers of the knitted fabric. With the use of this group of machines, it is also possible to manufacture circular knitted fabric structures.

Left-right relief structures manufactured using the wale micromesh weave technology can also be included in the group of spatial knitted fabrics. These structures are characterised by small depressions and protrusions which indicate the three-dimensional character of this product. However, scientific and university literature do not regard this group of knitted fabrics as having a 3D structure.
Warp-knitting machines are used in classical technologies with one flat or circular needle comb or with a maximum of two needle combs for manufacturing rib stitch products. The needle combs in these machines work in convertible systems, where the needle bars are driven in a pendulous way.

A review and analysis of scientific and patent literature carried out by us indicated that no other 3D structures exist, as well as no warp-knitting machines equipped with more than two needle combs.

The situation mentioned above inspired the authors to create a new innovative concept of a technology for manufacturing such spatial 3D - solids as knitted fabrics, which could be applied primarily for the production of technical textiles [6]. Our proposition in no way limits the application of this patented technology for the manufacturing of other groups of knitted fabric assortments.

Concept of the structure of the warp-knitting machine

A warp-knitting machine with a number of needle combs greater than two for manufacturing spatial knitted products in the shape of geometrical solids can be equipped with an even or odd number of needle combs. The number of needle combs and the essential features of their structure precisely determine the shape of the product manufactured. A warp-knitting machine has a preliminary assumed number of needle combs as well as a number of basic and edge needle bars. As an analogy to one– and two-comb flat rashel warp-knitting machines, the needle combs can be equipped with tube needles, bearded needles, latch needles, or shedding needles.

Similar to classical constructions of warp-knitting machines, a machine with a number of needle combs greater than two is equipped with holding sinkers and knocking –down combs. During the lifting motion of the needle combs, the holding sinkers hold the loop previously formed. The knocking–down combs form a closed external channel in which subsequently formed loops of the external layers and the threads of the internal layer are taken-up.

The way of feeding threads is already known from the structure of warp-knitting machines. Considering the structure of a warp-knitting machine designed for manufacturing spatial knitted products in the shape of geometrical solids, we analysed the possibility of negatively feeding thread but with the active aid of winding threads from warp beams by using using spring or pneumatic compensators. Feeding the knitting zone with thread from creeling frames is an alternative solution. In the structure of a warp-knitting machine with the number of needle combs greater than two, we designed an entirely different way of taking up the knitted fabric. The reason for this is that the product has a spatial form with a thickness of tens to hundreds of millimetres.

The warp-knitting machine described in this work is devoted to manufacturing spatial products in the shape of geometrical solids, in which we can identify two variants of driving the loop forming elements:
- the mechanical drive of lifting the needles, needle bars and sinkers;
- the mechanical-electric drive based on individual drives of the particular element realised with the use of a linear step motor.Special optimisation of the machine construction can be undertaken to use joined hybrid drives which connect the mechanical solutions with the electronic systems controlled by servo-motors.

A significant feature of this group of warp-knitting machines is their working speed, which, according to the author's concept, should be of a value within the range of 100 ÷ 150 spatial courses

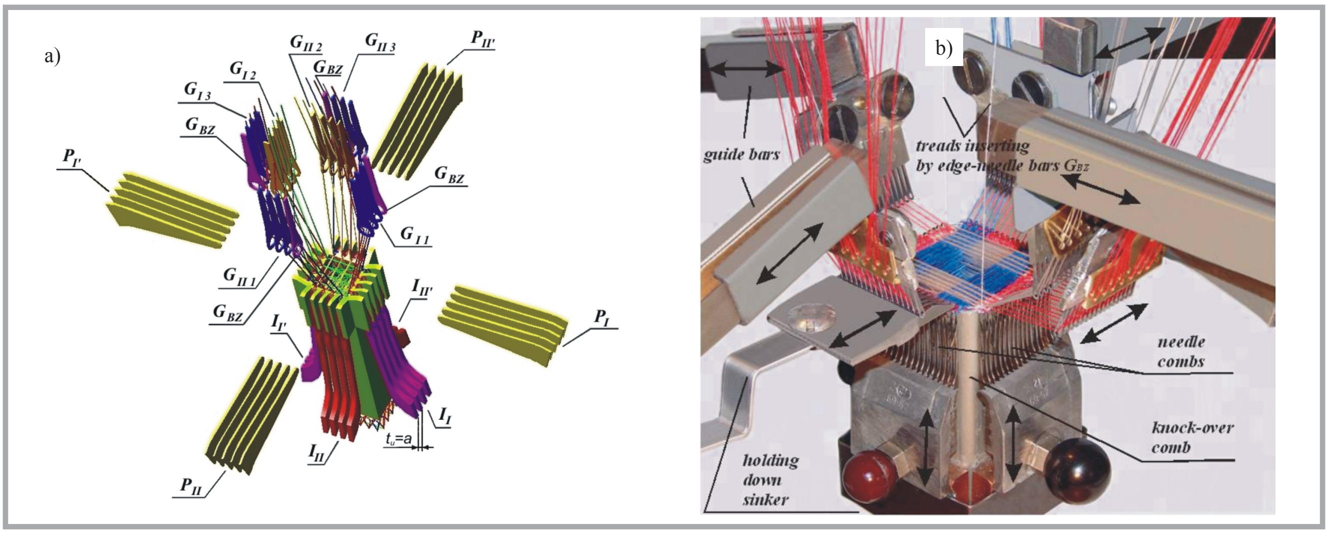

***Figure 1.** Concept of a four-comb warp-knitting machine for the formation of spatial knitted products: a) a schematic drawing of the structure and component elements of the machine, b) a photograph of a working model.*

per minute. This range is primarily limited by the complexity of the motion of loop forming elements, as well as their number.

Warp-knitting machine with an even number of needle combs greater than two.

In the case of a machine with an even number of needle combs, the pairs of these combs are placed mutually opposite each other on parallel planes or planes slightly declined out of plumb (***Figure 1.a***). The needle combs used were of the flat variety, which are placed

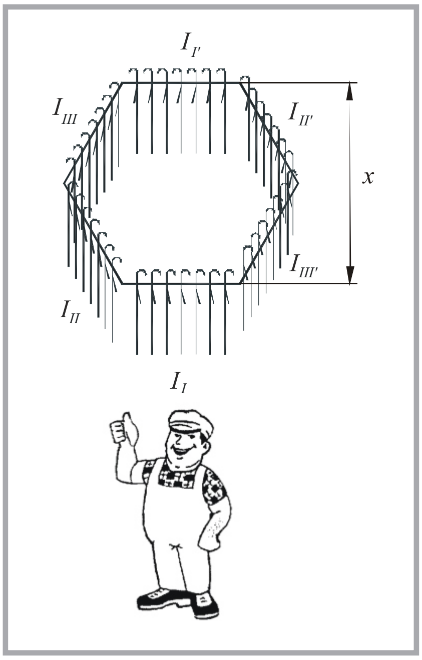

***Figure 2.** Principle of numbering of the needle combs in a six-comb warp-knitting machine.*

in a particular order that determined the shape of the solid's cross section of the spatial knitted product.

The new concept of the machine discussed was realised in the form of a working model, as presented in ***Figure 1.b***. The prototype of the machine built by us has four needle combs, six needle bars (four of them work in the formation of the external layers of the product, whereas there are two which insert threads for the internal layer), combs for the holding sinkers, and knocking down combs, which form a closed channel into which the final knitted product is taken up. Using the working model of a multi-channel warp-knitting machine, a fragment of a spatial knitted product was manufactured in order to confirm the correctness of the construction assumptions. For the new concept of warp-knitting machine discussed, we propose a new principle for numbering the needle combs. This numbering is presented in ***Figure 2***, using a six-comb machine as an example. The needle combs are numbered in such a way that we can assume that the first needle comb (designated as I_I) is placed nearest the operator of the machine, who stands in front of it. The comb opposite comb I_I is numbered as I_I'. Subsequent pairs of needle combs are designated I_{II}, I_{II}' and I_{III}, I_{III}', whose numbering increases in a clockwise direction.

Taking into account the same practical and economical factors, generally we assume the application of 6 ÷ 8 combs maximum. However, this statement does not limit the construction of machines with a greater number of such combs - applying a greater number of needle combs would allow to obtain spatial wale knittings forming a regular prism similar to a cylinder.

The needling number ***E*** of all the machine's needle combs can be the same for particular opposite pairs of combs or can have different values. This means that E_i = constant or $E_i \neq$ constant, where E_i is the needling number of the ***i-th*** pairs of needle combs. The width ***S*** of the particular needle comb pairs can be

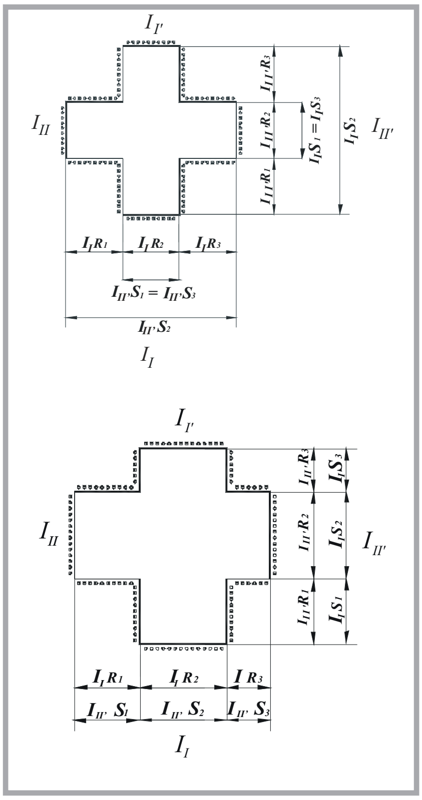

***Figure 3.** Arrangement concept of needle comb segments.*

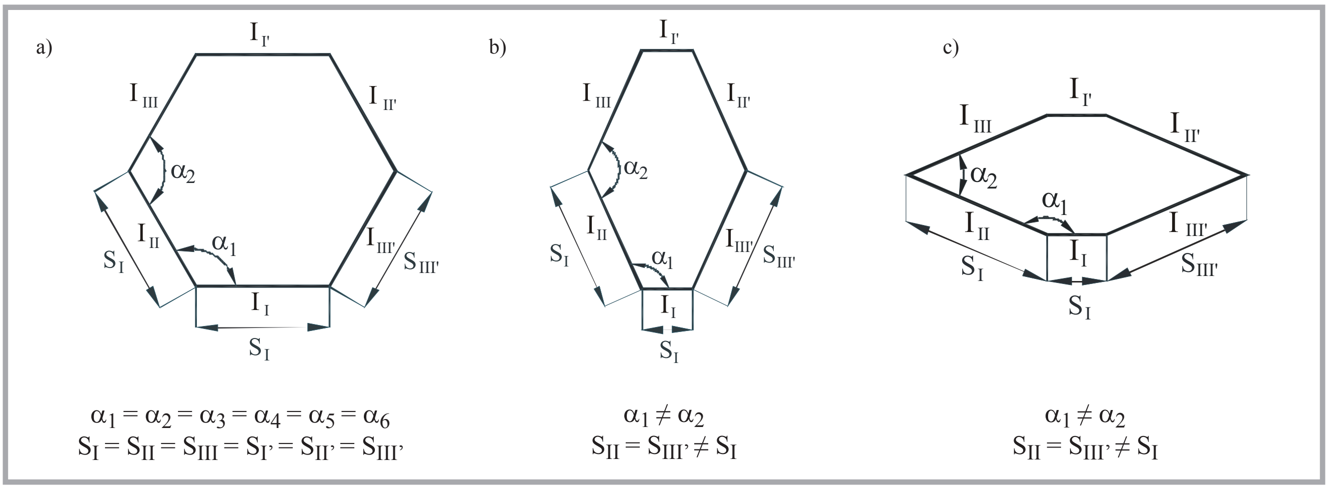

***Figure 4**. Examples of the mutual arrangement of needle combs in a six-comb warp-knitting machine.*

the same or different, which means that S_i = constant or $S_i \neq$ constant, where S_i is the width of the ***i-th*** needle comb pair. Parallel pairs of needle combs can be divided into ***k*** segments of different width R_i with differentiated distance between them, which will allow to manufacture a product with a more complex structure of the external layers (***Figure 3***). The width of needle bars or their segments determines the geometrical dimensions of the cross-section of the knitted product of a solid manufactured.

The angle α between neighbouring needle combs can have the same or different values, which means that α_i = constant or $\alpha_i \neq$ constant (***Figure 4***). Changes in the value of the needling number ***E***, width ***S***, as well as the angle α allow the creation of products with differentiated geometrical and structural parameters of the knitted product's external layers. In classical warp-knitting machines the needle combs are lowered by a a constant value of the knocking down depth in relation to the knocking down sinkers. In the warp-knitting machine designed to manufacture spatial knitted products in the shape of geometrical solids, the possibility of differentiating the knocking down depth is provided, due to separate needle combs, (which means that ($Z_i \neq$ constant of the distinct needle combs) in order to create different structural parameters of the external layers of spatial knitted solids.

On a warp-knitting machine devoted to manufacturing spatial knitted products in the shape of geometrical solids, groups of needle bars can be indicated which cooperate with particular needle combs or their pairs. In analogy to warp-knitting machines with systems of two needle combs, it is assumed that the number of needle bars can be different. Most often in order to manufacture technical products with the use of two-comb warp-knitting machines, six needles bars are applied. In the case of the warp-knitting machine presented in this article, which has a number of needle combs greater than two, the number of needle bars is unlimited), this concerns these bars which insert the threads of the external layers, as well as those which form the internal layer. Irrespective of the complexity of the structure of spatial knitting products in the shape of geometrical solids, the number of needle bars can be related to the number of systems of inserting the threads required. The needle bar's draw-in (threaded), with threads of the external layers and the internal layer, is designated by the capital letter ***G*** with two indexes ***p*** and ***k*** (G_{pk}),where ***p*** is the subsequent pair of needle combs and ***k*** the subsequent needle comb cooperating with the particular pair of needle combs. The index ***k*** = 1 is related to the needle comb placed nearest the needle comb designated I_i (without "prim"). The designation system mentioned above belongs to a new description that is consistent with the order of the mutual arrangement of loop forming elements of a warp-knitting machine. This system can also serve as a description of the component weave order of the spatial knitted product.

An example of the designation of the order of needle bars for system I_I - I_I' is presented in ***Figure 5.*** Some of the needle bars cooperate only with those needle combs forming the external layers of the product, whereas a number of pairs of combs produce the internal layer. In classical two-comb warp-knitting machines, the needle bars move in a swinging motion. The motion of the needle bars in a warp-knitting machine for manufacturing spatial knitted products has a push-pull character in the plane perpendicular to the knitted solid created. This kind of drive occurs primarily due to the new technology which is distinguished in that it creates empty spaces for subsequent systems of needle bars knitting on opposite needles. The work of these combs is strictly dependent on the order of formation of the knitted product loops.

Additionally in each of the needle bars G_{pk}, which insert threads in the external layers of the product, one of the edge needle boards G_{BZ} is individually controlled. These needle boards feed the edge needles of the neighbouring needle combs with a separate thread (***Figure 6***). Between the neighbouring systems of loop forming elements, this needle board moves in such a way that its motion closes the external structure of the solid of the knitting in the place where these systems are in contact (***Figure 7***). The number of separately controlled needle boards is exactly dependent on the shape

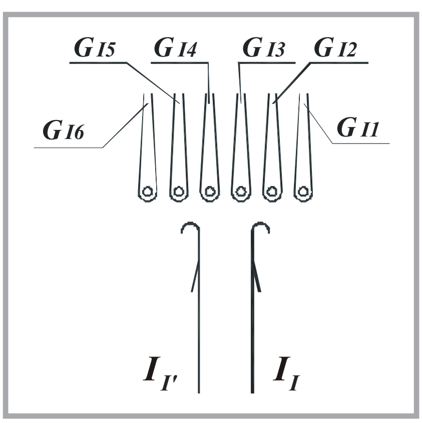

Figure 5. *Example of the numbering of needle bars for system I_I – I_I'.*

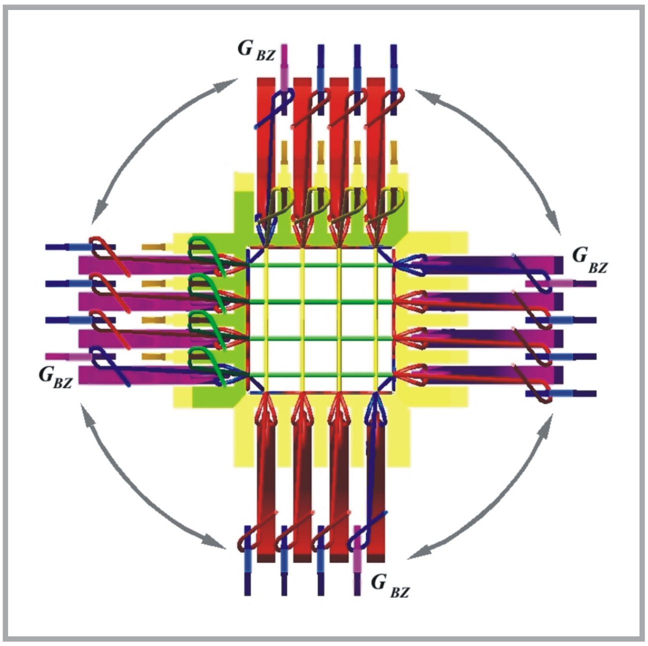

Figure 6. *Concept of individual control of the edge needle bars G_{BZ} in a warp-knitting machine with an even number of needle combs greater than two.*

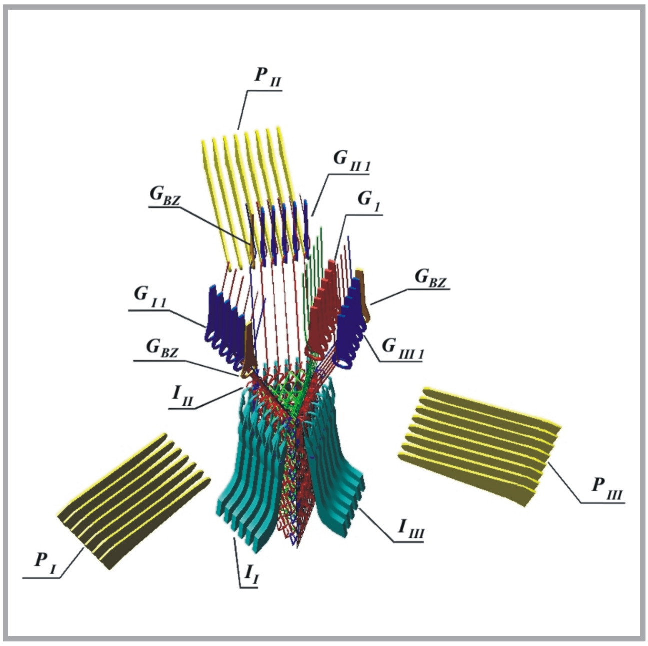

Figure 9. *Concept of a tree-comb warp-knitting machine for manufacturing spatial knitted products.*

of the figure forming the cross-section of the knitted solid and is related to the number of sides of this figure.

In the warp-knitting machine described in this paper, a new concept of the take-up mechanism and winding device for wale spatial knitting was applied. This concept has hitherto not been used in warp-knitting machines. The take-up devicee is built from take-up rolls whose number is equal to the number of sides of the knitted solid. The take-up rolls are arranged along the width of the needle comb, or its segments and act on the external layers of the spatial product manufactured. An alternative solution for a take-up mechanism can be the pneumatic type, which sucks air from outside, from the side of the needle hooks and acts on the threads of the external and internal layers, causing the creation of a take-up force. However, considering the relatively large electrical energy consumption of the sucking generator, this solution is not energy-saving, and is not generally recommended. A storing mechanism cooperates with the take-up device in the form of a dextrorotatory or laevorotatory screw shaft, whose structure prevents the deformation of the spatial knitting product under manufacture.

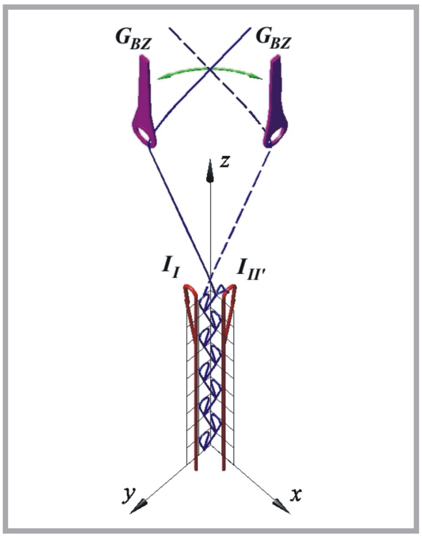

Figure 7. *Working principle of the individually controlled needle bar G_{BZ}.*

Warp-knitting machine with an odd number of needle combs greater than two

The next structural variant of a warp-knitting machine described in this paper is one with a number of needle combs greater than two, which is designed for manufacturing spatial knitted products in the shape of geometrical solids. It is a machine with an odd number of needle combs (***Figure 9***).

This machine, similar to warp-knitting machines with an even number of needle combs, can have constant or differing values of such parameters as the needling number $\boldsymbol{E}$ of all the needle combs, the widthe $\boldsymbol{S}$ of particular needle combs and the angle $\boldsymbol{\alpha}$ between neighbouring needle combs (***Figure 10***).

The needle combs are numbered in the same way as before, which means that by $\boldsymbol{I_I}$ we understand that this comb is the nearest to the operator standing in front of the machine. Subsequent needle combs have the following designations: $\boldsymbol{I_{II}}$, $\boldsymbol{I_{III}}$, etc. whose numbering increases clockwise. In the case of this machine, the needle combs are lifted from $\boldsymbol{I_I}$ to the last. Taking into account the construction of the warp-knitting machine in order to avoid the possibility of the occurrence of working collisions of neighbouring needle combs, it is not permitted to lift

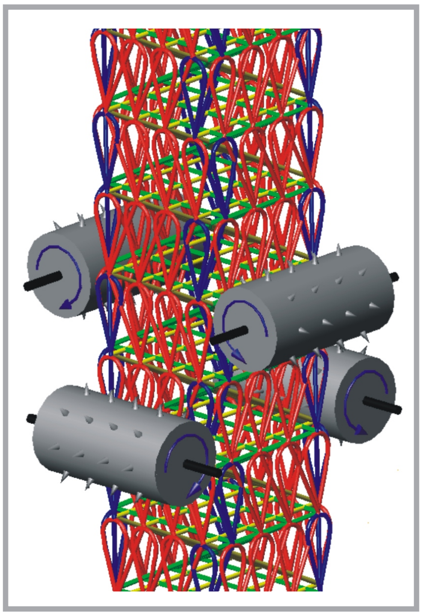

Figure 8. *Take-up devised for a spatial knitted product.*

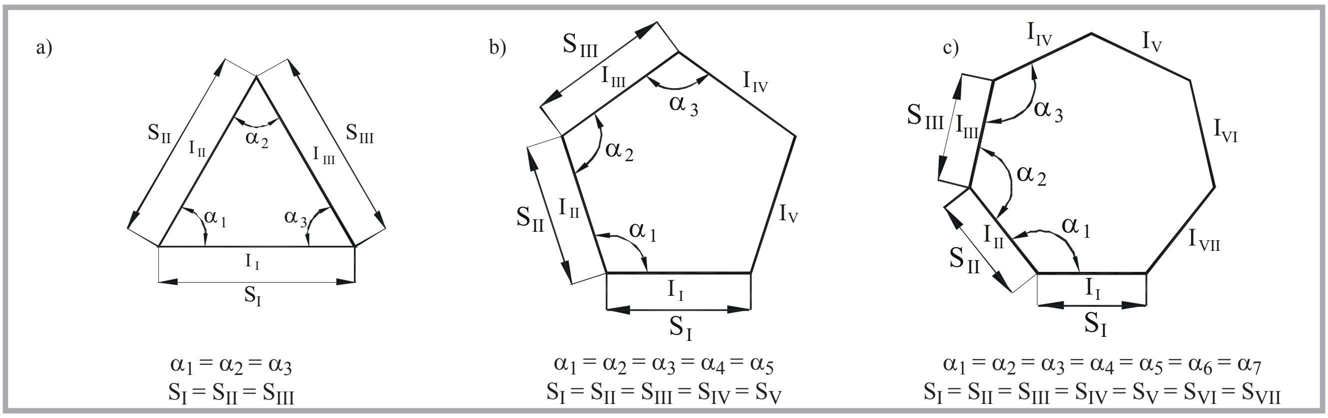

***Figure 10**. Examples of arrangements of the needle combs of a warp-knitting machine with an odd number of these combs.*

particular needle combs at the same time. Lifting needle combs at the same time is possible only in warp-knitting machines with a minimum of five needle combs. For example, in a five - comb knitting machine, the needle comb I_I can cooperate with combs $\boldsymbol{I_{III}}$ or $\boldsymbol{I_{IV}}$, whereas $\boldsymbol{I_{II}}$ cooperates with comb $\boldsymbol{I_{IV}}$ or $\boldsymbol{I_V}$.

In a warp-knitting machine with an odd number of needle combs devoted to manufacturing spatial knitted products in the shape of geometrical solids, we can identify groups of needle bars which cooperate with particular or with all needle combs. The motion of the needle bars also have a push-pull character in relation to the needle combs. The one or several needle bars inserting the threads into the internal layer are equipped with a rotary mechanism hitherto not used in warp-knitting machines, which allows it to cooperate with all needle combs; this can be clearly seen in ***Figure 11***. Similar to the machine with an even number of needle combs, here in each needle bar inserting threads into the external layers of the product, there are separately controlled edge needle boards, $\boldsymbol{G_{BZ}}$, which close the external layers of the product's form. The needle bars which are threaded with threads of the external layers are designated by indexes ***p*** and ***k*** ($\boldsymbol{G_{pk}}$), where ***p*** is the subsequent needle comb, and ***k*** is the next needle comb cooperating with the particular needle comb. The index ***k*** = 1 is related to the comb which is nearest in relation to needle comb $\boldsymbol{I_i}$, whereas the needle bars threaded with threads of the internal layer are designated by the capital letter ***G*** with index ***k*** ($\boldsymbol{G_k}$), where ***k*** is the subsequent needle bar cooperating with all needle combs $\boldsymbol{I_i}$, where ***k*** = 1 is related to the comb placed nearest needle comb $\boldsymbol{I_i}$.

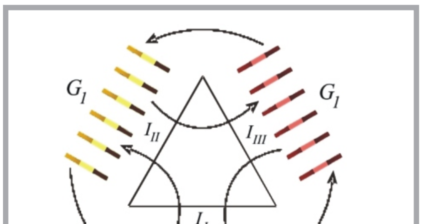

***Figure 11.** Working principle of the rotary mechanism of needle bars inserting threads of the internal layer.*

Summary

- A characteristic feature of the new concept of warp-knitting machine, which is primarily devoted to manufacturing spatial knitted products, is the existence of more than two needle combs. The new concept includes two types of warp-knitting machines: the first with an even and the second with an odd number of needle combs. The geometrical features of the needle combs determine explicitly the shape of the regular or irregular solids of the spatial product created, as well as the parameters of the knitted structure.
- In contrast to existing warp-knitting machines, the one proposed by us is equipped with a device characterised by the negative feeding of threads with a system of mechanical or pneumatic compensators, knocking down combs of the holding sinkers and needle bars. Taking into account the peculiarity of the technology for manufacturing spatial products, the needle bars have a push-pull motion, and in the case of a warp-knitting machine with an odd number of needle combs, it has an additional rotary motion. The needle bars are additionally equipped with separate edge needle boards, G_{BZ}, whose purpose is to connect external layers of the knitting in the edge zone. Regarding the motion of the needle combs, for the sinkers' combs as well as the needle bars, the application of a hybrid drive (a mechanical-electronic drive) can be considered.
- A novelty in the proposed machine is the structure of the take-up and storing devices. A characteristic feature of the take-up device is a group of rolls which does not deform the structure of the knitted product manufactured. Thanks to the suitable relief (tooth-like) structure of the rolls' surface, during rotation, the product being manufactured is taken-up and can be stored on a screw shaft or in a machine with a vertical system under it.
- On the basis of the defined structure assumptions of the new concept of multi comb warp-knitting machine, a working model was built. The model was equipped with four needle combs and six needle bars and was used to confirm the correctness of the assumptions accepted by us, as well as part verification of the possibility of manufacturing a spatial knitted product in the shape of a rectangular prism.

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