FANCY THREADS

Katarzyna Grabowska

Monographs of Lodz University of Technology 2019

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1. Introduction

The "Fancy Threads" project was implemented between 2000 and 2010. At that time, a certain regress of the textile industry in Europe in favour of Asia took place, while on the other hand, there was a strong tendency to search for modern technologies that could be the answer to the local demand for cheap and fashionable textile products designed as clothing or decorative products. This kind of demand was not wholly satisfied by the import from Asia. What is more, the expectations concerning the quality of textile products were high and did not translate neither to the production costs nor to the incomes of the spinning industry. That paradox was the genesis of the creation of micro and small local textile companies, based on short production technologies. On the other hand, clothing fashion generated ever more needs in the field of cheap raw materials with innovative properties, not necessarily functional ones. Special effects on textile products that created a diversified structure and the so-called texture proved to be the "quick path" in textile design. In that field, chemical finishing technologies, knitting techniques of production of fully fashioned garments, and in the field of spinning, production of fancy threads took on a special meaning.

Fig. 1. Examples of contemporarily produced fancy yarns

Fancy threads are not the basic material used in production of flat textiles or fully fashioned garments. Because of their complex structure or equally complex colour scheme, they are used as an additional element, which creates a phrase that is regularly repeated along the length and width of the flat textile. Figure 1 presents examples of contemporarily produced fancy yarns.

Fancy yarns are like jewellery, which should never be overused. The beauty of fancy threads is the bigger, the more delicate structure they are characterised by. Fine fancy threads with slightly changing colour elements delight us with their beauty and, at the same time, daunt producers of textiles, because they generate numerous problems in their processing. The more complex and finer structure characterises a given fancy thread, the more expensive and fine raw material was used to produce it, the greater the input of labour necessary already at the spinning or twisting stage and, thereby, the higher the price of a package of fancy thread. Because creating fancy threads with a specific architectural design requires a great deal of patience, not only at the stage of avoiding and eliminating breakages in the twisting process. The changes of structure present along the length of a fancy thread not only enhance the decorative value of a linear textile product, but also define the appearance of the external surface of woven and knitted fabrics, as well as influence the creation of spatially expanded fully fashioned garments, clothing or decorative products. This intended diversity of structure or colour is treated as an asset of textile products, as distinct from unintended effects of irregularity of structure, defined as fault. However, analysing faults in the art of spinning, knitting or weaving, one can often come to the conclusion that what is a fault from the point of view of an engineer, from the point of view of an artist takes on the values of unique art, i.e. art that would be difficult to fake or multiply on purpose. In other words, if we can multiply the effect of a compromised regularity of structure, from an artistic point of view our action can lead to the creation of work of art: a product with a pre-designed aim, being it decorative or functional. Designers of fancy threads that work for spinning mills have to meet at least two requirements that, on the one hand, stem from the effectiveness of production and, on the other, from the expectations of the consumer and the processor of fancy threads. Hence, certain generalisations occur that, checked and verified by means of the trial and error method, allow for developing an effective methodology of fancy threads production. The need of effective communication between the producers of fancy threads and their processors, calibrated with elements of structure of fancy threads led to the so-called popular classification of such threads and to giving them a random name identified above all with their producer and having not much reference to European Standards. It has to be mentioned that fancy threads are characterised by seasonal popularity and, thereby, in the Autumn/Winter season, those collections of clothes, in which fancy threads were used are preferred by designers. At this point, one should also point to the popularity of fancy threads controlled by the dictates of fashion, where even in a baroque or gothic version, fancy threads play a decorative part with a moderate intensity. Fancy threads are the object of design in the textile industry, not only because of their high design value but also the functional one. Thereby, fancy threads are a very rewarding raw material for designers, thanks to their diverse drapability, elasticity and susceptibility to creating new constructions that allow the designers to show off their imagination and talent.

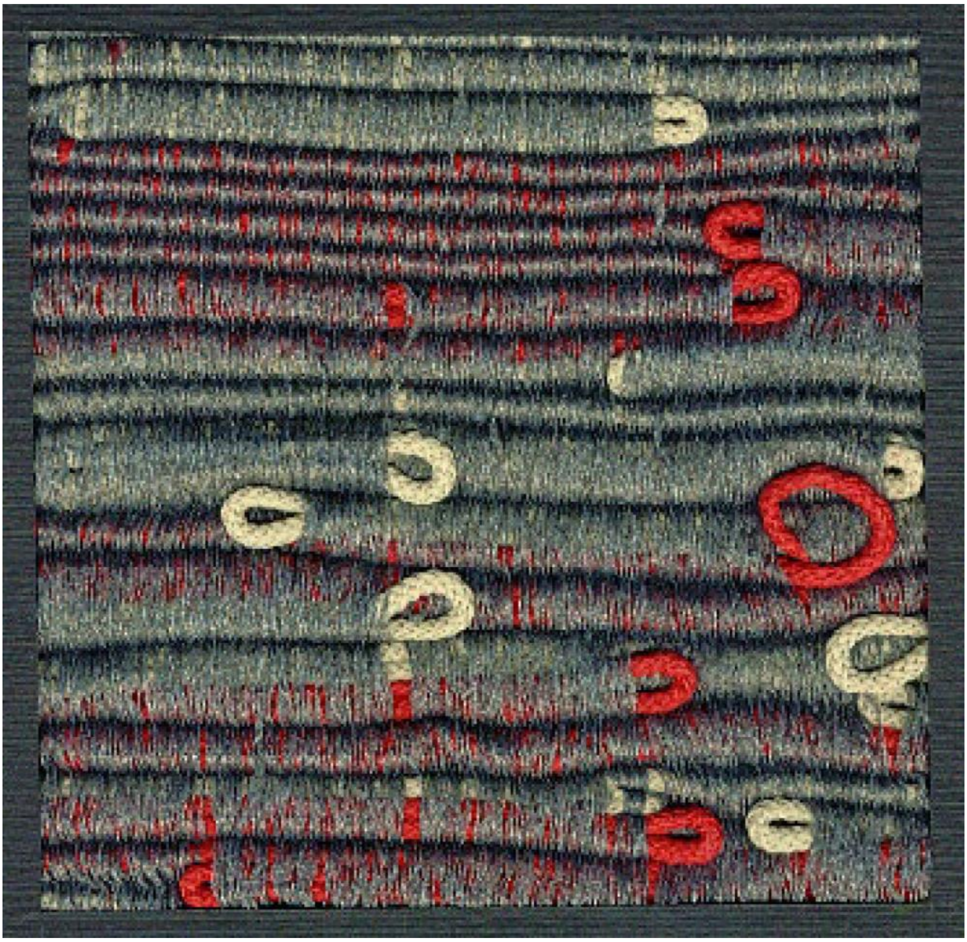


Fig. 2. Plain weave fabric with the use of loop thread as weft (source: Wójcik M., *Modelowanie faktur i własności tkanin wątkiem* [Modelling Textures and Properties of Fabrics with Weft], Master's Thesis, Lodz University of Technology 2003, Supervisor: Masajtis J.)

Production of fancy threads with the continuous effect is not a complicated process. What is more, fancy threads, due to their intended irregularity of structural parametres, very often do not require any thermal process of stabilising twist in an atmosphere of vapour. The majority of producers of decorative yarns and fancy twisted threads use highly efficient machines of the hollow spindle type, in which the twisting process takes place inside the spindle, the twisting system is separated from the system of taking off the ready thread into cylindrical packages, and the post-processing of binding twisting is unified with the principal process of fancy thread twisting. Currently, the efficiency of a singular hollow spindle reported by machine producers equals 100 m/min. All the more, it would seem that producing fancy threads is a really lucrative undertaking, especially in Italy and Turkey. On the other hand, however, the more structurally sophisticated the linear textile half-product is, the bigger problems it generates in the process of weaving or knitting. Following the diversified genesis of problems connected with the production and processing of fancy threads, there arose the need to summarise the current results of research on the properties of multi twist threads, characterised by a an elaborate external structure.

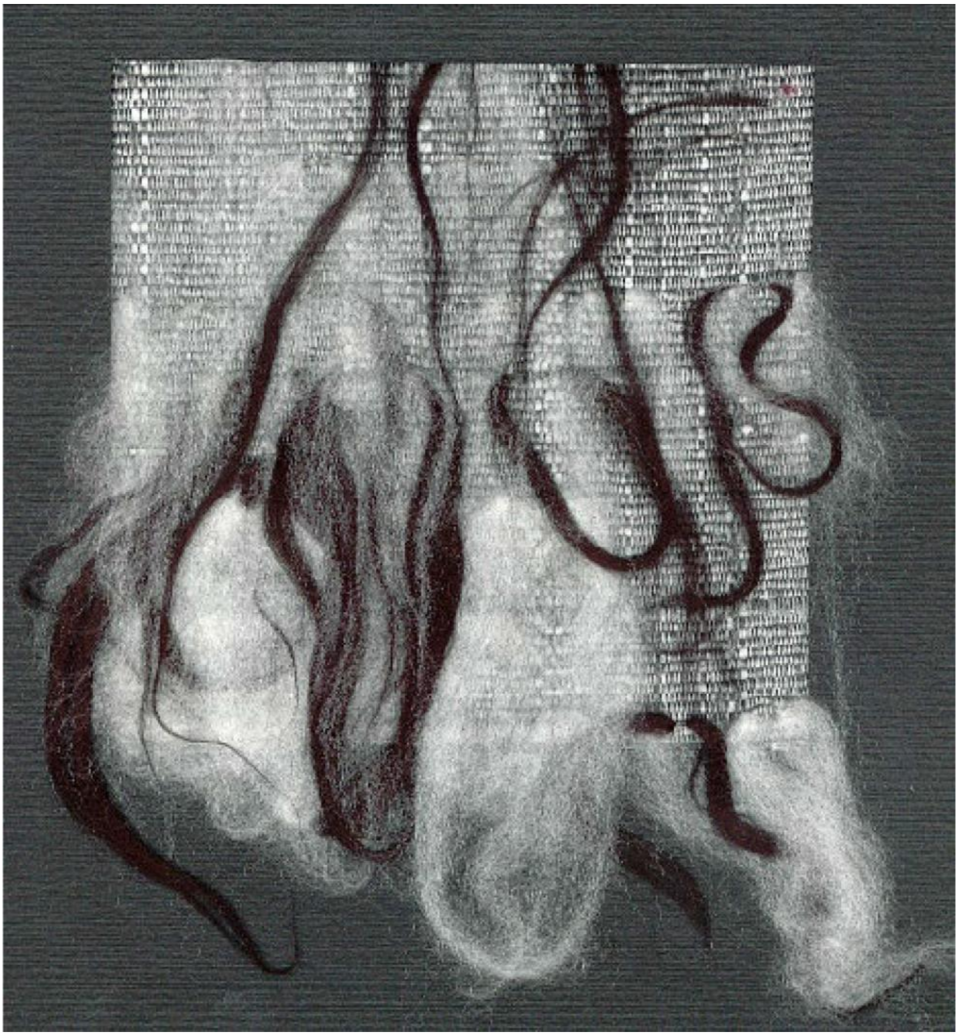


Fig. 3. Unique textile with a roving weft (source: Wójcik M., *Modelowanie faktur i własności tkanin wątkiem* (Modelling Textures and Properties of Fabrics with Weft), Master's Thesis, Łódź University of Technology 2003, Supervisor: Masajtis J.)

In the present monograph, two opinions are confronted: on the one hand, the commonly accepted idea, which describes fancy threads as a difficult and expensive textile material that generates numerous production and post-production problems, and, on the other hand, the view that appreciates the high decorative values of fancy threads. Then, statistical models characterizing the properties of fancy twisted threads were developed and their interpretations confronted with the design methodology used by designers in order to achieve design targets characteristic of light industrial forms. The analyses and conclusions presented in the monograph aim at organising knowledge in the field of design, production and processing of twisted fancy threads. Identifying a broad scope of problems connected with fancy threads, the author desires to remove the odium of mystery that surrounds fancy threads and, at the same time, create a broad ground for designing various conceptions of such threads and their uses in clothing products with the fancy structure and decorative designing effects.

2. Definitions

Citing European Standards that define fancy threads, the following nomenclature was adopted that defines fancy threads and decorative yarns as “threads characterised by an intended variability of colour, shine, twist, linear mass or other structural elements that give those threads decorative character, visible already before producing from them a flat textile product or fully fashioned garment as well as threads distinguished in a significant way by clear decorative features from ordinary smooth threads or yarns”. On the basis of this definition, a distinction of fancy threads and decorative yarns can be made into three groups: one that is characterised only by compromised and intended unevenness of structure and even colour, second that is characterised only by an intended variability of colour and concurrent evenness of structure, and the third one, characterised by both unevenness of structure and colour [Gong & Writght, 2002]. In other words, all intended variability of colour, shine, twist, linear mass or other structural elements that give threads their decorative character are defined as designing effects. The effect of fancy thread is the basic decorative element, which can be structural, chromatic or both structural and chromatic, created by a characteristic arrangement that arose as a result of diversified feeding speed of the effect strand in regard to the core strand, specific way of pairing of the components and/or their linear masses, twist and colour that gives the fancy thread its clear decorative features. Applying the definition of fancy threads to decorative yarns is not an overuse of the notion, because in English-language literature the term “fancy yarns” is used interchangeably by translators as both fancy threads (pol. nitki fantazyjne) and decorative yarns (pol. przędze ozdobne), despite the fact that this is denied by some textile engineers. That is why in the present monograph, the terms “fancy” and “decorative” are not used interchangeably in order to distinguish between smooth yarn and the group of fancy twisted threads and the group of single decorative threads. The interchangeable use of terms “thread” and “yarn” raises considerable controversy. Referencing once again the European Standards, one should evoke at this point the definition of yarn as a “thread built of segmental fibres, twisted, glued or subject to any other technology aimed at the production of a linear textile product”. The semantic analysis of the above-mentioned definitions, one can come to the conclusion that the notion of thread is of primary character, i.e. other definitions reference back to it. There is a definition of thread as a “cylinder, usually characterised by an oval, very small cross-section in proportion to its longitudinal measurement (length), and by flexibility, elasticity, drapability, and susceptibility to sagging and twisting, characteristic for linear textile products”. In the present monograph, because of repeated references to the notion of thread as a linear textile product that defines yarns and plied threads, the terms “thread” and “yarn” are not used interchangeably. The notion of thread refers to a linear product made of fibres, which continuity cannot be compromised by a single process of untwisting, because thread is built of filament threads or single yarns twisted with one another. Yarn, in turn, is a linear textile product made of segmental fibres joined together usually as a result of twisting, and the process of untwisting leads to its definite destruction. At the same time, multiple twisting of several singular yarns with one another leads to the production of a plied thread. The process of smooth multiple twisting of several singular yarns is called folding or plying and can be conducted in different directions of twist. That way, the so-called cable thread with an alternate twist of the S/Z/S or Z/S/Z type is produced, i.e. one, in which the direction of twist of a single yarn and secondary folding (i.e. retwisting) is the same, i.e. S or Z. The direction of the first folding, in turn, is opposite to the direction of single yarn. The process of twisting harmonised in such a way leads to stabilisation of twist and allows one to avoid the effect of formation of snarls. In turn, the arrangement of direction and sequence of folding twists in the form of: S/S/Z or Z/Z/S, i.e. one, in which the direction of twist of single yarn is the same as the direction of the first folding and opposite to the direction of the secondary folding leads to the production of a plied thread with the so-called linear twist.

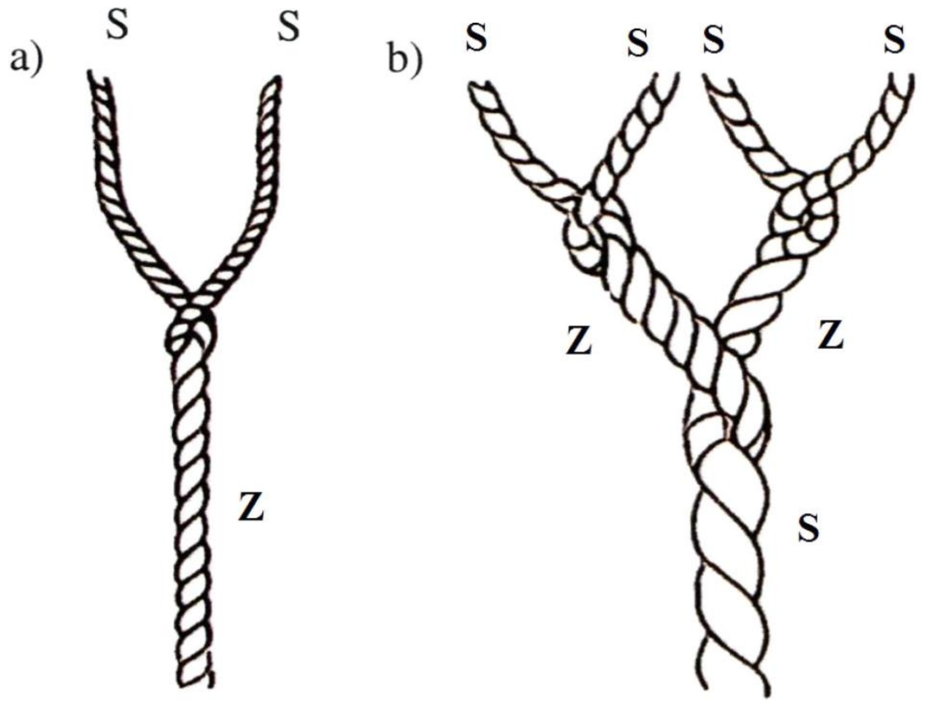


Fig. 4. Advised directions of twisting yarns (source: Łapka I., *Wpływ parametrów struktury przędz komponentowych na kreację struktury nitki ozdobnej* [The influence of Structural Parameters of Component Yarns on the Creation of Structure of Decorative Thread], Master’s Thesis, Lodz University of Technology, 2008, Supervisor: Grabowska K.E.)

3. Different kinds of decorative threads

In the present monograph, the properties of decorative yarns and multi twist fancy threads are described. Thus defined, the division of fancy threads and decorative yarns originates in the production technology. In connection with the above, decorative yarns form a group of single yarns characterised by an intended variability of colour, shine, twist, linear mass or other structural elements that give those yarns a decorative character as well as all other single yarns that are distinguished in a significant way by distinct decorative qualities from ordinary smooth single yarns. Decorative yarns are made with the use of spinning technology, i.e. they are usually produced from a card sliver subject to the process of drawing on drawing frames (usually roller ones) or from slubbing fed in the process of spinning conducted (most often) on the socalled hollow spindle or ring spinning frame. It has to be pointed out that while carrying out the process of fancy spinning, both of the above-mentioned machines have to be equipped with a drawing mechanism, which conditions the attenuation of blanket of segmental fibres that is characterised by an unevenness of linear mass or twist suitable for a given type of decorative yarn. The term "decorative yarn" always defines a single yarn.

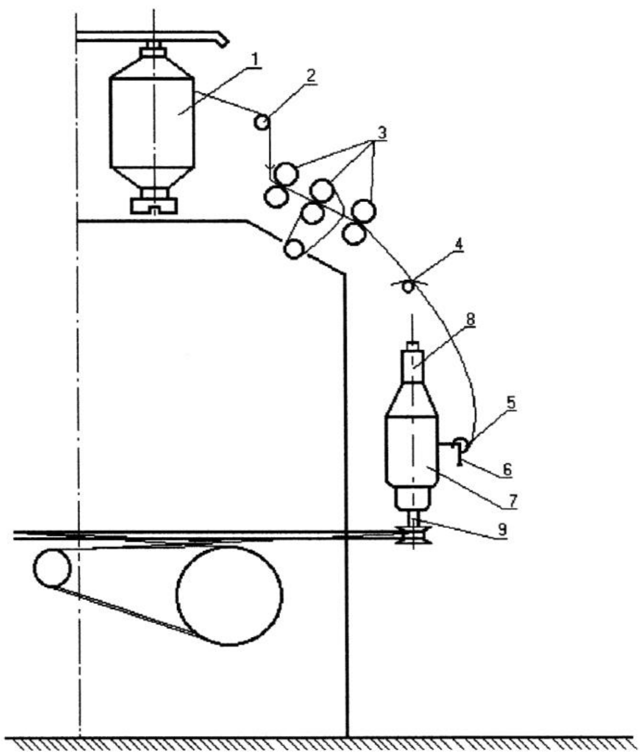


Fig. 5. Flow sheet of a ring spinning frame: 1 – roving bobbin, 2 – guide roller, 3 – drawing mechanism, 4 – top guide, 5 – traveller, 6 – ring, 7 – yarn bobbin, 8 – spinning bobbin, 9 – spindle

According to the classification corresponding to the production technology, i.e. the necessary machines used to produce fancy threads, the second group is constituted by multi twist fancy yarns. In this case, several, i.e. at least two, single yarns or multi-filament threads (filament fibres) are used for the production of fancy twisted threads; they usually feed hollow spindles or ring twisting frames. The difference in comparison with the machines used in the process of producing decorative yarns lies, above all, in the fact that in the process of twisting several single yarns to form a fancy twisted thread one does not use any drawing mechanisms and the effect of irregularity of structure of the fancy twisted thread is obtained as a result of the use overfeed of one of component yarns. Overfeed of one of component yarns means a multiplication of share of one of components of the fancy twisted thread in proportion to the share of the so-called core thread, i.e. one that is fed to the twisting zone in a straight form. Overfeed is expressed by a percentage rate defined as a quotient of the length of the effect component to the length of the core component. The notion of overfeed occurs only while defining the structure of fancy twisted threads. Overfeed does not appear in the case of decorative yarns. Both in the case of decorative yarns and fancy twisted threads, the effect of irregularity of structure can be also obtained on the basis of introduction of a periodical irregularity of twist carried out in the process of multi-twisting of filament threads. The effect in question is obtained as a result of controlling the variable rotary speed of spindles.

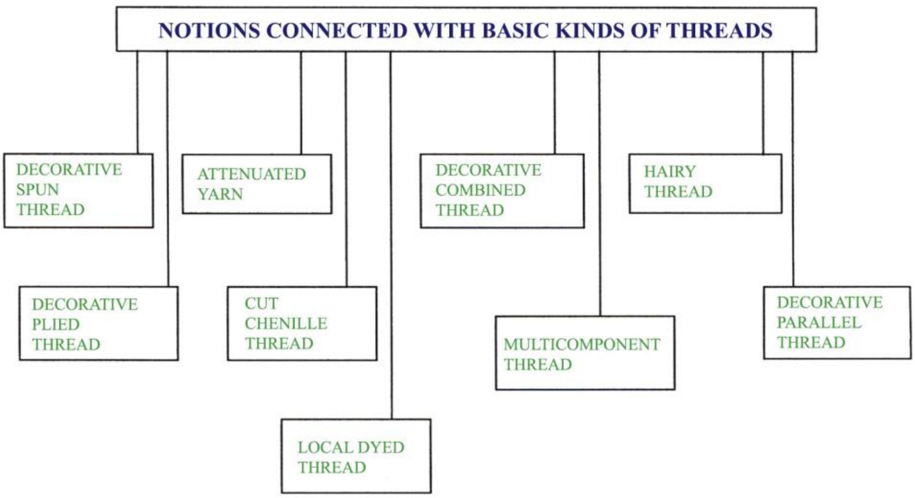


Fig. 6. Different kinds of decorative threads

While characterising multi twist threads, one has to define the component strands of those threads. As was previously characterised, fancy twisted threads are built of several, i.e. at least two, component single yarns twisted with one another. As the primary component strands of fancy twisted threads, one should enumerate the core component, the effect component and the binding component. The core component of fancy twisted threads is most often a yarn, which is fed to the twisting zone with the smallest overfeed, usually equal to one. That way, the core component takes in the fancily twisted thread a form similar to a straight one and transfers the majority of mechanical tension. The core yarn conditions the mechanical strength of the fancy twisted thread. Around the core yarn, decorative effects are created, built the effect yarn. The effect yarn is fed to the twisting zone with the biggest overfeed. That way, the effect yarn, binding the core yarn, generates the intended unevenness of twist and of final linear density of the fancy twisted thread. For the construction of the fancy twisted thread to be stable, an additional, third, binding component is introduced to stabilise the effects on the core yarn. Usually, the binding component is given the name of tie-in thread, due to the role it plays in the process of fancy twisting. Most often, the process of stabilizing effects on the core yarn with the use of the binding (tie-in) thread is conducted with minor twist in the direction opposite to the direction of twisting the core yarn with the effect yarn. That way, the twist is offset, the decorative effect is stabilised and the construction of the fancy twisted thread becomes durable. Usually, fine, invisible filament threads are used as binding threads, so that the designing effect would not be compromised, and at the same time, the stability of the structure of the fancy twisted thread would be preserved. Nevertheless, as it usually happens among designers – it is not a binding rule.

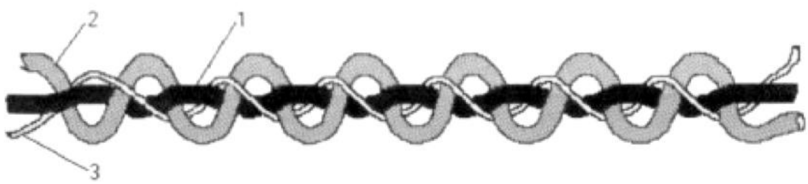


Fig. 7. Example diagram of construction of the terry thread with the distinction between: 1 – core strand, 2 – braid strand 3 – tie-in strand

Both decorative yarns and fancy twisted threads can be divided into those, in which decorative (fancy) effects are carried out in a continuous way and those fancy yarns and threads, in which effects are introduced periodically. In the case of decorative yarns and fancy twisted threads, in which effects are carried out periodically, another parameter that characterises this type of yarns and threads are effect scale and effect repeat. The effect scale is the distance between individual local effects, identical in terms of size and colour, or the distance between effect beginnings that constitute segments with a distinct and clearly decorative structure. The scale can be of either regular or irregular character. The regular scale is characteristic of decorative yarns or fancy twisted threads, in which effects are introduced intentionally and periodically. The irregular scale, in turn, characterises fancy threads, in which decorative effects are introduced in a random way. Currently, it cannot be unequivocally ascertained, which type of the effect scale is better or generates prettier, or more interesting, designing effects on a flat textile product.

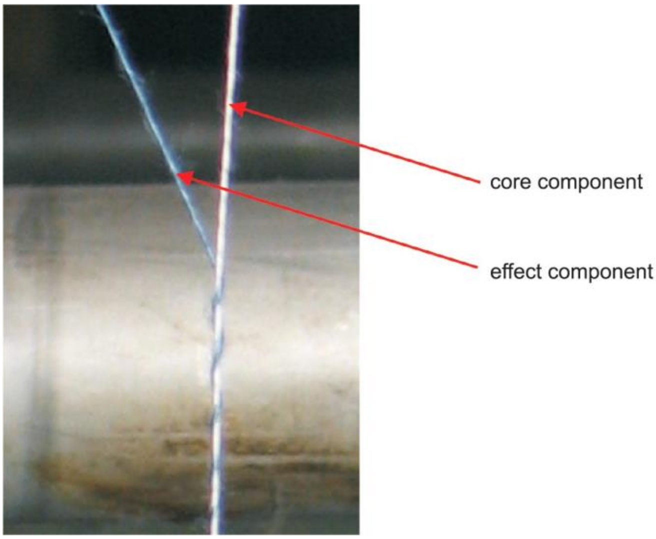


Fig. 8. Arrangement of component threads during the binding process (source: Mulczyk A., *Analiza naprężeń nitek komponentowych podczas produkcji nitek ozdobnych* [Analysis of Component Thread Tension during Production of Decorative Thread], Master's Thesis, Lodz University of Technology 2008, Supervisor: Grabowska K.E.)

Research showed that the regular scale of designing effects of fancy thread or decorative yarn leads to the so-called stripe on a flat textile product. The stripe effect was commonly considered as a negative phenomenon on flat textile products. That is, why fancy twisted threads or decorative yarns with irregular effect scales were usually used. That way, one avoided the introduction of stripe, because the designing effect was scattered over the surface of the flat textile product in a random way. On the other hand, the stripe effect of design repeat arrangement can be intentionally used for giving a decorative value to fully fashioned garments. Hence, it is difficult to judge, which type of scale is more effective. The effect repeat is, in turn, the shortest segment that connects the repeated arrangement of decorative effects of the same size, structure and colour. In other words, repeat is the shortest scale of effects that appear periodically.

Table 1. Different types of designing effects used on decorative threads, according to Polish Standard: Fancy yarns, PN-80/P-01728. Poland

Terms	Definitions	Appearance
spinning flame	Gradual local bulge of yarn up to the thickness of slubbing, which occurred in consequence of periodic lack of drawing of slubbing	

Table 1(continued)

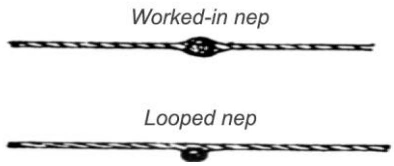
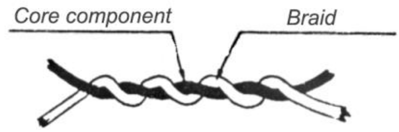
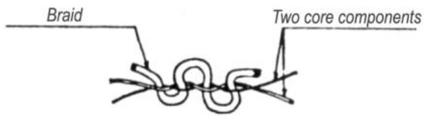
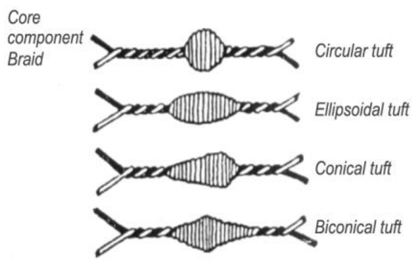
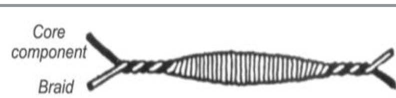
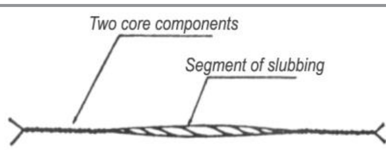
nep	Cluster of tangled fibres, slightly clinging to the thread, in an irregular globular form	
spiral	Helical arrangement of one component around the other, which is in an axial position	
loop	Local lay off of one component in the form of a circular loop	
coil	Spatial local arched elevation of the binding component in relation to the core component	
snarl	Tight local spiral binding the surplus of one of the components that creates aprotrusive section in a location more or less perpendi-cular to the axis of thread of seve ral millimetres long	
fancy thread tuft	Relatively short local thread bulged formed by a concentration of the core strand, in a form usually similar to circular, ellipsoidal, conical or biconical	
twisting flame	Local longitudinal threads, formed by a concentration of braid on the core strand, with slightly elongated ends	
caterpillar	Local cylindrical bulge of the thread, formed by an evenly conden-sed concentration of the binding component over the core component	
flame	Bulge created by a segment of slubbing wound between two core strands; the bulge has an elongated shape with a soft end	

Table 2. Different types of decorative threads, according to Polish Standard: Fancy yarns, PN-80/P-01728. Poland

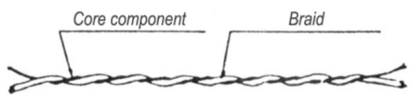
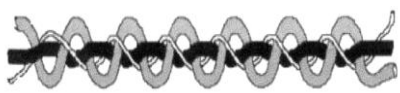
Terms	Definitions	Appearance
embroidery thread (embroidery floss)	Plied thread with single strands of the same linear mass and twist that differ visibly in colour	
spiral thread	Thread in which one component twists around the other, creating a helix that adheres to the whole length of the other, straighter one; this thread is made as a result of multi-twisting of two components, with a relatively minor overfeed of one of them, or two components with different directions of twist, which thickness is the same or differs only slightly	
wavy thread	Thread, in which a spiral in a wavy form is made by twisting with a minor twist of one component of considerable thickness around another one, considerably finer; the wavy effect of the spiral is created as a result of a minor overfeed of the binding component or opposite directions of twist of both components	
terry thread	Thread, in which a component of soft and supple characteristic twists is around another one, creating protrusive rippling; it is made by twisting together two components with a significant overfeed of one of them or by twisting a spiral yarn with two components and at the same time, binding them with a third one	

Table 2(continued)

loop thread	Thread, on which surface there appear regular, rounded loops of either the same or different size; it is made by introducing with big overfeed a flexible and pliable binding component between two core strands, thus creating loops.	
coil thread	Thread, on which there appear coils, of either the same or different size and shape; it is made by introducing with overfeed a binding component between two core strands, thus creating coils	
snarl thread	Thread, on which surface there occur protrusive spiral snarls; it is made of a binding strand with such high, unstabilised twist that its overfeed causes the formation of snarls rather than loops	
tuft thread	Thread, on which surface there occur at determined, regular or irregular, intervals local concentrations of one component, of diversified size, shape and very often colour as well, in the case of use of multicoloured components	
eccentric thread	Plied yarn that displays bulges in the shape of flames on the surface	

shaded thread	Thread characterised by the occurrence of sections of different colours; it is made as a result of twisting together two components of different colours, first with increasing and then with decreasing overfeed, by reason of which twisting one component around the other occurs, with a simultaneous increase in the density of twist, yet without any clear increase in the thickness of the decorative thread that is thus produced	

There are many methods of giving decorative features to yarns and filament threads that do not require the use of fancy twisting or spinning. One of the methods of implementing the intended unevenness of structure of fancy twisted threads and decorative yarns is the periodic introduction of additional decorative components, both into the structure of the yarn and the fancy twisted threads, in the form of tufts of segmental fibres fed into the web feeding the spindles before the twisting stage. An example of such a technique of production of decorative yarns is the nep yarn. This yarn is characterised by the occurrence of numerous clusters of tangled segmental fibres on its surface, intentionally introduced into the drawing sliver, directly before the process of spinning from the sliver, or into the card web in the carding woollen system. Nep yarn is the best example of a phenomenon, in which a spinning defect, in the case of smooth yarn defined as a compromised irregularity of structure of a linear textile product, takes on special decorative values by increasing the frequency of occurrence of the defect and reinforcement of its visualisation.

Another method of giving decorative qualities to single yarns is the process of stabilising po- lyacrylonitrile yarns that consists in treating a loosely hanging yarn (made with the use of both thermically shrinkable fibres and fibres without features of shrinkage) with water vapour, hot water or hot air. That way, as a result of shrinking of shrinkable fibres, the fibres devoid of features of shrinkage are pushed outside the single yarn and the yarn takes on the qualities of fluffiness and increased diameter. That way, pseudo-mohair yarn is made.

A very important method of generating designing effects in linear textile products is the ma- nipulation of colour effects. Within this methodology fall different variations of print, plotted especially on yarns or drawing slivers. Very interesting designing effects, as far as colour is con- cerned, are achieved with the use of the vigureux print, which consists in segmental printing of drawing slivers in transverse stripes with the use of a roller with a protuberant pattern. Then, thus printed slivers are subject to re-drawing, so that the colour designing effect undergoes colour blending, i.e. various colourful segments of fibres migrate among themselves, creating a choice of colours that resemble the rainbow effect. The process of spinning from slivers printed in that way is conducted on classic ring spinning frames or twisting-spinning frames with a hollow spindle, which additionally strengthen the colour effect in the form of migration of fibres in different colours within the cross-section of the yarn as a result of twisting, and enables the plotting of additional effects in the form of compromising the irregularity of structure of the decorative yarn. Most often, however, the ready yarn is dyed in skeins. The process also consists in periodic dyeing of yarn coiled in skeins, underslung in yarn dyeing machines with a periodic circulation of dyeing bath. This method is used to obtain the so-called strip yarn.

Discussing the compromised structure of fancy yarns, one has to enumerate the intentional process of stretching smooth multifilament threads. This process is conducted in order to increase the volume of filament threads, i.e. increase their fluffiness, soft grip, drapability and hairiness. The latter quality is often treated as a defect and consists in the occurrence of ends of broken single filaments on the surface of stretch threads. Breakage of filament threads occurs in the process of stretching of mulitifilament threads with the use of mechanical devices in the increased temperature. That way, there appear lasting crimps on the surface of the filament thread or additional twists as a result of the process of twisting, thermal stabilisation of twist and then, the process of mechanical untwisting. That way, rudimentary twist appears on the surface of the fluffy multifilament thread. The process of stretching multifilament threads is characterised by the stretch level, durability of stretching and fluffiness. Stretched multifilament thread is usually a textured thread. The process of texturing multifilament threads is conducted in order to increase their fluffiness or elasticity. The process of texturing can be conducted with the use of the false twist method, with the real twist method, the movable twist method, the knit de knit method, the drop wire method, the air jet method, and with the use of toothed wheels.

4. The history of decorative yarns and fancy twisted threads

We lack an evidence that the production of decorative yarns and fancy twisted threads in prehistoric times was intentional. Of course, this statement does not prove that decorative yarns and fancy twisted threads were not produced before the birth of Christ. Textile materials used in those times were biodegradable, hence there is the lack of preserved evident artefacts. The oldest fragment of textiles was dated with the use of radiocarbon dating to have originated around 7000 B.C.E. According to the definition of decorative yarns, no linear textile product with an intentionally extended surface was observed in that artefact. Textile products that come form the first centu- ries of the modern era were by default characterised by unevenness of structure, due to unstable methods of fabric production. We should speak about unevenness of fabric structure, especially in the case of textiles intended for making clothes for the needy that lived in the Middle Ages. In that period, like in any other for that matter, clothes were a discriminant of wealth and position of the person, who wore them. In the case of people, who did not have a high social position, clothing design was based above all on the implemented colour scheme and was primarily made of linen.

Flax was the most easily available textile raw material, which cultivation did not generate high costs in comparison with other fibres. Similarly, processing the flax did not require any additional financial expenses. Thereby, linen characterised menial social status. On the other hand, the qualities of linen designated this raw material as the basic one for the production of clothing for the low-life. Linen embodied comfort of use of fabrics that had a direct contact with the skin. Nevertheless, those social groups that performed prominent professional functions preferred natural silk as the basic raw material for the production of clothing.

Silk, however, was difficult to obtain and, thereby, costly, since it was imported from The Central Asia and the so-called Middle East via the so-called Silk Road. The production of silk fabrics was a state secret in China, Turkey and Iran. Only the richest people, who manifested their class membership through haute couture, could afford silk fabrics. In the cold climate of Northern Europe, the dominant textile raw material was wool. Nevertheless, the process of sheep breeding and the production of wool was very labour consuming. Hence, wool was the basic, but at the same time costly, textile raw material in the cold climate. The production of fine and even woollen yarns caused a lot of production problems. This was the reason behind the great unevenness of the produced yarns and fabrics. In the Middle Ages and earlier, textile raw materials were not mixed together, both due to processing problems and to the fact that the notion of high quality textile products was defined on the basis of homogenous material composition.

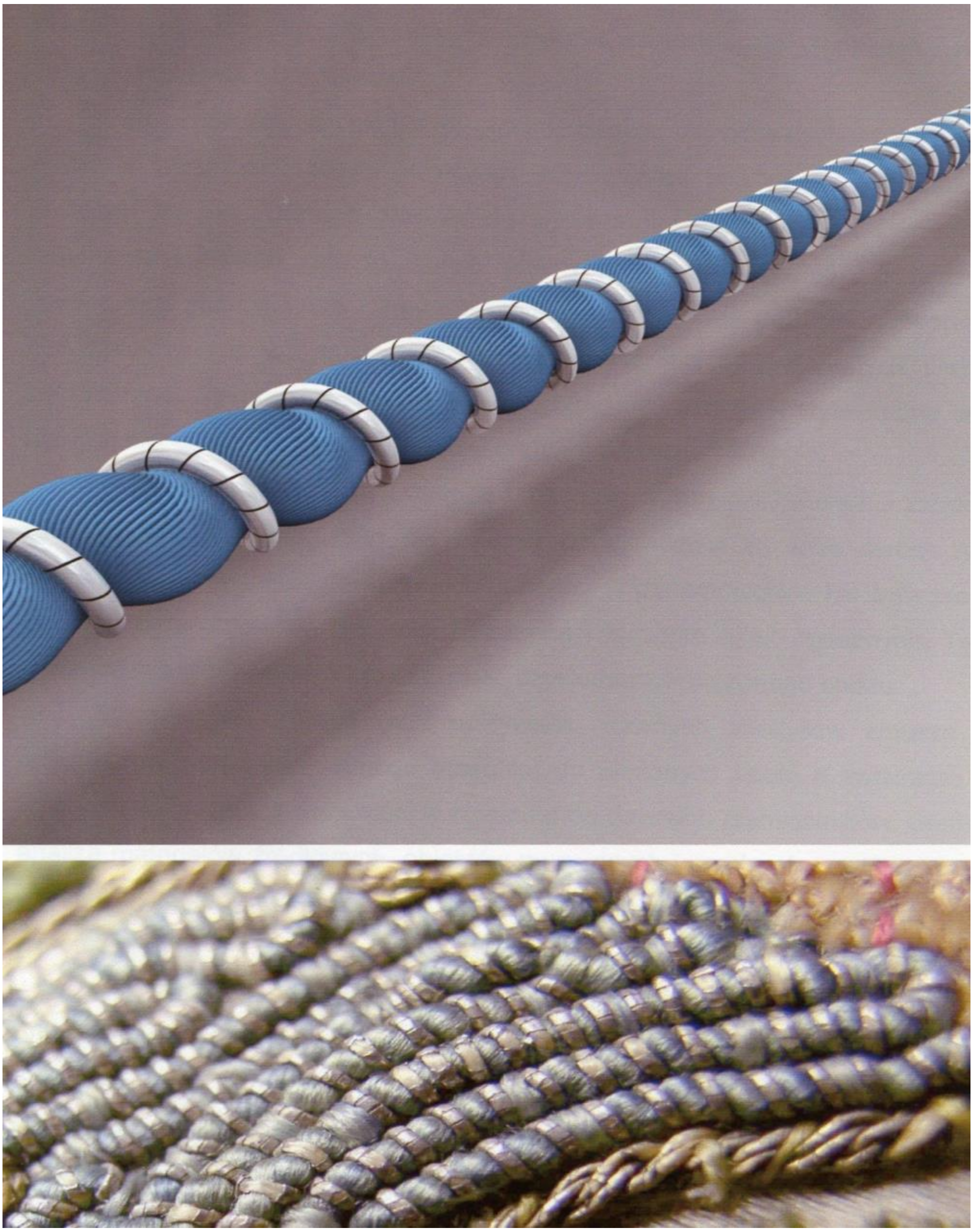


Fig. 9. Reconstruction of the Leonese thread (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative threads in a Historical Perspective], Master's Thesis, Lodz Technical University 2007, Supervisor: Grabowska K.E.)

Cotton was the basic textile raw material in countries with a hot climate, and with time it started to be imported to Europe as luxury merchandise, due to the fact that it was not possible to cultivate it in the cold climate. As can be seen, in the Middle Ages and much later there was no diversified raw material base for the textile manufacture. With time, the need to externalise one's financial status or the prominent function one performed in the society with the use of worn clothes was more and more externalised in the form of decorations introduced into the fabrics with the use of decorative yarns. Especially, visible decorative values characterised ritual clothing, i.e. clothing connected with carrying out religious rites. The most spectacular design was presented by representatives of the church. Of course, it was mainly the colour scheme that distinguished prelates, i.e. shades of cardinal red, gold, and amaranth dominated in vestments. Elements of gold were introduced with particular determination in order to increase the prestige of the people, who wore clothing with those decorative elements. Thin strips of gold were twisted around the core thread, e.g. made of silk, and that way created diverse and costly designing effects. From that period come a few basic fancy twisted threads, in which different elements, non-textile in character, were twisted together with the threads. These are: Leonese thread, Cyprian gold, Japanese threads, drop wires, wire threads and chenille threads. (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative threads in a Historical Perspective], Master's Thesis, Lodz Technical University 2007, Supervisor: Grabowska K.E.).

Leonese threads

Metallic threads were produced and used in fabrics as ornaments much earlier than in the Middle Ages in Europe. Also today, metallised threads, as a lighter and finer form of metallic threads, find their use especially in decorative textile products. Such a long period of undiminished interest in this kind of threads is connected with an exceptionally precious appearance and, at the same time, simple production technology. Metallic threads produced in that period were characterised by a construction typical for parallel thread, i.e. they were fancy twisted threads built from a core spun thread, which was usually a woollen or silk thread, which was twisted with a varying frequency with fine strips of forged gold. Metallic threads were produced in different qualities, which differed in terms of the thickness of metal tape and the type of the core that was used – they were either shiny or matte, crinkle-cut or smooth, with a see-through core thread or completely covered by the metallic thread. Brocade fabrics, borts and other textiles using gold or silver threads were also counterfeited with the use of copper and tin. In the territory of Poland, Leonese threads were produced under the name of "Leonese wares" since 1748 in Wrocław by Reiss' manufactory and in 1757 a competing company was established – Eckardt's manufactory.

Cyprian gold

Starting from the 10th century, to the territory of Western Europe, textile products were imported, in which a thread built from core thread (typically linen or silk thread), which was twisted with fine fragments of membrane that came from sheep or pig intestines, gold-plated on one side as the decorative thread. Those threads were used especially in the production of raised embroidery, in weft insertion, and in the brocading technique. Cyprian gold was the cheaper equivalent of “Leonese wares” and was popularised under the name of “membrane gold”. Cyprian gold was imported from Middle-Eastern countries, but Cyprus was the transfer market to Europe, and hence the original name of this kind of products. Cyprian gold was very popular in Spain and on Sicily. Vestments as well as clothing of rich Moors and Saracens was woven from The Cyprian gold.

Japanese threads

Japanese threads and the textile products in which this kind of threads was used were imported from the territory of China and Japan since the 10th century. In those threads, cotton or silk wrapped with strips of paper that was gold-plated on one side were used as the core thread. Hence, their idiosyncratic name, paper threads, was popularised. It stemmed from the low compatibility of gold and paper – subject to mechanical strain, gold very easily disappeared from the surface of such a thread. Due to that fact, Japanese threads were used only in raised embroidery, since it does not require frequent interlacing between individual threads.

Drop wire

Drop wire is a kind of thread made of strips of gold or silver, in which no core spun thread was used. Drop wire constituted the most precious form of decorative thread. Drop wire was most often used as brocading weft. Due to the flat character of drop wire and the phenomenon of reflecting or even refracting light, wonderful designing effects appeared on the drop wire, depending on the kind of lighting. Drop wire was used to produce fabrics that were called lama or lametta (from Italian lametta and French lamette, meaning lamella or lamina). Lama (Arabic for shiny, glossy) was the name given to a plain or patterned silk fabric with the background partially or wholly covered by the metal, gold or silver weft introduced in the form of strips (drop wires). This type of textile products of highest quality were called Venetian products and they were characterised by the fact that the basic, load-bearing weft, as well as the warp, were completely invisible as a result of cooperation between the reflexes of light and the use of fine threads. Lama was woven in small geometric patterns, such as squares, chequers or fish scale.

Wire threads

The technique of filigree forging of fine gold wires found its application in the textile industry as well as long ago in 1400 years BCE. Wires, or rather threads, were twisted with one another and arranged on the fabric surface with the use of weft insertion in silk fabrics. Originally, this technique was used in the territory of Italy; the so-called wire fabrics were imported from Venice or Milan.

5. Technologies

Characterising the scientific achievements in the field of properties of decorative yarns and fancy twisted threads, the review of source literature in that topic was divided according to the technique of production of linear textile products with an extended surface. This classification focuses primarily on the fact, whether a given textile product is made with the spinning method and then a single decorative yarn is produced, or whether the linear textile product is made with the method of twisting together single component yarns and then the fancy twisted thread is produced. Further classifications depend on the technological details of the spinning or twisting machines. The classification of decorative threads according to the production technique assumes the division into decorative threads produced with the methods of ring spinning, hollow spindle spinning and open end methods. The classification of fancy twisted threads includes threads produced with the method of ring twisting frame and the method of hollow spindle.

5.1. Production methods of decorative yarns

In compliance with the definition, a decorative yarn is a single thread built of segmental fibres on the principle of twisting slubbing attenuated in a drawing mechanism or drawing slivercharacterised by clear decorative qualities, i.e. most often an unevenness of structure or colour. Three production methods are characteristic for decorative yarns: the ring spinning technique, hollow spindle technique and open end spinning technique. The quality that distinguishes spinning technique from fancy twisting is the use of roller drawing machine in a spinning frame, which stimulates the process of attenuation of blanket of segmental fibres that feed the spinning frame in a periodic or stochastic way. What is more, spinning frames are fed with an assembly of segmental fibres in the form of a drawing sliver or slubbing; whereas fancy twisting frames are fed withsingle yarns.

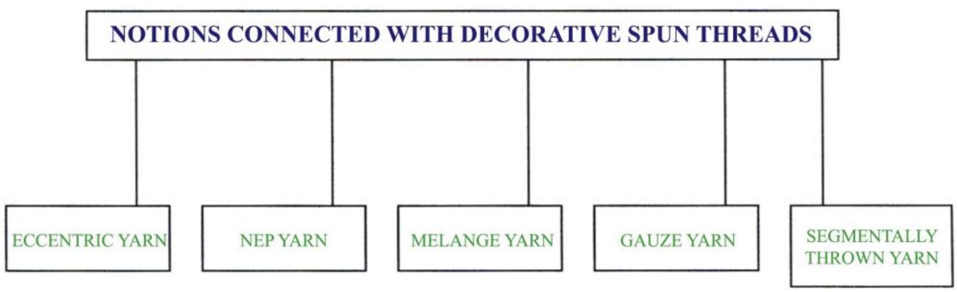


Fig. 10. Different kinds of decorative yarns

Fig. 11. The composition of nep fabric (source: Kujawa K., *Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych* [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

Fig. 12. The composition of segmentally thrown thread (source: Kujawa K., Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

5.1.1. Techniques of ring spinning

The machine that plays the key part in the process of production of decorative yarns is the spin- ning frame. As the basic machine used in the production of decorative yarns one has to mention the ring spinning frame, in which the arrangement of traveller that moves around the ring, in the centre of which there is a spindle, is used to produce twist. Research conducted on the effectiveness of ring spinning allowed to specify the boundary conditions of this system, limited, above all, by the traveller and ring friction system. The productivity of spinning decorative yarns amounts to 10 m/min. at the maximum, with the highest possible delivery speed of approximately 15 m/min. In the ring spinning technique the system that twists the fibres is connected with the system taking off the finished yarn to a spinning cop fixed on a spindle mounted inside the ring. Research concerning the production process were carried out by Jackowski, Chylewska, Cyniak [Cyniak, Czekalski, & Jackowski, 2008], [Jackowska-Strumillo, Cyniak, Czekalski & Jackowski, 2007]. Research on the structure of yarns produced with the use of ring spinning frames were also carried out in Japan, France, Tunisia and Australia [Takemura, Nakazawa & Kawamura, 2003], [Ben Hassen, Sakli, Sinoimeri, & Renner, 2003], [Tang, Wang, & Fraser, 2004]. The fundamental work on the topic of the qualities of decorative yarns is the article entitled *A Study of the Fundamental Parameters of Some Fancy Yarns* by Testore and Minero [Testore & Minero, 1988].

Fig. 13. Plain weave fabric with weft with periodically thrown colourful embroidery thread (source: Kurek E., *Techniki zdobienia tekstyliów z wykorzystaniem nieklasycznych struktur i faktur nitek* [Techniques of Decorating Textiles with the Use of Non-Classical Structures and Textures of Threads], Master's Thesis, 1998, Lodz University of Technology, Supervisor: Masajtis J.)

Significant differences in the construction of ring spinning frames concern the construction of the drawing mechanism, since the traveller – ring – spindles arrangement in this system is a classic one and it is widely used. The classic system of drawing mechanism concerns roller machines together with the so-called guiding leather that control the movement of segmental fibres in different drawing zones.

Fig. 14. Ring spinning frame with a drawing mechanism

Modification of build and settings of delivery rollers of the drawing mechanism in relation to the guide that controls the movement of the assembly of segmental fibres fed into the twisting-winding system that takes off the ready yarn bore fruit in the form of an increased control of fibres migrating inside the yarn during the process of spinning. Yarn produced in this system is called the compact yarn and is characterised by an increased evenness of structural parameters and mechanical properties [XiaXin, Wenxiang, Xu, & Eltahir, 2011], [Xia & Xu, A Review of Ring

Staple Yarn Spinning Method Development and Its Trend Prediction, 2013], [Xia, et al., 2009]. Due to its high functional values and high indicators that characterise the migration of fibres, the compact yarn embodies the values of decorative yarn above all through mixing fibres of different colours.

Similarly, the control of movement of segmental fibres after they have been delivered by the delivery rollers of the drawing mechanism to the twisting zone through multiplication by feeding them with two or more attenuated slubbings leads to an increase in fibre mixing in the final yarn. Research on the structure of such yarn was conducted by Dinkelmann and Herdtle [Dinkelmann & Herdtle, 1981] as well as Sun and Cheng in 2000 [Sun & Cheng, 2000]. The yarn produced with the use of the aforementioned method is called SiroSpun and its decorative effects stem from the drawing process and mixing of two or more assemblies of segmental fibres of different colours in the process of twisting.

Another change in the ring spinning technology that was based on the control of movement and mixing of segmental fibres in a roller drawing machine is the SoloSpun technology. Like in the case of the two aforementioned yarns, the decorative yarns produced with the use of this method are characterised by a high evenness of linear mass with a simultaneous production of the melange effect as a result of mixing segmental fibres of different colours. Research on the structure of SoloSpun yarn was conducted by Cheng, Fu, Yu [Cheng, Fu, & Yu, 2004] et al. [Rui-Hua Yang, 2012], [Soltani & Johari, 2012], [Beltran, Wang, & Wang, 2007].

5.1.2. Hollow spindle spinning method

The basic technique, which is most the often used nowadays, competing with the ring spinning technique is the hollow spindle technique. It guarantees a high production effectiveness in the full range of linear density and twist. Average turnout of a spinning frame with a hollow spindle amounts to about 50 m/min. The characteristic feature of spinning frames with a hollow spindle is that the computer-controlled system that attenuates the blanket of segmental threads cooperates with the twisting-spinning system, in which the function of traveller and ring was substituted with a false twist hook and a hollow spindle, in which the process of spinning (giving twist to segmental fibres) takes place inside the spindle, which spins at a very high speed. The durability of structure of the thread produced with the use of the hollow spindle method is the result of the use of a filament binding thread fixed in the form of a package on the hollow spindle. The filament thread, unwound at a high rotary speed of about 30.000 revolutions per minute, twists around the attenuated assembly of segmental fibres delivered by the final pair of rollers of the drawing mechanism. That way, the parallel yarn is produced, which is a composition of an assembly of segmental fibres and continuous filament thread. The process of binding the assembly of segmental threads takes place inside the hollow spindle. The turnout of production of decorative yarns with continuous effects produced with the use of the hollow spindle method is more than twice as big as the turnout of decorative yarns with the use of the ring method and equals ca. 50 m/min. in the case of a single spindle. High productivity of spinning with the use of the hollow spindle method validates the separation of the twisting system from the system winding ready yarn on a cylindrical beam. The hollow spindle technique is effective and specially dedicated both to the production of parallel decorative yarns and fancy twisted threads. In this spinning technique, the decorative character of yarn can be obtained in the easiest way with the use of multicoloured components fed to the twisting zone with varied initial tension. The hollow spindle method was used by Baoyu and Oxenham to analyse the influence of spinning parameters on the production of effect of decorative yarn in comparison to smooth yarns [Baoyu, 1994]. Research on the structure and mechanical properties of parallel yarns produced with the use of the hollow spindle method and concerning the role of the false twist hook mounted at the mouth of the hollow spindle in order to modify the structure of decorative yarn was conducted by Konova and Angelova [Konova & Angelova, 2013].

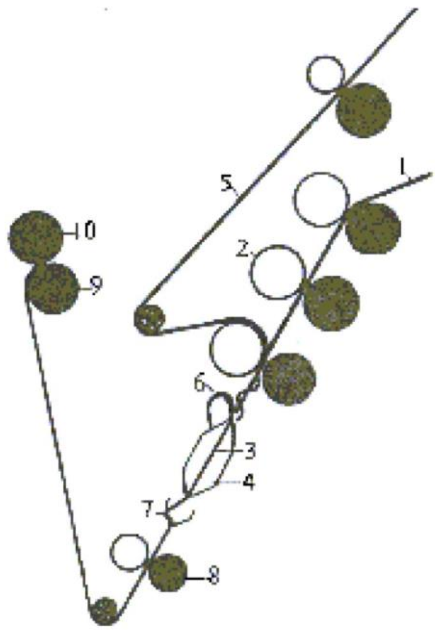


Fig. 15. Flow sheet of a hollow spindle spinning frame with a drawing mechanism: 1 – slubbing, 2 – rollers of the drawing mechanism, 3 – assembly of twisted slubbing, binding thread and effect yarn inside the hollow spindle, 4 – beam with the binding thread, 5 – effect yarn, 6 – binding thread, 7 – false twist hook, 8 – taking-off roller, 9 – lap roller, 10 – cylindrical beam with a ready fancy thread

5.1.3. Open end techniques of spinning decorative yarns

The technological progress that took place in the area of increasing the effectiveness of production within the textile industry consisted in bringing the spinning technique to perfection. This way, especially in the second half of the 20th century, four new spinning techniques were developed and implemented in production. They consisted in substituting an ineffective system of twisting segmental fibres with the use of the ring method based on coupling a spinning spindle with a traveller system that made a rotary motion around the ring race. The turnout of decorative yarns produced with the use of ring spinning frame is limited by the effectiveness of work of the travellerring system. The maximum performance reached within this field amount to 15 m/min. of decorative yarn from one spindle. Among modern spinning techniques, in which the classic spindle was eliminated, we can rank the rotor method, the air jet method, the friction method and self twist spinning. Simultaneously with the technologies substituting the spindle-traveller system with unconventional yarn production methods, the hollow spindle method was intensively developed and it met with singular appreciation on the part of producers of decorative yarns and fancy twisted threads. With the use of the hollow spindle method it is possible to increase the effectiveness of production of decorative yarns from the feeding blanket of segmental fibres up to 70 m/min. It has to be born in mind, however, that the productivity of production of decorative yarns is lower than the productivity of production of smooth yarns.

Research on the structure of decorative yarns produced with the use of the rotor method was conducted by Wang and Huang [Wang & Huang, 2002], [Matsumoto, Saito, & Sakaouchi, 2004]. In the rotor method, rotor plays and important part in the process of spinning. It is responsible for the real twist, onto which the so-called false twist is put on, which results from the process of friction of the blanket of fibres fed into the rotor. The rotor technique of yarn production is dedicated to semi-combed yarns in the fineness of 15 tex up to 200 tex, which means it is especially adequate for decorative yarns, in which the evenness of linear density does not play any important part upon measuring the quality of the production output. There appear numerous upgrades within the field of decorative yarn production with the use of the rotor technique. In 2004, Pouresfandiari published a new method of production of loop yarn with the use of rotor [Pouresfandiari, 2004]. The properties of decorative yarns produced with the rotor method were studied by Kwaśniak in 1996 [Kwasniak, 1996].

Research on the structure of decorative yarns produced with the air jet technique were conducted, i.a. by Stasiak and Janke in 1989 [Stasiak & Janke, 1989]. The effect of twist of an attenuated web of fibres is achieved in this technology with the use of producing a spinning air stream. There are different ways of air jet spinning, i.e. in a spiral rotor, in a deformed rotor or in a circular rotor as well as the system of air jet spinning with the use of the principle of false twist and the system of binding of the assembly of segmental fibres. Research on the structure of yarns produced with the open end air jet technique proved a diversified construction of those yarns stemming from the migration and segregation of segmental fibres during the spinning process: long fibres migrate to the inside of the yarn, while the short ones migrate to the outer layers. As a result, the hairiness of the air-jet yarns is multiplied [Rosiak & Przybyl, 2006]. The method of spinning decorative yarns with the use of air jet was used in the research on the structure of those yarns by Kwasniak and Peterson in 1994 [Kwasniak, 1997].

Another open end method of producing decorative yarns is the friction method, in which the high value of the coefficient of friction and cling between segmental fibres was used. This technology is most often distinguished under the name of DREF and used as a technology of production of decorative yarns [Das, Ishtiaque, & Yadav, 2004].

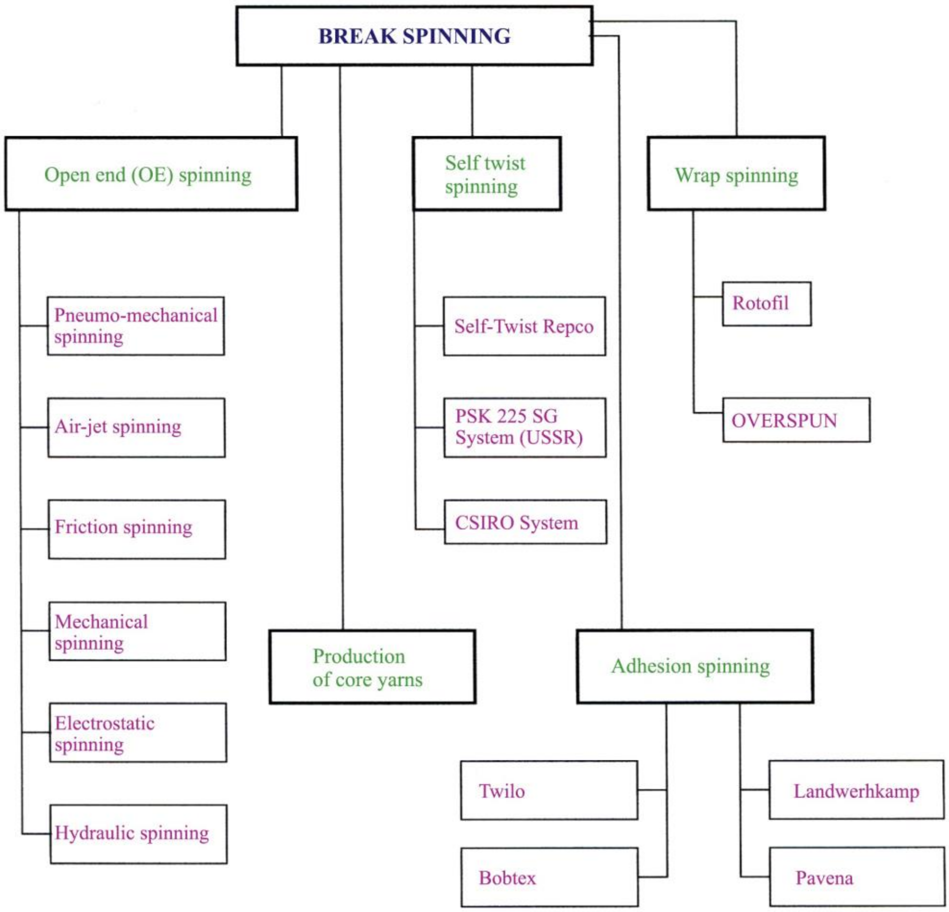


Fig. 16. Classification diagram of open end spinning

The self twist technique has to be listed as a derivative of the aforementioned spinning method. It makes use of the principle of mutual twist of two assemblies of segmental fibres characterised by the same direction of twist. Usually, the term Repco was assigned to that technique. Self twist yarn is a textile material extremely susceptible to the introduction of an intended changeability of structure, due to the variability of the direction of twist alongside the whole yarn, both natural and stemming from the spinning technology. Introducing additionally some variability of the linear density of components of the assemblies of segmental fibres, one can easily and effectively generate decorative yarn. One of disadvantages of that kind of yarn is the high coefficient of unevenness of tenacity. Because of that producers of those yarns often advise the use of additional twisting of the self twist yarn at a separate stage of production, carried out with the use of a twisting frame. Of course, the process of additional twisting elevates the production costs, which are maintained at the level characteristic of the costs of production of decorative yarns. What is more, it has to emphasised that high values of unevenness of tenacity of decorative yarns are a feature that distinguishes those yarns in quality terms. High values of coefficients of structural parameters variability influence generating high CV values of mechanical parameters, and thereby, are one of the most frequent reasons of breakage of decorative yarns in the weaving process. Due to their nature and the compromised tenacity, decorative yarns are linear textile products dedicated specifically to the knitting industry to be used in the course knitting technique, were yarns are not subject to big tension fluctuations. However, decorative yarns generate significant problems during the weaving process and producers of textiles strongly avoid the use of decorative yarns as warp.

The technique of texturing filament threads is widely used in the textile industry to elevate the functional and decorative values of manmade filament fibres. In that technique, the mechanical interaction of friction element or air jet on the assembly of filament fibres is used. Of course, it causes the weakening of the strength of the web of fibres and, at the same time, introduces increased fluffiness of fibres, which can be also characterised by intended unevenness. The most often, this method is used to produce yarns with the effect of local flakes, the so-called slubs [Drobina & Malkiewicz, 2014].

The knitting technique of the production of decorative threads consists in creating decorative effects with the use of course or warp loop stitches. It is a relatively costly technique of decorative thread production, which stems from the effectiveness of production of knitting machines. Nevertheless, fancy threads produced with the use of this technique are characterised by extraordinary beauty stemming from the introduction of elements of knitting loop stitches into the structure of linear textile products. Machines used in the production of decorative knitting yarns are equipped with knitting heads and latch needles for the production of chain cord yarns. Decorative yarns produced with the use of that method are very narrow course or warp knitting products [Belov, Lomov, Truevtsev, Bradshaw, & Harwood, 1999]. The factors that influence the production of decorative yarns produced with the use of the knitting method were analysed in 2002 by Nergis [Negris, 2002]. In turn, Ciukas, Tvarijonaviciene and Mikucioniene conducted research on the mathematical assessment of the structural parameters of knitting yarns [Ciukas, 2006].

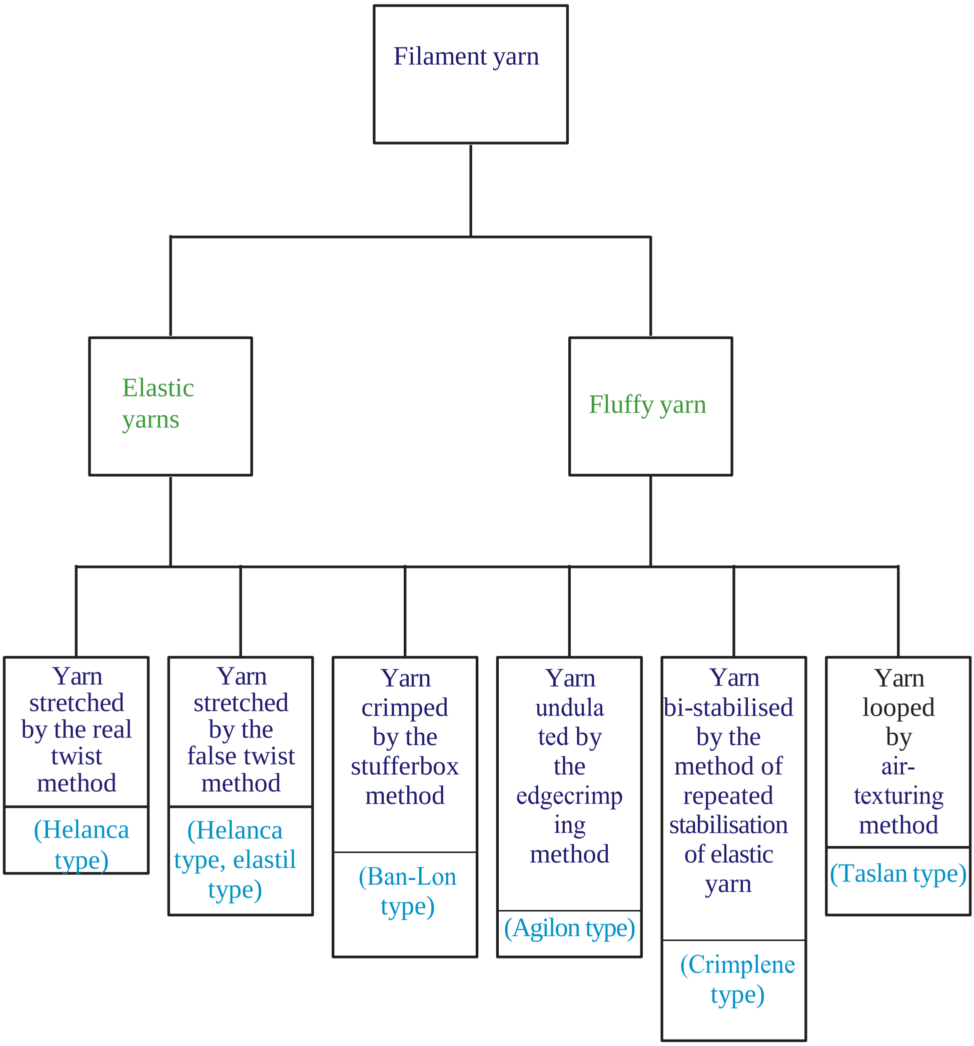


Fig. 17. Classification of textured threads

Fig. 18. Decorative threads produced with the use of the knitting method by COMEZ company

5.2. Production methods of fancy twisted threads

Fancy twisted threads constitute a dominating group within linear textile products with expanded surfaces. High decorative values as well as the functional ones that the threads possess as a result of use of simple production methods allow for transfer of longitudinal tension. All of those values stem from the possibility of using a composition of different structures of single yarns twisted together multiple times with different overfeed. There are two basic techniques of production of fancy twisted threads: the ring twisting frame method and the hollow spindle method.

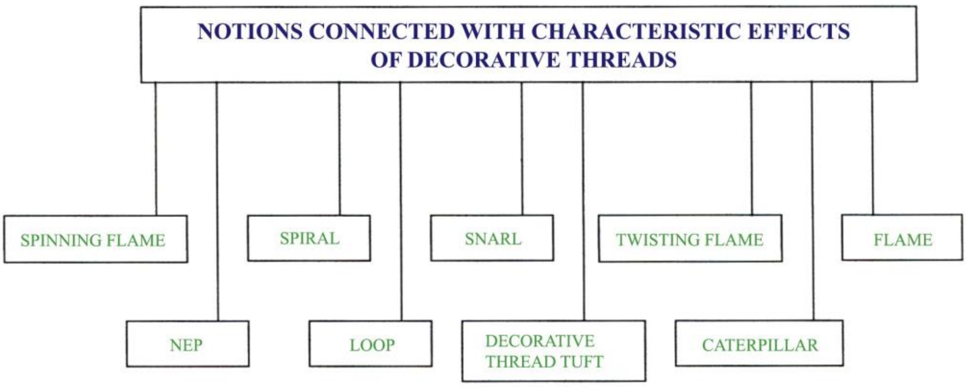


Fig. 19. Different kinds of design effects of fancy twisted threads

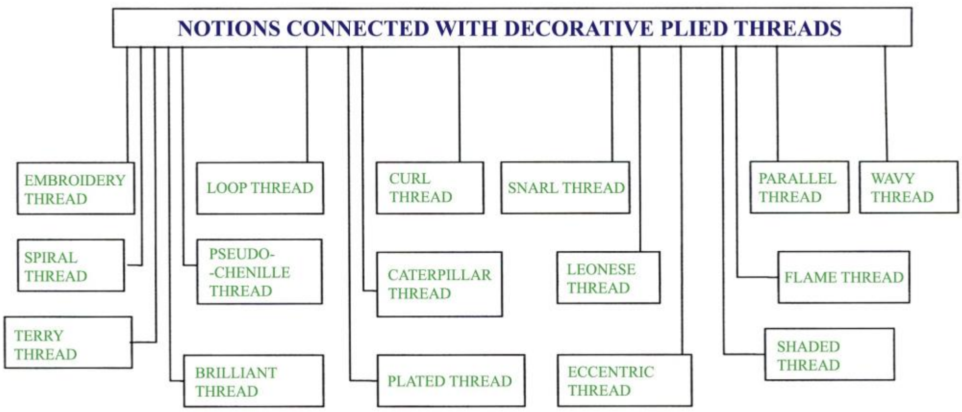


Fig. 20. Different kinds of fancy twisted threads

5.2.1. Ring twisting frame method

The production method of fancy twisted threads with the use of a ring twisting frame is a classic one and currently is very seldom used. The low popularity of that production method stems from its low effectiveness and low success rate of the repeatability of effects, all the more if the feed system of the twisting mechanism is not computer-controlled. All the designing effects obtained with the use of this production method are produced only in the twisting-winding system of the machine, since ring twisting frames are not equipped with a drawing mechanism. According to the definition, fancy twisted threads produced with the use of ring twisting frame are built of multiple single yarns twisted together. In order to achieve designing effects in fancy twisted threads, one has to diversify the overfeed of individual components, and consequently, diversify the tension, with which individual threads are fed to the twisting zone. Apart from the overfeed, there are precisely seen the differences in tension of the components of fancy twisted threads that cause the diversification of structure of those threads. The most frequent parameters characterising the structure of fancy twisted threads include: overfeed, diversification of linear density or other structural parameters of component yarns, periodical changes in twist between the core thread and the effect thread and the number of individual component yarns twisted together. The productivity of a ring twisting frame producing fancy twisted threads with continuous effects amounts to 15 m/min. from one spindle at the maximum. This productivity is limited by the cooperation between the traveller and the ring, and the dominant phenomenon that occurs in this system is the mutual interaction between the force of friction, the centrifugal force, the Coriolis force, the force of gravity and inertia of the traveller, and the torque. The productivity of the ring twisting frame is lower by half during the production of fancy twisted threads with point effects than the productivity of production of fancy twisted threads with continuous effects and equals 7-10 m/min. It is caused by the fact that during the production of fancy twisted threads with point effects it is necessary to periodically decrease the speed of delivery of one of the component threads from the system that feeds the traveller and the ring. Thereby, it is possible to produce periodical bulges in the form of tufts or rolls. Fancily twisted threads with point effects are characterised by the most interesting designing effects as well as high production costs. On the other hand, fancy twisted threads with diversified designing effects cause numerous problems during transformation into flat textile products. Those threads are characterised by a high unevenness of structure, which causes periodical changes in tension during weaving or knitting. In extreme cases, one should note that fancy twisted threads with point effects are not used in flat textile products as warp. Diversification of the overfeed of component yarns is caused by differences in the rotary speed of delivery rollers that deliver the individual components of the fancy twisted thread. Similarly, the diversification of twist alongside the fancy twisted thread is generated by periodic changes in the speed of delivery of one of the components of the fancy twisted thread and it usually occurs as a result of retardation of delivery of the core component with the simultaneous preservation of the high value of delivery of the effect component. That way, a local accumulation of twist of the effect component over the core component occurs [Mertová, Moučková, Neckář, & Vyšanská, 2018].

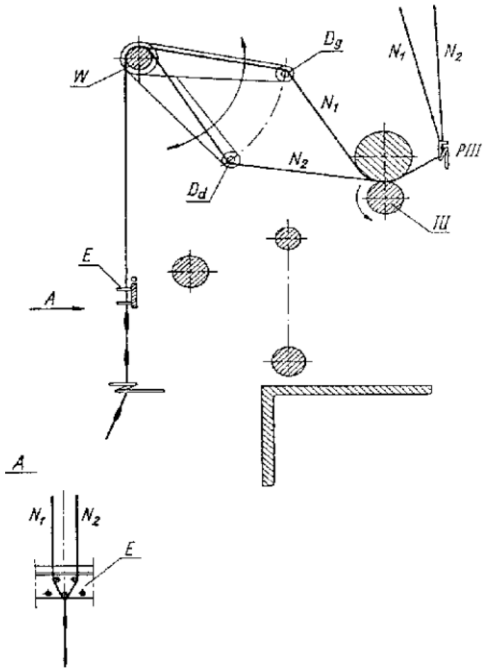


Fig. 21. Scheme of fancy twisting by ring twisting frame: N1, N2 – component threads, E – guide beneath which the twisting of threads occurs, W – rocking shaft, Dg – faller wire that crosses the upper arms of the working beam, Dd – faller wire that crosses the lower arms of the working beam, PIII – first thread guide, III – feeding roller

5.2.2. Hollow spindle method

The hollow spindle method is currently used with the greatest frequency due to its high production effectiveness and wide design possibilities. Practically every spinning mill is equipped with machines of that type. The productivity of fancy twisting of threads with continuous effects equals 70 m/min. The simplicity of the idea of production of fancy twisted threads with the use of the hollow spindle methods lies in the introduction of at least two single yarns inside the spindle, fed with a different delivery speed of the delivery rollers: the yarn that is fed more slowly into the hollow spindle is fed with the high initial tension and, at the same time, with overfeed, which equals one, creates the core of the fancy twisted thread. On the core of the fancy twisted thread, the effect thread is twisted, introduced inside the hollow spindle with the biggest overfeed. The system of feeding component threads into the twisting zone is computer- controlled. That way, one can periodically retard or accelerate the feed of one of the components of the fancy twisted thread so that the intended unevenness of structure could be achieved. On top of the hollow spindle, there is a bobbin with a package of continuous filament thread.

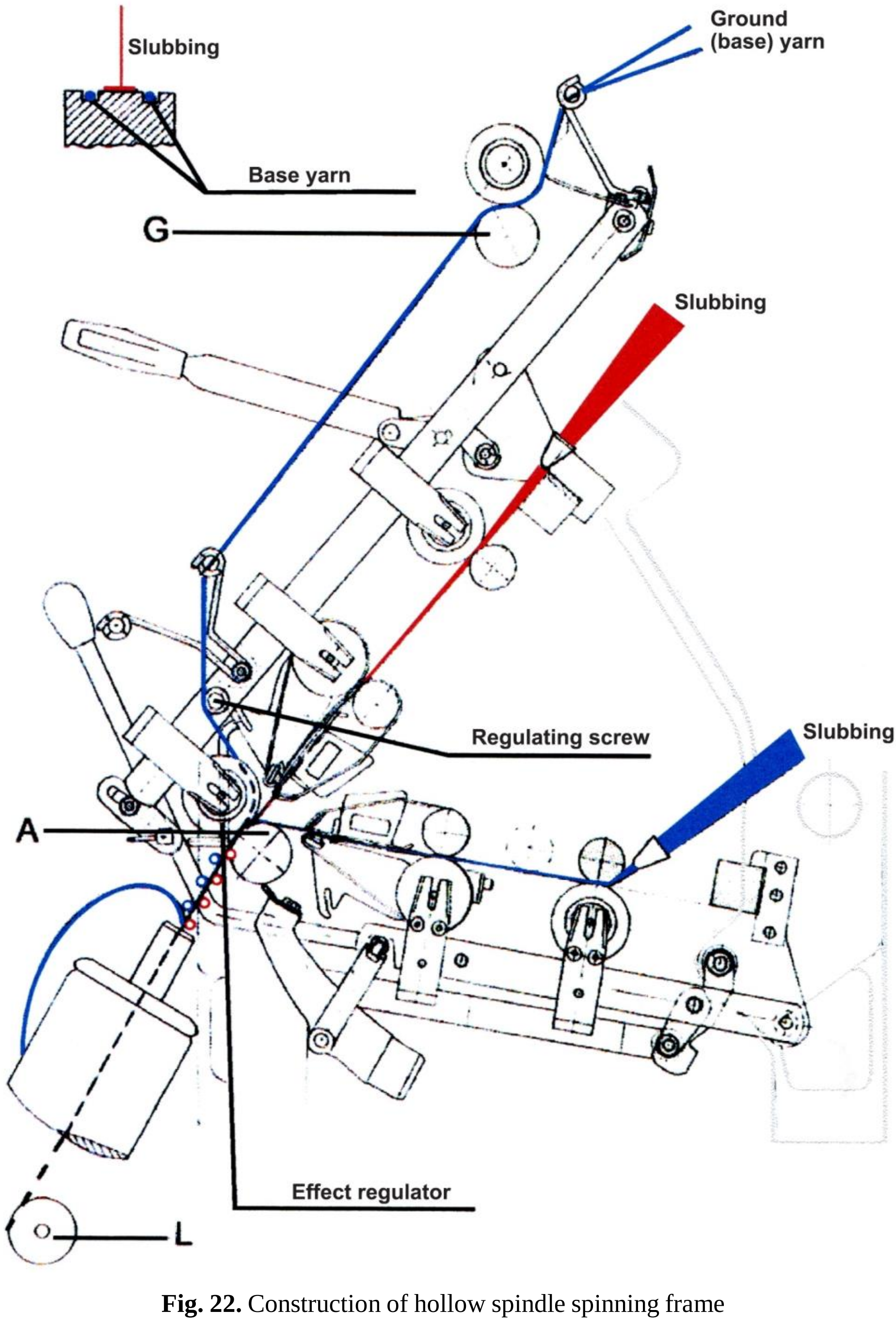


Fig. 22. Construction of hollow spindle spinning frame

This thread is also fed inside the hollow spindle, which makes very fast rotary motion (ca. 30.000 m/min.). Inside the hollow spindle, the filament thread twists around the core yarn and the binding yarn, which are fancy twisted together. The filament thread unwound from the hollow spindle performs the function of the tie-in thread that strengthens the decorative effects created by the effect thread over the core thread. Designing fancy twisted threads, one has to bear in mind the rule that the tie-in thread should be very fine and, thereby, invisible in the whole structure of the fancy twisted thread.

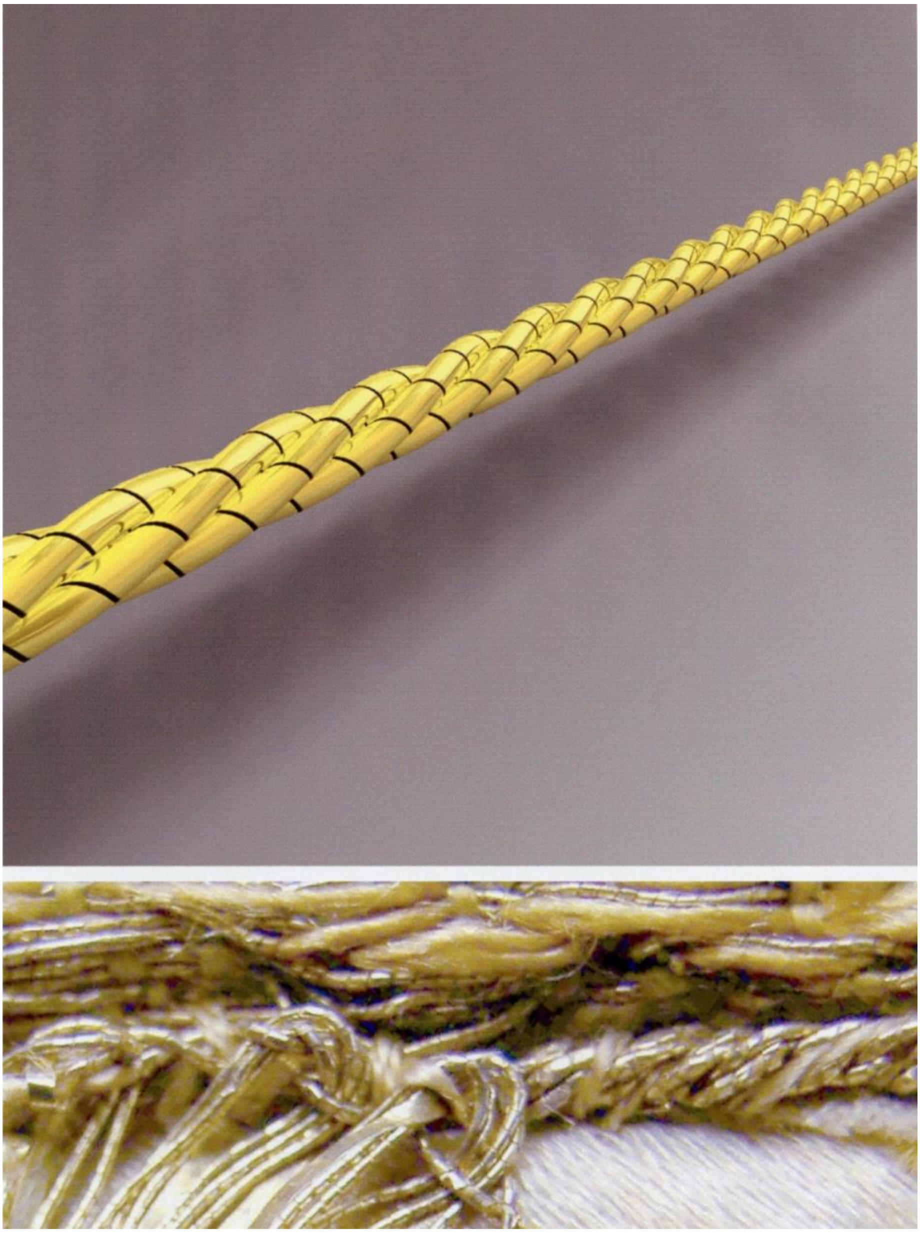


Fig. 23. Reconstruction of plied thread (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative Threads in a Historical Perspective], Master's Thesis, Lodz University of Technology 2007, Supervisor: Grabowska K.E.)

The tie-in yarn should also be very strong, because it is fed to the twisting zone with a very small overfeed, close to one. Nevertheless, the overfeed is bigger than in the case of the core thread. The tie-in thread does not create effects and it does not set itself along a straight line as it happens with the core thread. Nevertheless, the tie-in thread transfers longitudinal weight during the drawing process. That is, why continuous polyester threads are best suited for the role of the tie-in thread. The core thread is also supposed to transfer the longitudinal tension and, usually, this is the thread that breaks as the first one in the process of drawing. As a rule, designers hide that thread by using continuous polymer threads. Because the effect in the fancy twisted thread is the most decorative, heat stabilised yarns, fluffy, constructed from segmental threads twisted into the form of yarn are used as the effect thread. There are different types of fancily twisted threads, which names were assigned depending on the type of effect characteristic of a given kind of fancy twisted thread. The most often, the names were assigned by producers and hence the various classifications of fancy twisted threads. Research on the structure and properties of fancy twisted threads were conducted by Petrulyte in 2004. The aforementioned research bore fruits in the form of a review dissertation describing the methodologies of production and problems connected with producing different structures of fancy twisted threads [Petrulyte, 2004]. Mathematical modelling of the structure of fancy twisted threads depending on the input variables, which constituted the parameters of the hollow spindle twisting frame settings (primarily, the influence of the overfeed and twist on modelling of the designing effect on the thread was studied) was carried out by Ragaisiene in 2009 [Ragaisiene, 2009].

6. Classification of decorative yarns and fancy twisted threads depending on the designing effect

The basic and elementary classification of fancy twisted threads is based on the characteristics of the designing effect that appears on the thread. This is a basic classification, the most often used beside the classification that consists in the characteristics of the machine that produces the thread. Classification of fancy twisted threads and decorative yarns focuses mainly on the distinction, whether the designing effect appears along the length of the thread in a continuous way or periodically with varying frequency. Apart from the characteristics of the frequency of the appearance of designing effects on the thread, another important feature of fancy twisted threads and decorative yarns is the type of the design effect. Due to the type of designing effect, within the group of single decorative yarns there are: eccentric threads, nep threads, melange threads, gauze and segmentally thrown yarn. The names of those yarns are commonly used in the industry. Within the group of fancy twisted threads we distinguish: embroidery thread, spiral thread, wavy thread, terry thread, loop thread, coil thread, snarl thread, eccentric thread, shaded thread, flame thread, caterpillar thread, chenille thread, plated thread, Leonese thread and brilliant thread [Grabowska, 2001].

6.1. Characteristics of decorative yarns

The nep decorative yarn is characterised by the simplest structure. This yarn is most often identified with the system of card spinning of the woollen type and consists in adding small tufts of wool in the final stage of the carding process in such a way that the tufts are not removed in the carding process. Neps create the designing effect. Tufts of wool are kept inside the structure of the yarn as a result of twisting them into the structure of the yarn. The forces of friction and cling that occur between the fibres and the tufts, i.e. neps, keep the structure of the yarn stable. The neps are introduced into the yarn in different colours, so that they would make colourful stains on the surface of the yarn, and thereby, the flat textile product. The designing effect is original and interesting. However, each user of flat textile products or fully fashioned garments is well aware of the uniqueness of such a product (in the pejorative sense of the word). Because tufts and neps are systematically removed in the process of using the textile product and after a year, as a result of washing, tumble drying or just beating of card textile products, the neps are almost entirely removed from the surface of the woven or knitted fabric. One of the variations of the nep yarn is the spotted yarn, also known under the name of segmentally thrown yarn. In that case, segments of fibres longer than the nep are doped to the drawing sliver or to the card web in the woollen system and they are subjected to the process of drawing, blending and then twisting within the structure of single yarn. That way, elongated colourful effects are created in the background of the monochrome structure of the yarn. This type of doping with accumulations of fibres longer than the nep is stronger and better fixed to the yarn.

Using drawing slivers that differ in colour in the spinning process and blending them at the stage of the last drawing frame preparatory stage results in the production of melange yarn. The designing effect in the melange yarn is created by multicoloured assemblies of fibres twisted together. The melange yarn produced in a classic production process is characterised by a greatstructural evenness. In turn, it is distinguished by a spectacular range of shades, different colours, shine and other visual effects. The melange yarn is attractive, it is even and it does not generate problems in the post-production process as well as in further usage of the textile product. The melange yarn produced with small twist, i.e. below the maximum of 200 t/m is called crewel and is dedicated to the production of knitted products, usually with the use of hand crochet or the so-called knitting needles.

A variation of the melange yarn is gauze yarn, which is created as a result of twisting together two attenuated slubbings of different colour. The two assemblies of attenuated fibres that differ in colour create clearly visible streaks connected by twist. The designing effect is based on two assemblies of fibres of a different colour that are arranged along the helix of the yarn.

Eccentric yarn is characterised by the great unevenness of twist and linear mass. The design effect is created as a result of change in the draft in the spinning process, which occurs periodically. Most often, the draft diminishes for a short period of time, sometimes down to the value of R = 1, which means a lack of attenuation of the slubbing out, of which the eccentric yarn is produced. It causes a temporary bulge in the yarn and, thereby, diminishing the twist in that segment. The designing effect is a local, periodical bulge in the yarn. The eccentric yarn is more fluffy in the thick places, which visually gives nice structural effects in flat textile products, especially knitted ones.

The attenuated yarn is the structural opposite of the eccentric yarn. The attenuated yarn is produced as a result of periodic changes in the draft of the spinning frame: the draft increases periodically. That way, the slubbing feeding the spinning frame is in places greatly attenuated. The designing effect is a local attenuation of the yarn. At the same time, there is an increase in the twist in those places. It is necessary because of the need to preserve the continuity of the structure of the attenuated yarn, which is compromised in the places, where the effect occurs. The attenuated yarn is characterised by an unbalanced twist: it displays a high tendency to form snarls. The attenuated yarn has to be subject to the process of steaming in order to stabilise the twist. The attenuated yarn generates a lot of problems during post-processing, due to the fact that it is compromised in the places, where the attenuation occurs.

6.2. Parametric classification of fancy twisted threads with continuous effects

The parametric classification of fancy twisted threads was developed on the basis of mathematical models derived for the arrangement of three component yarns twisted with different values of the overfeed. The mathematical models, verified experimentally, described the specific tenacity of different possible constructions of fancy twisted threads with continuous effects. The experimental verification demonstrated compliance of around 85%. On the basis of the conducted model optimisation a formula was derived that determines the coefficient of shape of fancy twisted yarns:

$$K = D_{sR0}/D_{sE0} \tag{1}$$

where:

D_{sR0} – diameter of the helix formed by the outer edge of the core yarn within the fancy twisted thread [mm],

D_{sE0} – external diameter of the helix formed by the outer edge of the effect yarn within the fancy twisted thread [mm].

The maximum permissible value of the coefficient of shape of fancy twisted threads was determined and it equals 1. This case is embodied by a fancy twisted thread built of structurally identical component yarns, twisted together in such a way that each of them transfers the same tensile stress, all perform the same function in the construction of the fancy twisted yarn, i.e. as far as its construction is concerned, one cannot differentiate between the core thread, the effect thread or the tie-in thread. Such a thread is called a spiral thread, because all of the component threads are arranged along a spiral line with the same shift and radius vector, and at the same angle of inclination in relation to the longitudinal axis. The component yarns produce helices twisted the vertical longitudinal axis, which centres are apart from each other at a distance of the diameter of a single component yarn. The decorative effect of the spiral yarn is defined by the diversification of the colour of the component yarns.

If the diameter of the helix formed by the outer edge of the core yarn equals the diameter of the core yarn, i.e. if:

$$D_{sR0} = d_{R0} \tag{2}$$

where:

d_{R0} – diameter of the core yarn [mm],

D_{sR0} – diameter of the helix formed by the outer edge of the core yarn [mm], then the structure of a fancy twisted thread is created and it is called a parallel thread. The coefficient of shape of the parallel thread is expressed by the following formula:

$$K = d_{R0}/D_{sE0} \quad (3)$$

where:

K – coefficient of shape,

d_{R0} – diameter of the core yarn [mm],

D_{sE0} – diameter of the helix formed by the outer edge of the effect yarn [mm].

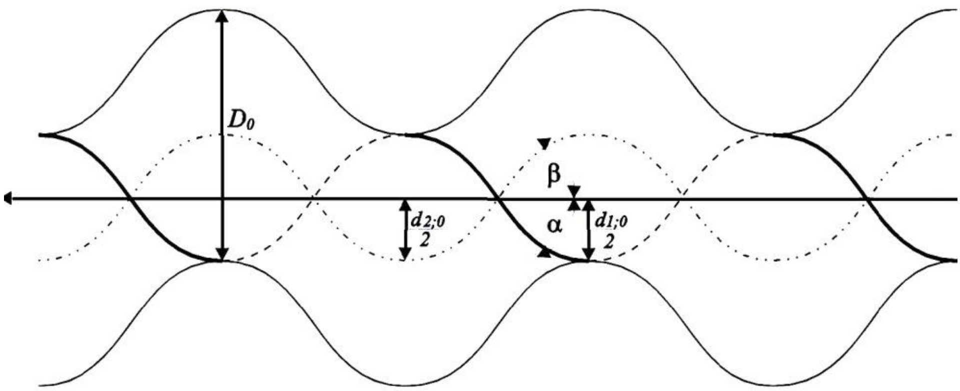


Fig. 24. Structure of parallel thread

The shape coefficient K determines the so-called liminal value for fancy twisted threads. The name was adopted due to the fact that fancy twisted threads with the values of the coefficient of shape higher than the liminal value are characterised by the fact that all the component strands adhere to one another along the whole length of the fancy twisted thread. In turn, fancy twisted threads characterised by the values of the coefficient of shape lower than the liminal value are plied yarns, in which there is an overfeed of the effect thread that is much bigger than one and, thereby, the effect thread does not adhere to the core thread along the whole length of the fancy twisted thread: it forms loops. The parallel thread is characterised by a straight core, around which the binding yarn in twisted. That way, the parallel thread is constructed from two component yarns, i.e. the straight core thread and the binding thread that is twisted around it. The biggest tension is transferred by the core thread and it is the thread that breaks first in the drawing process. The decorative effect of the parallel thread is created either as a result of diversification of colour of component yarns or as a result of diversification of linear mass of component yarns.

If the coefficient of shape of the fancy twisted thread assumes a value within the range between 1 and the liminal value, such a fancy twisted thread is ranked as a wavy thread, i.e. one, in which the effect thread is twisted around the core yarn along its whole length; and moreover, it is fed with an overfeed slightly bigger than 1. It causes a situation, in which the effect yarn is fed with an overfeed, which does not cause a break in the continuity of contact with the core thread. Nevertheless, it causes flakes in the effect thread in relation to the core yarn, flakes visible in the form of waves. It has to be emphasised that all the constructions of fancy twisted threads with the coefficient of shape bigger than or equal to the liminal value can be produced with the use of only two component yarns. Such threads are stable in terms of construction and strength for two component yarns twisted with each other. In turn, if the coefficient of shape of the fancy twisted thread is smaller than the liminal value, the production of a stable fancy twisted thread, built on the basis of two component threads twisted with each other is not possible. Fancy twisted threads with the coefficient of shape smaller than the liminal value require in their construction three component threads, i.e. the core thread, the effect thread and the tie-in thread. Because the tie-in thread performs the function of a stabiliser of all the flakes of the effect thread, which generates a lack of continuity of adherence between the core thread and the effect thread, which were twisted together to form the fancy twisted thread.

If the shape coefficient of the fancy twisted thread is slightly smaller than the liminal value, fancy twisted threads characterised by a structure without a visible local adherence between the core thread and the effect thread are produced, which causes the production of a terry fancy twisted thread. In case of this thread, the effect thread forms bigger local flakes in the form of a visible lack of adherence to the core thread. Those flakes are not characterised by the form of a loop: they are wavy sinusoidal helices twisted around the core thread.

A loop visibly formed by the effect thread can be isolated in the case of fancy twisted yarns with the coefficient of shape significantly smaller than the liminal value. Loop is understood as a clearly circular shape formed by the effect thread twisted around the core thread. Both the terry thread and the loop thread require the introduction of a tie-in thread that stabilises the overfeed of the effect thread twisted around the core thread.

7. Characteristics of multi twist fancy threads

The analysis conducted in the present work as well as the characteristics of the properties of fancy twisted threads have been conducted on the basis of the author's own research carried out over the last twenty years. The results of the conducted analyses will be presented in order of increasing of the complexity of the designing effect of the fancy twisted thread. The spiral thread was adopted as the simplest example of the fancy twisted thread, while the fancy twisted threads with diversified point effects were qualified as the most complex ones. The group of threads with continuous effects includes spiral and loop threads. Fancy threads with point effects are tuft and flame threads.

7.1. Plied fancy threads with continuous effects

Within the group of plied fancy threads with continuous effects there are threads, which designing effect is produced on the basis of diversification of colour of the component threads and their thickness as well as the value and direction of twist, and in the final structure of the fancy thread, all the component threads adhere to one another along the whole length. The group of threads with continuous effects include:

- spiral threads,
- loop threads,
- chenille threads.

The second subgroup of plied fancy threads is constituted by threads that differ in colour, thickness, size, and direction of twist and, at the same time, there occurs a periodical break of continuity of adherence of the component threads along the length of the fancy thread. These are loop threads. Chenille threads, due to their consistent structure, can be ranked among threads with continuous effects. However, there are variations on the chenille thread with clear point effects.

7.1.1. Spiral threads

Spiral threads constitute a group of fancy twisted threads characterised by the fact that either the component threads or the component yarns are twisted together in such a way that all the component strands adhere to one another along the whole length of the spiral thread. A spiral thread can have two or more components. The designing effect obtained in the spiral thread can stem from the diversification of colours of component threads or the structural diversification of the component strands. The group of spiral threads includes the embroidery thread, which is produced as a result of twisting together two or more component yarns that differ only in colour, parallel thread usually built from two or three component threads, in which the core yarn is straight and the binding threads constitute continuous filament threads and a wavy thread, in which not only diversification of colours and structural parameters characterising the components is implemented, but also diversification of initial tension of individual component threads fed into the twisting zone. The embroidery thread and the wavy thread differ from each other also in terms of the shape coefficient:

- Embroidery thread: $K = l$ (4)
- Parallel thread: $K_{gr} = d_{R0}/D_{sE0}$ (5)

where:

K_{gr} – liminal value of the coefficient of shape,

d_{R0} – diameter of the core yarn [mm],

D_{sE0} – external diameter of the helix formed by the outer edge of the binding thread in the parallel thread [mm],

- Wavy thread: K € $(d_{R0}/D_{sE0}, 1)$. (6)

Numerous research has been conducted that allows for the verification of the significance of correlation between different structural parameters of the spiral thread and its physical properties. A significant linear correlation between the thickness of the spiral thread and the final twist of that thread ($R^2 = 0.65$, significance level – 0.01) was proven: the bigger the twist result of the spiral thread, the smaller the diameter of the thread. Moreover, a linear correlation with the value of $R^2 = 0.65$ between the breaking force of the spiral thread and the linear density of that thread was verified at the 0.01 significance level: the bigger the linear density of the spiral thread, the bigger the breaking force of the spiral thread it achieves. Applying the same significance level as the last time, the coefficient of determination $R^2 = 0.65$ for the relation between the stiffness of bend of the spiral thread on the one hand and the linear density of the spiral thread and its final twist on the other was verified. It is a directly proportional relation: the bigger the linear density and final twist of the spiral thread, the bigger its resistance to bending. However, the increase in the linear density of this thread has a more significant influence on the stiffness of bend of the spiral thread than the twist. The results of research were confirmed by the analysis of hysteresis of bend of the spiral thread. It was confirmed that the width of the hysteresis of bend of the spiral thread depends upon the linear density of that thread. In turn, the final twist of the thread does not influence the width of the hysteresis of bend. Research was also conducted on the tendency to form snarls on the spiral thread in relation to its linear density and twist. It was proven that there is a correlation of around $R^2 = 0.95$ with the significance level of 0.01 between the standard deviation from the average value of distance between the clamps of the device used for the analysis of the formation of snarls and the linear density of the spiral thread and its final twist. It proves the fact that an increase in the unevenness of the linear density of the spiral thread influences significantly the tendency to form snarls. The tendency to form snarls is conditioned by the introduction of high value of final twist of the spiral thread.

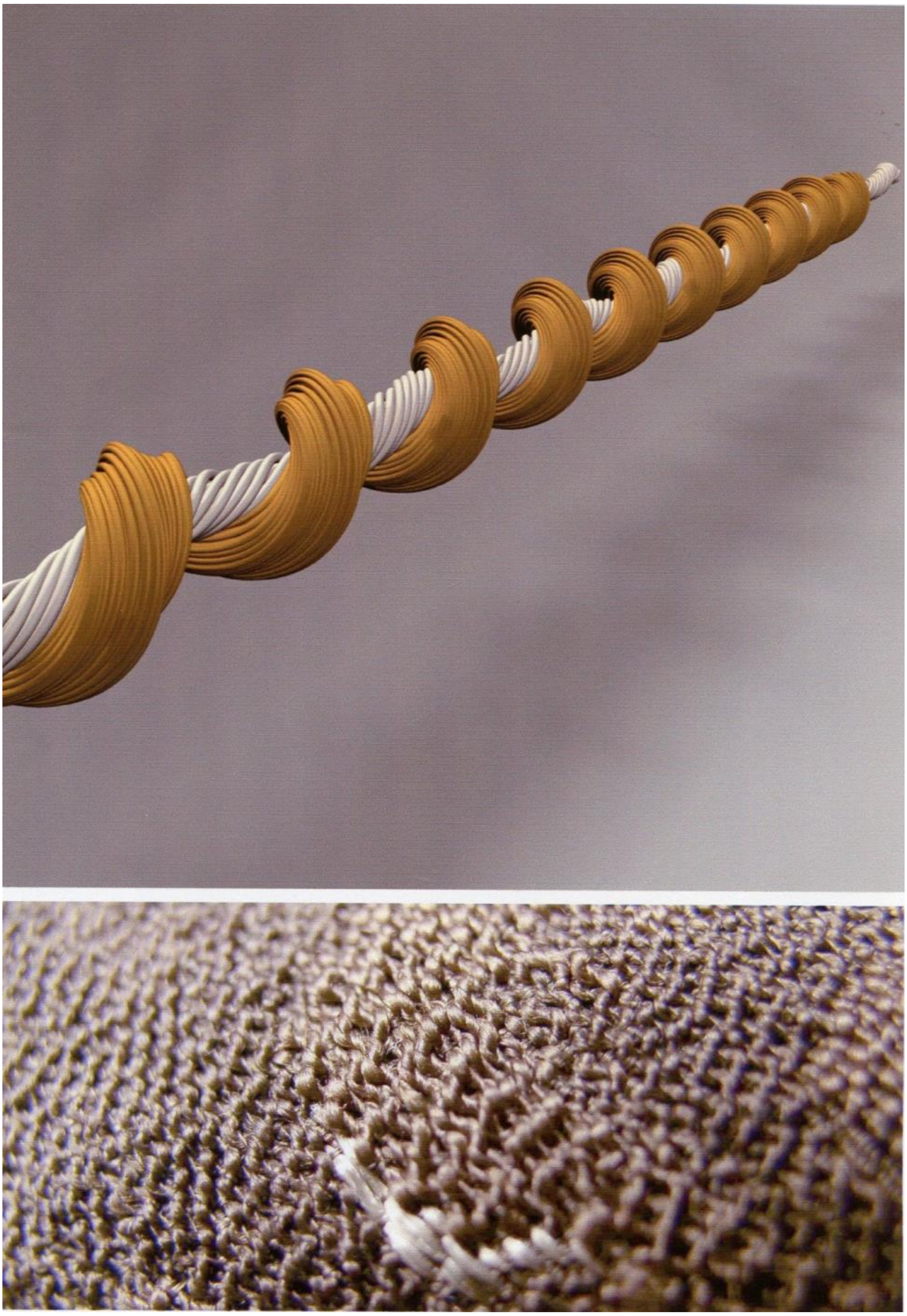


Fig. 25. Reconstruction of spiral thread (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative Threads in a Historical Perspective], Master's Thesis, Lodz University of Technology 2007, Supervisor: Grabowska K.E.)

In other words, the higher the value of twist of the spiral thread, the higher the tendency to form snarls in this thread. In turn, the influence of the linear density of the spiral thread has an inverse effect on the tendency to form snarls. The bigger the linear density of the spiral thread, the higher its stiffness of bend and the lower the tendency to form snarls. The tendency to form snarls is a negative phenomenon, which hampers the process of winding and then all the processing stages of this thread. The tendency to form snarls is eliminated as a result of twisting the component threads together in the direction of final twist of the spiral thread opposite to the direction of twist of component threads. It has to be borne in mind, however, that the final twist, also known as the plying twist, should not be too big, because it can cause the component threads to untwist and the whole spiral thread to weaken. Another method is the use of the steaming process of packages of the spiral thread in an elevated temperature.

It makes the production process more expensive. Nevertheless, both of the above-mentioned methods that help to eliminate snarls on a spiral thread are frequently used. Research was also conducted to assess the level of tendency to process the spiral thread into the form of fabric with the use of an air jet loom. The so-called “air index” method was used to this end, which helps to determine the tendency to transport thread with the use of air. It was concluded that at the significance level of 0.01 there is correlation (R^2 = 0.96) between the air index and the linear density of the spiral thread. It means that the higher the linear density of the spiral thread, the lower the tendency to transport the spiral thread with the use of a stream of air generated by the jet of an air jet loom.

7.1.1.1. Embroidery thread

Embroidery thread is the simplest example of a fancy twisted thread, in which the design effect is produced only thanks to the differentiation of colour of component threads. The component yarns that form the embroidery thread are structurally identical and differ from one another only in terms of colour. What is more, the structurally identical component yarns are introduced into the twisting zone under the same technological conditions, i.e. it is not possible to differentiate among the component strands of the embroidery thread the core thread, the effect thread and the tie-in thread. All the component yarns play the same part in the structure of the embroidery thread. As far as the material composition is concerned, the embroidery thread is usually a cotton thread. The embroidery thread is characterised by a coefficient of shape that equals to one. That is why embroidery threads are characterised by the highest breaking strength, and the lowest parameters characterising the unevenness of structure and coefficients of variation among all the fancy twisted threads. The Polish name of the embroidery thread (nitka mulinowa) stems from the fact that all the component yarns that form the embroidery thread form a spiral with the same shift and the value of angle of inclination of the helix. Embroidery threads can be very elegant due to the discreet charm of the composition of colours and to the fact that they do not flaunt any structural values. What is more, embroidery threads are more effective in production and easy when it comes to reprocessing them into the flat textile product, such as woven or knitted fabrics. Embroidery threads can be used both as the weft and as the warp. Embroidery threads determine the resource base in weaving and knitting mills. The smallest number of component yarns that defines the embroidery thread is two, but the designing effect obtained in the process of twisting together two component yarns of different colours is not impressive. That is, why usually three component yarns that differ in colour are twisted together under conditions of technological and structural parity. Of course, more complex structural variants of embroidery thread built from five or more component threads twisted together are also possible. However, in the case of five and more component yarns that differ in colour, we obtain a clear melange effect (colour blending) and such embroidery threads are characterised by a high value of linear density and great thickness. In case of embroidery threads, the influence of the value of twist on the design effect is important. What is more, the value of twist and the direction of final twist of the embroidery thread impacts the strength of the thread. Analysing the designing effect, one has to conclude that the big twist implemented in the embroidery thread causes, as a result, flickering of colours of the component threads, because they appear on the embroidery thread in very short segments defined by the shift of the helix generated by the component yarns twisted together. If, on the other hand, the final twist of the embroidery thread is small, there is a clear division of individual colours of the component threads used.

Fig. 26. Drawing of a two-ply embroidery thread (source: Bączyńska M., *Wirtualne modelowanie przędz fantazyjnych* [Virtual modelling of fancy yarns], Master's Thesis, Lodz University of Technology 2006, Supervisor: Szosland)

On the other hand, the final twist of the embroidery thread defines the strength of the embroidery thread: the relationship between the twist and the strength of the embroidery floss is directly proportional up to the value of boundary twist, crossing of which causes a sharp decline in strength of the embroidery floss. What is more, the production of a relatively fine embroidery floss with a high value of twist causes the formation of snarls, which hamper the winding process or cause the situation, in which the so-called warped thread is fed into the shed. As a result of conducted research, it was concluded that the optimal twist for the embroidery thread is between 150 t/m and 300 t/m. Nevertheless, the embroidery floss may require the thermal stabilisation in the atmosphere of elevated temperature and high humidity. Most often, the embroidery thread is built of three cotton yarns that differ in colour.

Fig. 27. Embroidery thread (source: Grabowska K.E., *Modelowanie własności wybranych liniowych wyrobów włókienniczych o rozbudowanych powierzchniach* [Modelling of Properties of Choesn Linear Textile Products with Expanded Surface Area], Habilitation Dissertation, Lodz University of Technology, 2006)

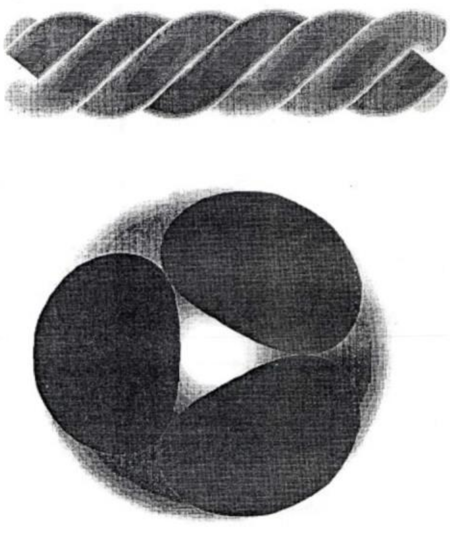


Fig. 28. Three-plied embroidery thread

Research was conducted on the strength of the embroidery floss, which aimed at the realisation of mathematical models describing the properties of the embroidery floss as the function of its structural parameters. A mathematical model was derived, which main input variable is the distribution of tensile stress of the individual component yarns that form the embroidery thread. The static tenacity of the embroidery thread is, above all, the function of the parameters describing physical phenomena that occur during the process of drawing of the embroidery floss:

$$P = kS\frac{Tt_k}{Tt_N}\frac{\delta e_k}{\delta e_N}\sec\alpha_{k0} \tag{7}$$

where:

P – specific static tenacity of the embroidery thread [cN/tex],

k – number of component yarns that form the embroidery thread,

S – tensile stress of a single component yarn [cN/tex],

Tt_k – linear density of a single component yarn of the embroidery thread [tex],

Tt_N – final linear density of the embroidery thread [tex],

$\delta e_k / \delta e_N$ – partial derivative of the elongation of the component yarn of the embroidery thread in regard to the elongation of the embroidery thread,

$\sec\alpha_{k0}$ – trigonometric function of the angle of inclination of helix formed by the axis of the component yarn of the embroidery thread with the vertical longitudinal axis of the embroidery floss subject to initial tension.

Statistical analysis of the results of drawing the embroidery thread proved the greatest significance of the tensile stress of a single component yarn and the twist on the strength of the embroidery thread.

In turn, the tensile stress of a single component yarn is the function of friction that occurs during the process of drawing a single yarn in individual segmental fibres. The formula describing static tension that occurs during the process of drawing the embroidery thread and falls on a single component yarn is as follows:

$$S_k = \frac{R_k(1-F_s)l_h\cos\beta_{wk}}{Tt_{fk}\left(l_{\max}^2 - l_{\min}^2\right)^2}\left\{l_{\max}^4 - 4l_h l_{\max}^3 + 8\left(l_h^2 l_{\max}^2 - l_h^3 l_{\max}\right) + \frac{48}{15}l_h^4\right\} \tag{8}$$

where:

S_k – tensile stress of a single component thread of the embroidery thread subject to static drawing [cN/tex],

R_k – force of friction converted to units of length of a single staple fibre, applied to this fibre during the process of pulling it out of a static assembly of staple fibres that form part of the component yarn, adjusted by the lateral pressure from other component yarns of the embroidery thread [N/m],

F_s – share of staple fibres of length smaller than the minimum length of fibres in the sliver,

$l_{\max}$ – maximum length of staple fibres in the component yarn of the embroidery thread [mm],

$l_{\min}$ – minimum length of staple fibres in the component yarn of the spiral thread [mm],

$cos\beta_{wk}$ – trigonometric function of the angle of inclination of segmental fibres that form a single component yarn to the vertical longitudinal axis,

l_h – braking length of segmental fibres in a single yarn that forms the embroidery thread, which occurs during the process of drawing [mm],

Tt_{fk} – linear density of a single segmental thread that forms the component yarn [tex].

The braking length that appears in the formula is present during the process of drawing of the component yarn and is calculated as the length of the segment present at both ends of a single fibre that forms part of the component thread of embroidery thread. Along the braking length there occur variables of tensile stress that draw a single segmental fibre, generated in an assembly of fibres that form the component yarn of the embroidery thread that is subject to drawing. The value of the tensile stress is always lower than the value of the breaking force of a single segmental fibre. Thus, segmental fibres along the braking length can slip between themselves. In turn, the difference in length of a single segmental fibre and a doubled braking length determines the area within the length of a segmental fibre, where the constant tensile stress is present that is equivalent to the breaking force of a single segmental fibre. Within this length of the fibre, the phenomenon of breakage of fibres occurs.

The force of friction converted to units of length of a single segmental fibre that is applied to that fibre during the process of pulling it out of a static assembly of segmental fibres that appear in the component yarn, adjusted by the lateral pressure from other component yarns of the embroidery floss is a function of structural parameters of the embroidery thread:

$$R = \frac{\mu\gamma_f u\pi 10^5 F(1+e_r)dT}{2\sqrt{1+(D-d)^2\pi^2T^2}}\sin 2\alpha \qquad (9)$$

where:

μ – coefficient of friction between fibres,

γ – specific density of fibres [kg/cm^3],

u – diameter of a single fibre [mm],

e_r – relative deflection of the diameter of a single component yarn of the embroidery thread,

d – diameter of the component yarn under a preload [mm],

T – twist of the embroidery thread [t/m],

D – external diameter of the helix formed by the component yarn that forms part of the embroidery thread [mm],

α – angle of inclination of the helix formed between the component yarn and the vertical axis of the embroidery thread,

F – tensile stress of a single component yarn of the embroidery thread (without adjusting by the lateral pressure from the neighbouring component yarns of the embroidery thread) [cN/tex].

In order to calculate the tensile stress of a single component yarn of the embroidery thread (without adjusting by the lateral pressure from the neighbouring component yarns of the embroidery thread), we apply the formula derived by [Frydrych, *Model wytrzymałości przy jednokierunkowym rozciąganiu klasycznych przędz bawełnianych* (Model of Endurance in One-Directional Drawing of Cotton Yarns), Habilitation Monograph, Lodz University of Technology 1995].

The analysis of the formula that determines the strength of the embroidery floss proves that the coefficient of friction between the fibres and twist of single component yarns as well as the final twist of the embroidery thread have a significant influence on the strength of this thread. The analysis of phenomena that occur during the process of drawing the embroidery thread proved a significant influence of the secondary migration of staple fibres that take place during the process of twisting single yarns to the form of the embroidery thread. As it turned out, a migration of staple fibres takes places in two stages, i.e. we can distinguish primary migration of staple fibres that takes places during the process of spinning a single component yarn and the secondary migration, which takes place during the process of twisting component yarns to the form of the embroidery thread. However, regardless of which type of migration has a bigger influence on the strength of the embroidery thread, it was proven that the migration of staple fibers is determined by the length of fibres used in the production of yarn and the value of twist of a single component yarn as well as the final value of twist of the embroidery thread. Secondary migration of fibres makes the segmental fibres in component threads of the embroidery thread migrate inside the embroidery thread. Thereby, the biggest share of staple fibres of the embroidery thread is accumulated inside that thread. Research on the migration of component yarns during the process of twisting to the form of the embroidery thread proved that all component threads try to arrange themselves along the circumference of the embroidery thread, thus creating embroidery threads with the so-called empty core. As a result, the embroidery thread is characterised by the biggest compaction of staple fibres inside the embroidery thread with a simultaneous production of a hollow area

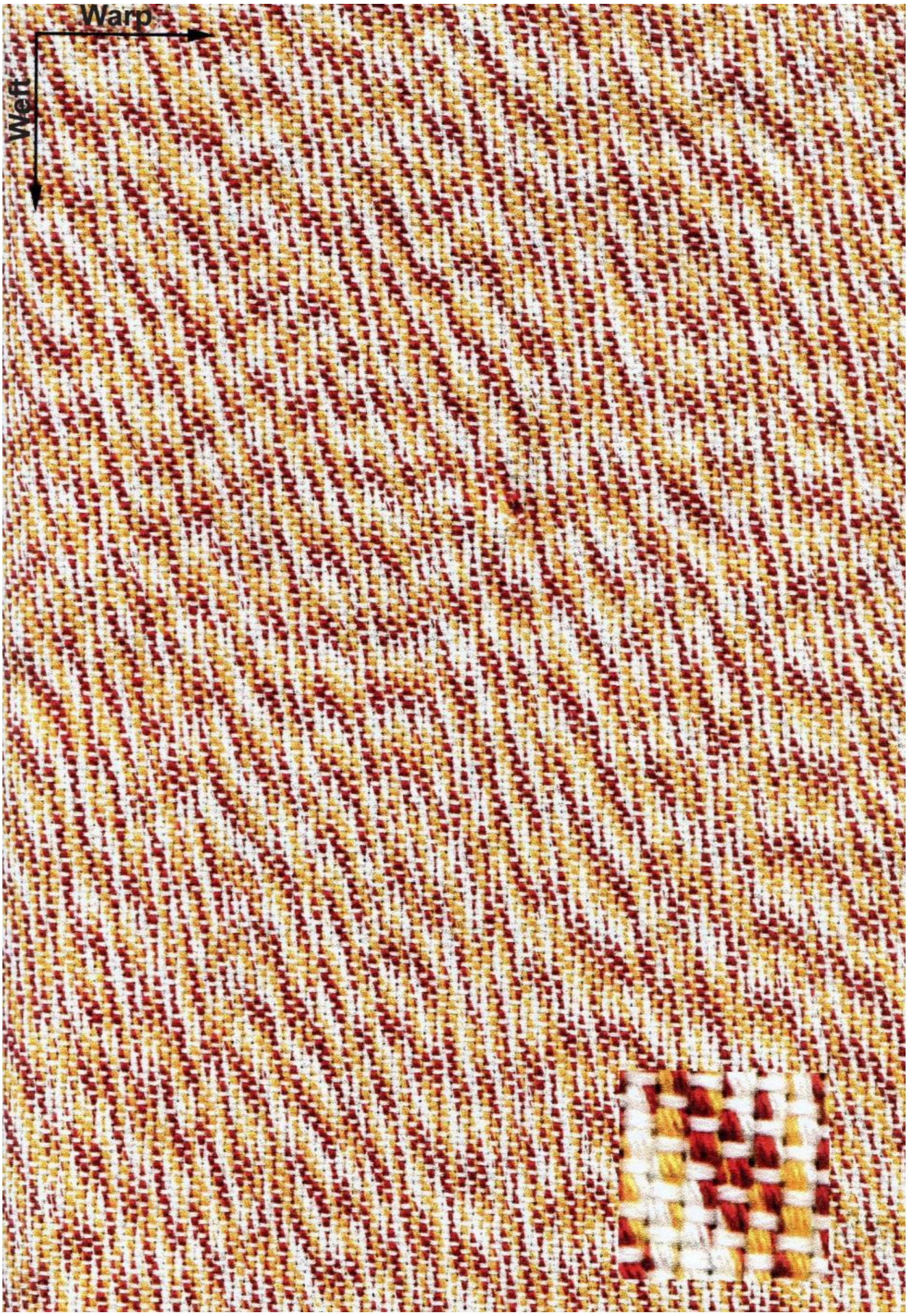


Fig. 29. Plain weave fabric with embroidery thread used as weft (source: Kurek E., *Techniki zdobienia tekstyliów z wykorzystaniem nieklasycznych struktur i faktur nitek* [Techniques of Decorating Textiles with the Use of Non-Classical Structures and Textures of Threads], Master's Thesis, 1998, Lodz University of Technology, Supervisor: Masajtis J.)

inside the embroidery thread and a flattening of the cross-section of the component yarns to a triangular form. It has to be pointed out that the embroidery floss is built from identical component yarns that perform equivalent functions within the embroidery thread. The embroidery thread lacks core yarns and binding yarns.

Research was conducted on the experimental verification of the validity of derived formulas that determine the static tenacity of the embroidery floss. The validity of theoretical results was confirmed at the level of 78%. The scheme of variations in the tensile stress in relation to displacement generated by a device called Instron is the characteristic feature of the embroidery thread: irrespective of the number of component yarns, the course of the diagram is similar, i.e. there is one peak corresponding to the maximum breaking force of all of the component yarns at the same time. What is more, the course of the diagram of the variations in the tensile stress of the embroidery thread in relation to displacement is flat (Fig. 29) and there are no shifts of variations in the tensile stress corresponding to the mutual slipping of staple fibres (Fig. 28), which are characteristic of single yarns. The lack of slipping effect of staple fibres during the drawing process (shifts and unevenness of the course of variations in tensile stress in the case of drawing a three-plied thread (Fig. 30), because all of staple fibres are locked by twist and friction.

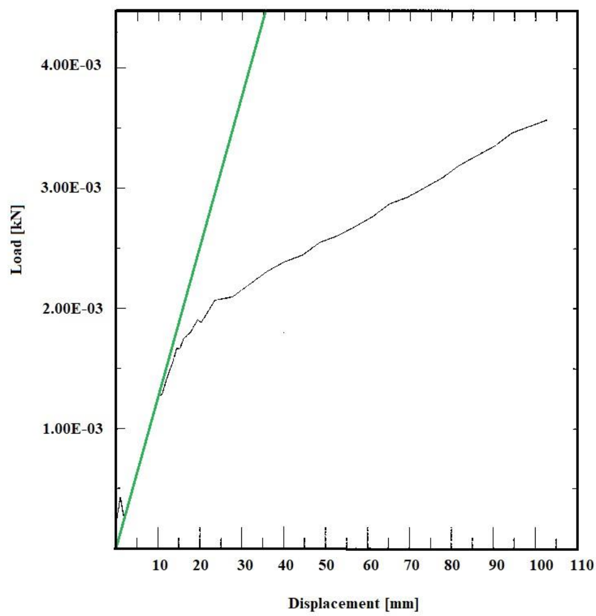


Fig. 30. Scheme of the relationship between the tensile stress and displacement for the single yarn [author's own research]

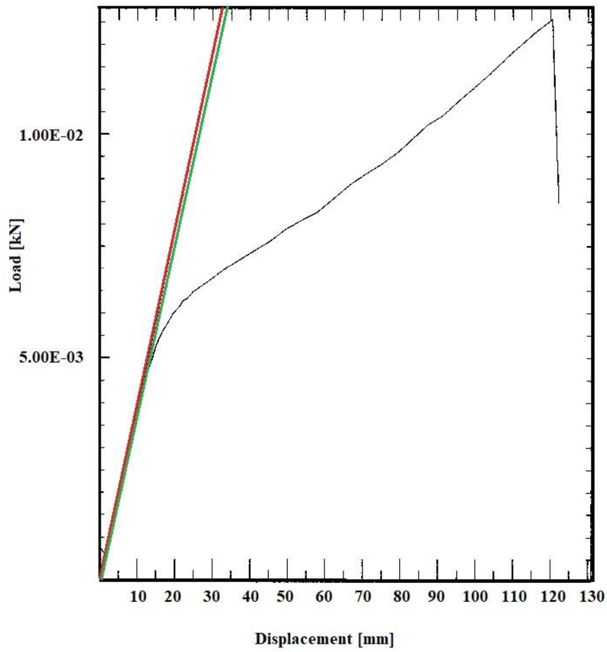


Fig. 31. Scheme of the relationship between the tensile stress and displacement for the two-plied spiral thread (embroidery thread) [author's own research]

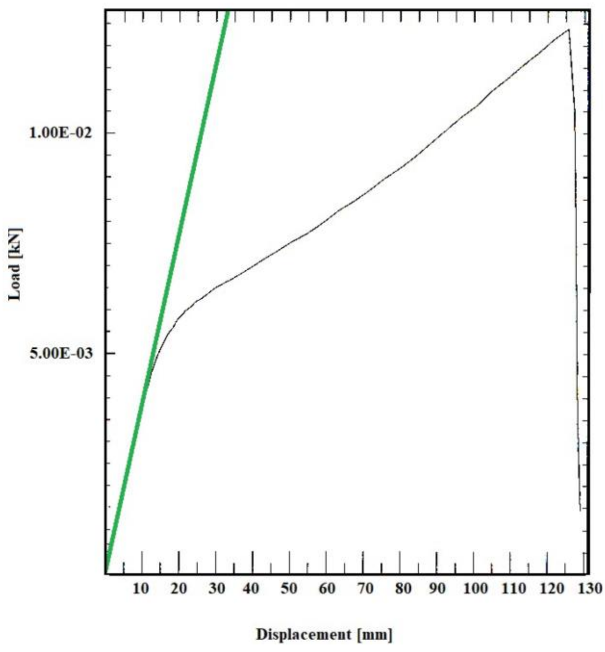


Fig. 32. Scheme ot the relationship between the tensile strength and displacement for the three-plied spiral thread (embroidery thread) [author's own research]

The embroidery thread is twisted in the direction opposite to the direction of twist of its component yarns. On the one hand, it diminishes the tendency to form snarls in the embroidery thread, but on the other hand, it may cause a drop in tenacity as a result of the reduction of twist in the component yarns: component yarns twisted together in the direction opposite to the direction of twist proper for component yarns become untwisted. For that reason, the small final twist of the embroidery thread is used so that no excessive reduction of twist in the component yarns would occur. The twist that is left in a single component yarn after the process of twisting it with other component yarns to the form of the embroidery thread is calculated on the basis of the so-called Zimilki's formula [Zimilki, Kennedy, Hirt, Reese: Determining Mechanical Properties of Yarns And Two – Plied Cords From Single Filament Data. Model Development And Prediction, Textile Res. J., 70, (11), 2000, pp.: 991-1004]

$$tt = t + (-)\frac{T}{4\pi^2 R^2 T^2 + 1} \tag{10}$$

where:

T – folding twist, – twisting to the form of embroidery thread [t/m],

t – twist of single yarn before twisting it to the form of embroidery thread [t/m],

R – radius of the embroidery thread [m],

tt – twist of single yarn after the process of twisting it with other single yarns to the form of the embroidery thread [t/m].

It was verified that if the twist of single yarn before the twisting process was the same as the folding twist, i.e. twisting several single yarns to the form of the embroidery thread, but it was introduced in the direction opposite to the direction of twist of the single yarn, the reduction of twist in the component yarn equals 50%. It causes untwisting single yarns and, thereby, their weakening and a stronger tendency of individual segmental threads that protrude from the yarn to pill.

7.1.1.2. Parallel thread

Parallel thread has a more complex structure in comparison with the embroidery thread. This difference stems from the fact that the component strands of the parallel thread differ from one another in terms of structure and material. Typically, there are two threads, i.e. one of them plays the part of the core thread and the other one of the binding thread. Tensions in the feeding zone of component threads to the twisting zone decide, which of the threads plays the part of the core and which plays the role of the braid. The thread that is fed to the twisting zone with the highest tension usually performs the function of the core thread. Apart from the value of tension, with which the component threads are fed into the twisting zone, the angle of feeding of component threads is also important, i.e. if a thread is fed to the twisting zone parallel to the longitudinal axis of the spindle, i.e. the component thread is an extension of the axis of the spindle, it is this thread that constitutes the core of the parallel thread. The component thread, which is fed at a random angle (other than 0°) to the axis of the spindle usually constitutes the binding thread. The parameters that decide on the differentiation between the core and the binding thread are:

- linear density – the component thread that is characterised by a big linear density forms the core thread, under the condition that both component threads are fed on the same terms to the twisting mechanism,
- stiffness of bend and twist – the component thread that is stiff forms the core of the parallel thread.

It is an important feature of the parallel thread that the core thread is straight and the binding thread clings along the whole length of the core thread and does create any structural deformation of the core thread. The core thread decides on the strength of the parallel thread: it breaks first during the drawing process.

Fig. 33. Parallel thread (source: Grabowska K.E., *Modelowanie własności wybranych liniowych wyrobów włókienniczych o rozbudowanych powierzchniach* [Modelling of Properties of Choesn Linear Textile Products with Expanded Surface Area], Habilitation Dissertation, Lodz University of Technology, 2006)

The simplest example of a parallel thread is a thread formed from an assembly of staple fibres twisted together, fed to the hollow spindle and twisted with the use of a binding thread unwound from a cop fixed on the hollow spindle. This technique is used to produce parallel threads built from a fibrous core and bound with a continuous filament thread. In the hollow spindle technique, a cop with a package of light continuous synthetic thread is put on the hollow spindle. The thread is fed inside the hollow spindle and binds the staple fibres also fed to the hollow spindle in the form of an attenuated drawing sliver. In order to strengthen the structure of the attenuated sliver of staple fibres, a false twist hook is mounted at the mouth of the hollow spindle. As a result of friction against the assembly of fibres, above the hook, i.e. inside the hollow spindle, real twist is produced, while beneath the hook the assembly of fibres is untwisted. It increases the breaking strength of the assembly of fibres attenuated with the use of drawing rollers, which inside the hollow spindle is not yet fully stabilised to the form of a linear textile product, i.e. is not yet bound by a continuous filament thread. The process of untwisting of staple threads already fixed with the help of a filament thread, which takes place below the false twist hook, causes an increase in the fluffiness of the core yarn. The shape coefficient of the parallel thread is equal to the liminal value and totals:

$$K_{gr} = d_{R0}/D_{sE0} \tag{11}$$

where:

K_{gr} – coefficient of shape of the parallel thread,

d_{R0} – diameter of the core yarn [mm],

D_{sE0} – external diameter of the helix formed by the outer edge of the binding thread in the par- allel thread [mm].

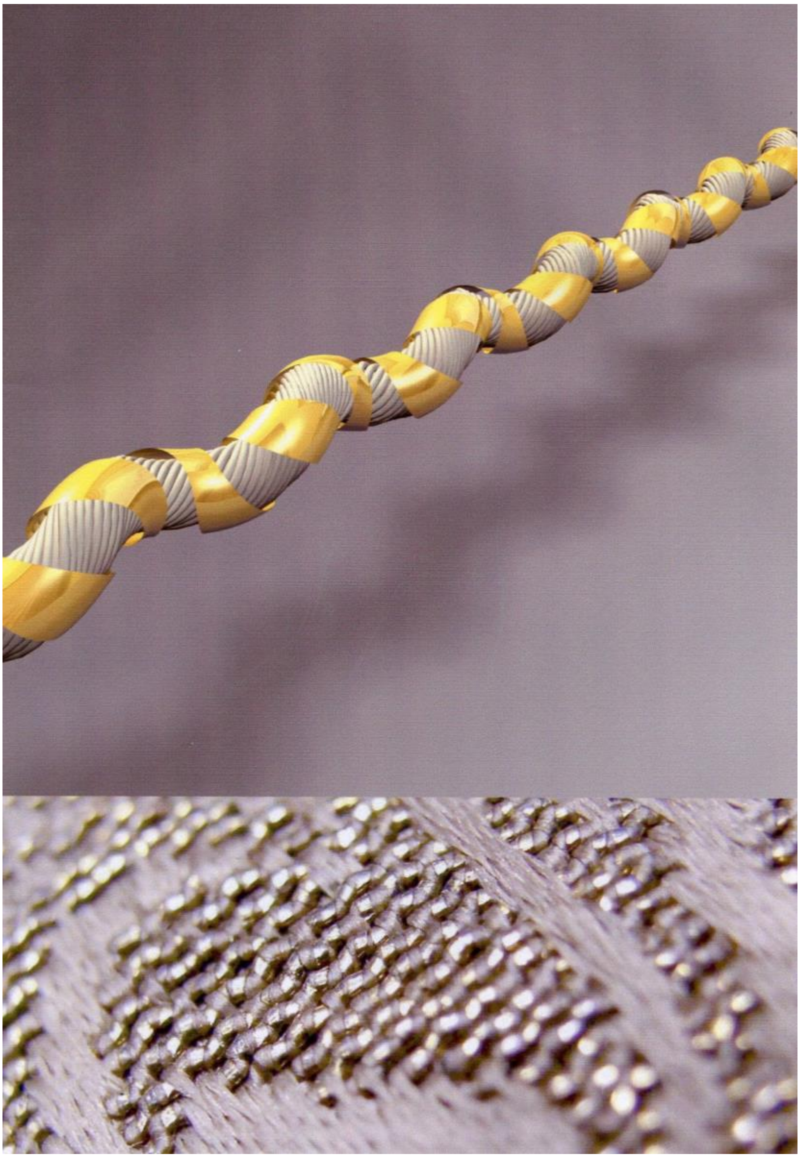


Fig. 34. Reconstruction of parallel thread (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative Threads in a Historical Perspective], Master's Thesis, Lodz University of Technology 2007, Supervisor: Grabowska K.E.)

Fig. 35. Binder thread (source: Bączyńska M., *Wirtualne modelowanie przędz fantazyjnych* [Virtual modelling of fancy yarns], Master's Thesis, Lodz University of Technology 2006, Supervisor: Szosland J.)

Due to the fact that the component threads of the parallel thread differ from one another not only in terms of the function they perform in the parallel thread, but there are also significant structural and material differences between those threads, the formula describing specific tenacity of the parallel thread is significantly more complex than in the case of the embroidery thread:

$$W_p = f_w \frac{T_w}{T_p} \sqrt{1 + (\pi \frac{(d_{R0})^2}{D_{sE0}} t_0)^2} \left\{ \frac{\mu u \gamma_f \, 10^5 \, (1+e_r) \frac{(d_{R0})^3}{D_{sE0}} (\pi t_0)^2}{\left[1 + \left(1 - \frac{d_{R0}}{D_{sE0}}\right)^2 (\pi d_{R0} \, t_0)^2\right]\left[1 + d_{R0}^3 \left(\frac{\pi t_0}{D_{sE0}}\right)^2\right]} \frac{l_h}{T_f} \left[1 - \frac{2 l_h}{L} + \frac{4}{3} \left(\frac{l_h}{L}\right)^2\right] + 1 \right\} \quad (12)$$

where:

W_p – specific static tenacity [cN/tex],

f_w – tension of the binding thread during the drawing of the parallel thread [cN/tex],

T_w – linear density of the binding thread [tex],

T_p – linear density of the parallel thread [tex],

d_{R0} – diameter of the core spun thread [m],

D_{sE0} – diameter of the spiral formed by the axis of the binding thread [m],

t_0 – twist of the parallel thread [t/m],

μ – coefficient of friction of staple fibres in the core yarn,

u – diameter of a single staple fibre in a yarn [m],

γ_f – specific density of staple fibres [kg/m^3],

e_r – relative value of variations in the diameter of the core yarn during the drawing process,

l_h – braking length of staple fibres [m],

T_f – linear density of a single staple fibre [tex],

L – average length of staple fibres [m].

The analysis of the formula clearly points to the significance of the structural parameters describing the phenomena that take place in the assembly of staple fibres that form the core yarn to the strength of the parallel thread. The diversity of effects that can be obtained by designing parallel threads can stem both from the diversification of colours of yarns used as core and as binding thread, and from the diversification of the structure of component threads. Usually, the thread built from long segmental threads, i.e. woollen or polyacrylonitrile, is used as the core, while polyester filament thread is used as the braid. This division stems directly from the fact that the package put on top of the hollow spindle has to be light. That is why the classic structure of the binder thread supposes a straight core yarn bound with a fine filament thread. However, research proved that if extremely fine yarn, with a diameter comparable to the diameter of a filament thread mounted as a package on the top of the hollow spindle, is used as the core yarn and the twist of the parallel thread is above 400 t/m, an exchange of functions performed by the two components of the parallel thread is possible: the filament thread will form the core of the parallel thread and the yarn built from staple fibres will form the braid. Such a phenomenon is present in cases, when the shape coefficient of the binder thread is lower than 0.2, i.e.:

$$K = d_{R0}/D_{sE0} < 0,2 \qquad (13)$$

$$D_{sE0} > 5\ d_{R0} \qquad (14)$$

where:

K – shape coefficient of the parallel thread,

d_{R0} – diameter of the core yarn [mm],

D_{sE0} – external diameter of the helix formed by the outer edge of the binding thread in the |parallel thread [mm].

The external diameter of the helix formed by the outer edge of the binding thread in the parallel thread is the function of twist of the binder thread.

It is a distinguishing feature of the parallel thread that the diagram of variations in the tensile strength of the parallel thread in the function of displacement is heterogenous and subsequent peaks point to break moments of individual component yarn. With regard to the above, in the case of breaking drawing of a two-plied parallel thread, in which the core is formed by a yarn built from staple fibres and the braid is a continuous filament thread, in the diagram of variations in tensile stress there are two peaks in the function of displacement. Whereby the first peak corresponds to the process of breakage of the core yarn and in this section the diagram is jagged due to the mutual slipping of staple fibres (Fig. 34).

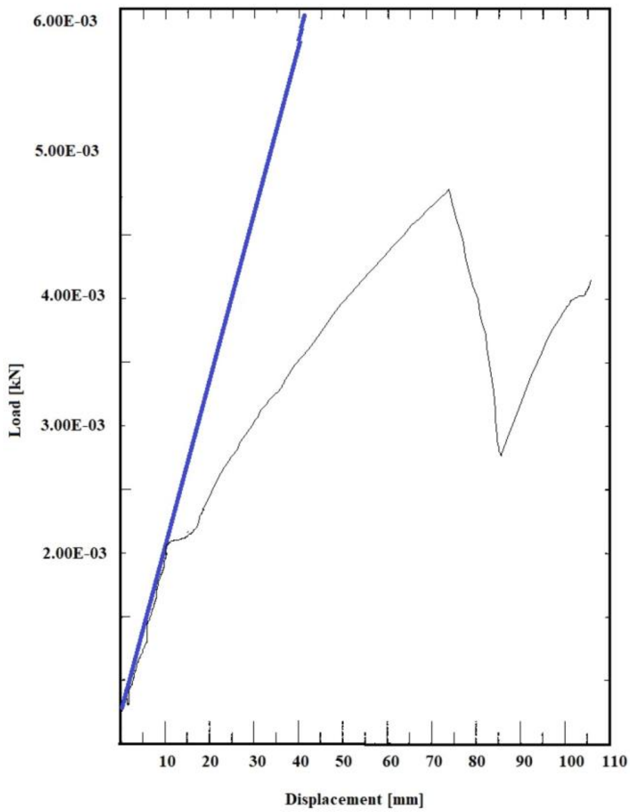


Fig. 36. Diagram of the relationship between tensile stress and displacement for a two-plied parallel thread [author's own research]

The group of parallel threads includes plated threads. Plated threads are built from several thick core threads, most often cotton ones, bound with a fine thread made of a precious raw material, e.g. gold, silver or copper. In turn, the group of plated threads include Leonese threads, brilliant thread and diamond thread. The Leonese thread is built from a cotton or silk thread that con- stitutes the core thread bound with a very fine metallic thread in such a way that the binding thread forms a dense layer on the surface of the core thread, while the core thread is not visible. In turn, the brilliant thread is also a parallel thread built from the core thread distinguished by an intensive colour, bound with a metallic thread in such a way that the core thread is visible. The diamond thread is a thread built from the core thread bound twice in opposite directions of twist with a fine metallic thread in such a way that the trajectories of the metallic thread cross on the surface of the core thread.

7.1.1.3. Wavy thread

The wavy thread is characterised by a coefficient of shape, which value falls between the boundary coefficient of shape and one. It means that the component strands are twisted together with a small twist in such a way that along the whole length of the wavy thread the component strands cling to one another. The component strands differ from one another especially in terms of the linear density. Apart from that, one of the components is fed into the twisting zone with a small overfeed, of maximum 8%, which, however, still guarantees that the component yarns cling to one another. Such an effect can be achieved by controlling the tension in the twisting zone of the component threads: the core thread is fed into the feeding zone with a higher tension than the effect thread. The wavy thread can be divided into the core thread and the effect thread. The wavy thread is usually built from two component threads, or less frequently, from a bigger number of them. Twisting together two component yarns that differ in terms of linear density and direction of twist leads as well to the production of the wavy thread.

For the two-plied wavy thread the following formulas were derived that describe the tensile strength:

$$P = S_k \frac{Tt_k}{Tt_p} \frac{\delta e_k}{\delta e_p} \sec\alpha_{k0} + S_{k+1} \frac{Tt_{k+1}}{Tt_p} \frac{\delta e_{k+1}}{\delta e_p} \sec\alpha_{(k+1)0} \qquad (15)$$

where:

P – tenacity of the two-plied wavy thread [cN/tex],

S_k – tensile stress of the component yarn [cN/tex],

Tt_k – linear density of the component yarn [tex],

Tt_p – linear density of the wavy thread [tex],

$\delta e_k/\delta e_p$ – partial derivative of elongation of the component yarn of the wavy thread in relation to elongation of the wavy thread,

$sec\alpha_{k0}$ – trigonometric function of the angle of inclination of the helix formed by the axis of the component yarn of the wavy thread and the vertical longitudinal axis of the wavy thread subject to initial tension.

The partial derivative of elongation of the component yarn of the wavy thread in relation to the elongation of the wavy thread is calculated according to the following formula:

$$\frac{\delta e_k}{\delta e_p} = \frac{\cos \alpha_{k0}}{\cos \alpha_k}\left[\frac{\sin \alpha_k}{\cos \alpha_k}\left(1 + e_p\right)\frac{\delta \alpha_k}{\delta e_p} + 1\right] \tag{16}$$

where:

e_p – longitudinal deflection of the wavy thread (lab estimated),

α_{k0} - angle of inclination of the helix formed between the axis of the component yarn and the longitudinal axis of the wavy thread subject to initial tension (estimated with the use of the method of computer image analysis),

α_k – angle of inclination of the helix formed between the axis of the component yarn with the longitudinal axis of the wavy thread corresponding to the deflection of the wavy thread (assessed with the use of the method of computer image analysis and the linear regression method).

Fig. 37. Wavy thread (source: Grabowska K.E., *Modelowanie własności wybranych liniowych wyrobów włókienniczych o rozbudowanych powierzchniach* [Modelling of Properties of Choesn Linear Textile Products with Expanded Surface Area], Habilitation Dissertation, Lodz University of Technology, 2006

Fig. 38. Wavy thread (source: Bączyńska, *Wirtualne modelowanie przędz fantazyjnych* [Virtual Modelling of Fancy Yarns], Master's Thesis, Lodz University of Technology 2006, Supervisor: Szosland)

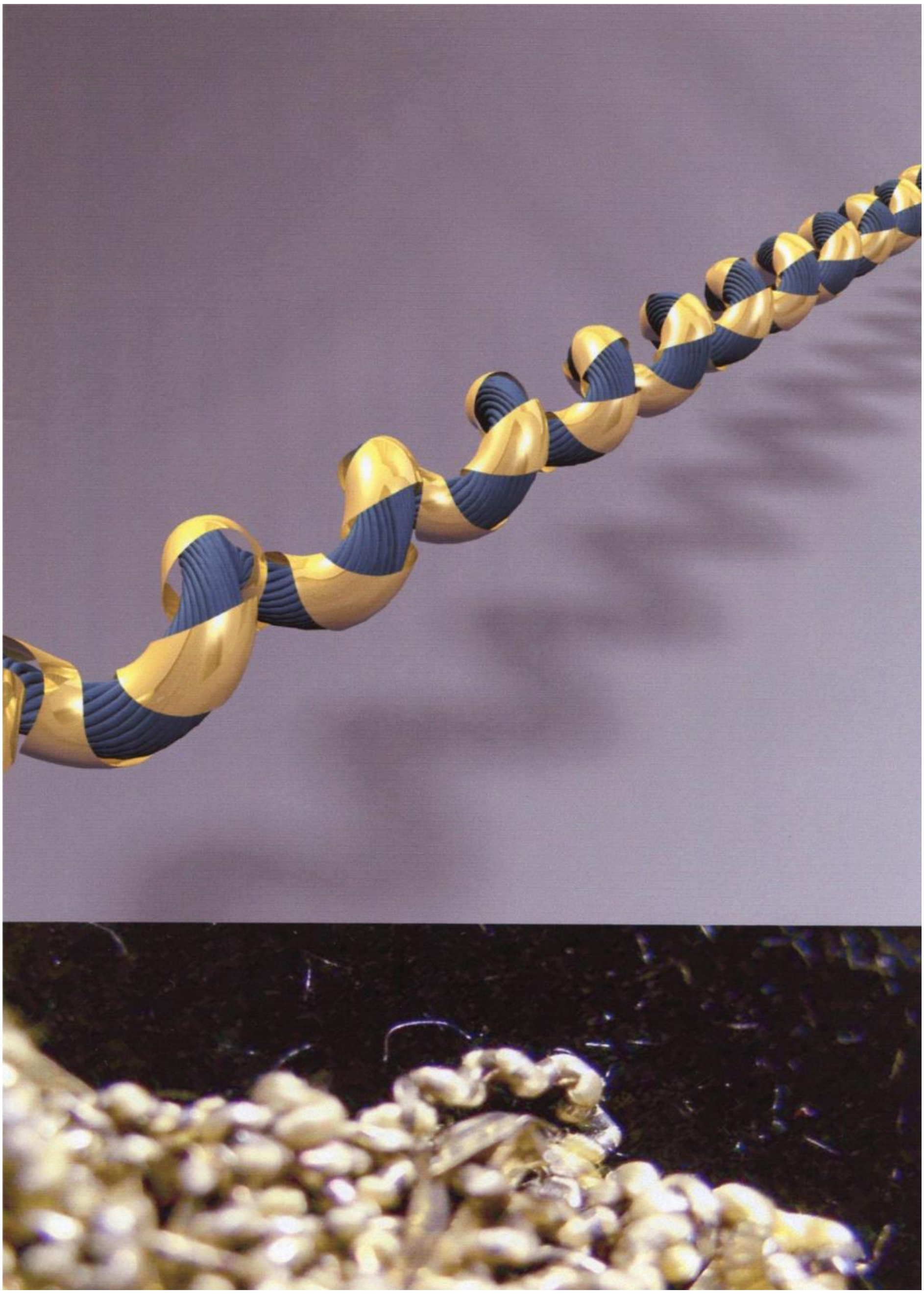


Fig. 39. Reconstruction of wavy thread (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative Threads in a Historical Perspective], Master's Thesis, Lodz University of Technology 2007, Supervisor: Grabowska K.E.)

In the wavy thread, the core of the thread breaks first, because it transfers the greatest tensile stress. In the analysis of the diagrams of variations in the tensile stress in the function of displacement one can distinguish the number of break peaks corresponding to the number of component threads. The first peak always corresponds to the core thread. Subsequent peaks correspond to the breakage of the effect threads. On the basis of this diagram, one can estimate the number of component yarns of the wavy thread.

The wavy thread can be produced by the following methods that consist of:

- twisting together at least two components with the same length, i.e. without overfeed, under the condition that two component yarns that differ in terms of direction of twist are twisted together. In connection with different directions of twist in the component yarns, the process of twisting them together will lead to a shortening of one of them and elongation of the other one as a result of untwisting,
- twisting together two components of the same length, but different thickness,
- twisting together at least wo components, one (or more) of which is delivered at a slightly higher speed. This group of yarns forms the overfeed of the effect yarn. If, additionally, there are differences in the thickness of the component yarns, the direction of twisting them together should be opposite to the direction of twist of the thicker component yarn.

7.1.2. Chenille threads

The oldest fabrics featuring chenille threads come from the early 18th century. Charles Germain de Saint-Aubien described and characterised the chenille thread in a book dedicated to Louis XV, the King of France, and entitled „Art of the Embroiderer" [de Saint-Aubien, 1983]. The short history of chenille threads results from their relatively difficult production technology. Only the so-called industrial revolution and the employment of special machines for the production of this type of thread popularised chenille fabrics. The first patent for the mechanical production of the chenille thread with the use of a special type of spinning frame comes from the 1970s. Originally, chenille threads were produced on the basis of cutting a fabric along the warp. That way, warp threads provided base threads and the cut weft threads constituted the hair pile. Produced that way, i.e. with the use of the weaving method, chenille threads were characterised by a flat structure, unlike the chenille threads produced with the use of the spinning method, which are characterised by a round cross-section. Chenille fabrics have enjoyed amazing popularity up to the present day, due to their diversified structural and colour forms, which can be achieved with the use of a periodic system of feeding with staple fibres of an arrangement of two or more yarns twisted together. Chenille threads are built from two or more base threads twisted together in such a way that between those threads cut segmental fibres are introduced, placed in the structure of the chenille thread parallel to the base threads. Staple fibres form the hair pile of the chenille thread and, thereby, the soft structure of the fabric. The disadvantage of the chenille thread is that it easily loses the hair pile as a result of the process of rubbing, wiping or falling out of the hair pile.

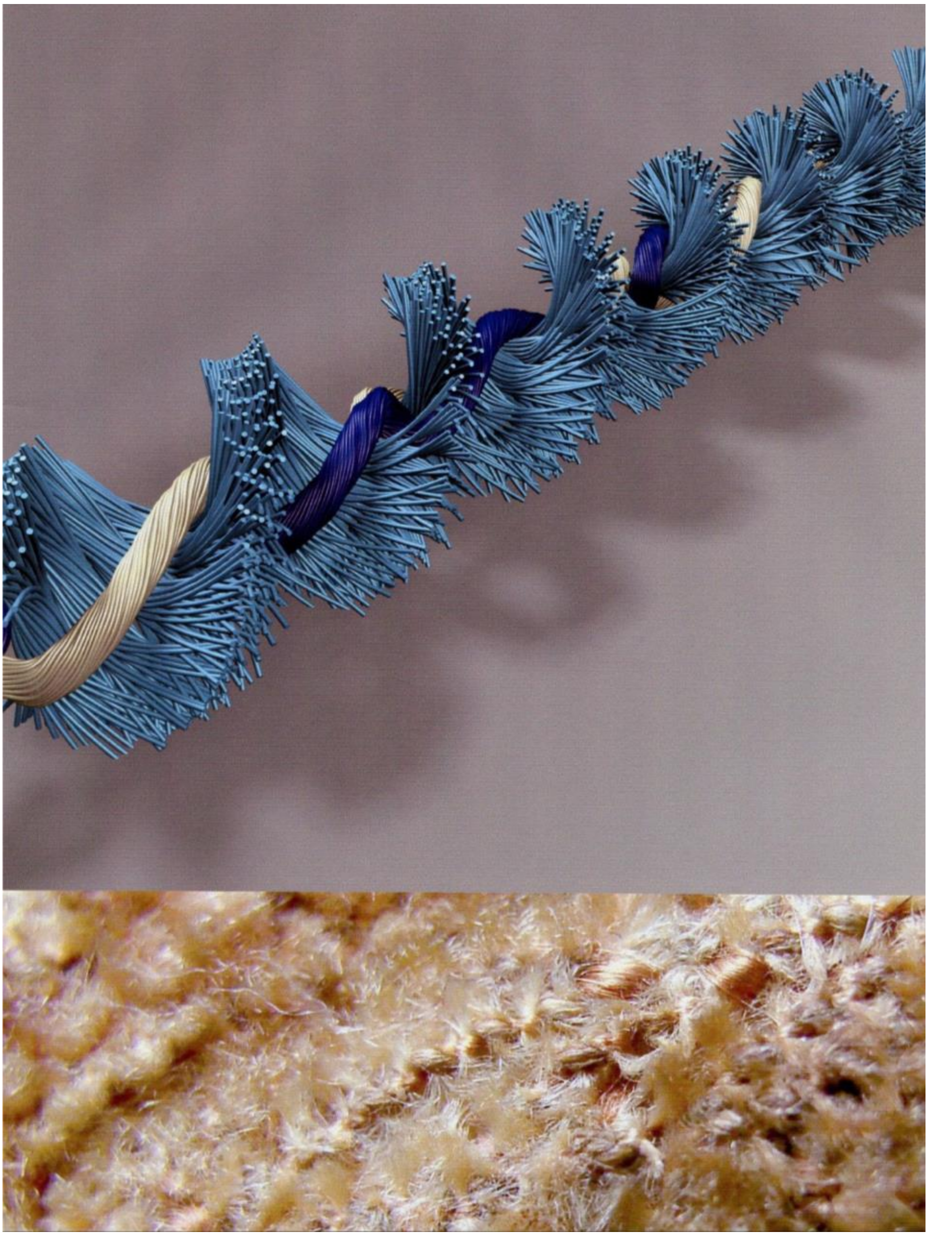


Fig. 40. Reconstruction of chenille thread (source: Szrama W., *Nitki ozdobne w aspekcie historycznym* [Decorative Threads in a Historical Perspective], Master’s Thesis, Lodz University of Technology 2007, Supervisor: Grabowska K.E.)

The name of the chenille thread comes from French and it means caterpillar, which well characterises the structure of that thread, because it usually is a fluffy thread, nice to the touch. The effect of fluffiness is achieved as a result of placing the staple threads parallel to the longitudinal axis of the chenille thread. The longitudinal axis of the chenille thread overlaps with the arrangement of core threads twisted together, between which the staple fibres were introduced. Staple fibres are clamped by the core threads and only the force of friction between the fibres decides on the stability of the structure of the chenille thread. Users of products, usually knitted ones, observe with concern the falling out of the hair pile when they use those products.

Fig. 41. Chenille thread with a segment where a loss of the hair pile took place (source: Goździk I., *Ocena zmian właściwości strukturalnych fantazyjnej nitki pętelkowej w wyniku działania na tę nitkę strumienia powietrza* [Assessment of Structural Properties Changes of Fancy Loop Thread as a Result of Applying Air Jet to That Thread], Master's Thesis, Lodz University of Technology 2003, Supervisor: Grabowska K.E.)

Research was conducted on the topic of stabilisation of the structure of chenille thread with the use of high temperature and in the atmosphere of water vapour in order to increase the cling between fibrous materials (Zając, *Ocena metod modyfikacji mechanicznych nitek szenilowych w aspekcie odporności na ścieranie* (Assessment of Chenille Threads Mechanic Modification Methods in the Perspective of Resistance to Abrasion), Master's Thesis, Łódź University of Technologu 2006, Supervisor: Grabowska K.E.). The chenille thread is usually subject to the process of steaming also in order to stabilise the twist of core threads. The peculiar structure of the chenille thread stems from the atypical production process that consist in connecting two systems of twisting component yarns together, i.e. the hollow spindle system with the twisting-winding system of ring, spindle and traveller. A thread, typically a filament one, is fed into the hollow spindle and then wound on the mandrel, out of which it is unwound in the direction parallel to the cutter that cuts the filament thread into individual segmental fibres. The staple fibres produced with the use of that method are then introduced between an arrangement of two core yarns twisted together, this time with the use of a traditional method of ring, traveller and spindle with a spinning cop put on the top that take off the ready chenille yarn. Even the production method itself indicates that the most important factor that influences the stability of the structure of the chenille thread is the twist of component yarns: the higher the twist value, the bigger the force of friction between the staple fibres and the bigger resistance of the textile products, in which the chenille thread was used to the loss of pile. The complicated production process of chenille threads generates low machine productivity, i.e. ca. 15 m/min. or even less if complex structures of the chenille thread are produced. Hence, the relatively high price of one package of this type of yarn is. On the other hand, there is a high value of distrust of users of knitted products, in which the chenille thread was used. The chenille thread is also used in fabrics as the weft. The intended use of those fabrics is the production of upholstery fabrics. Here, there is also the risk of losing the hair pile as a result of rubbing the surface of the textile product. It seems that the best place to use the chenille thread is decorative fabrics. However, the relatively pronounced thickness of this thread influences the appearance of the product in a dominant way.

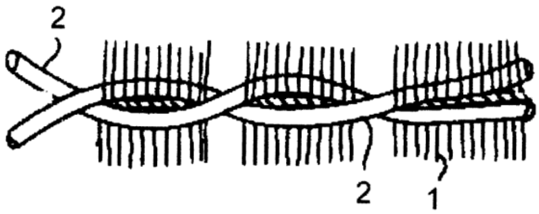


Fig. 42. Construction of the chenille thread produced with the use of the spinning method: 1 – hair pile, 2 – component threads (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master's Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E)

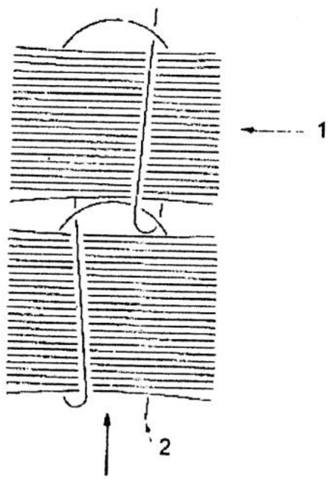


Fig. 43. Construction of the chenille thread produced with the use of the knitting method: 1 – pile, 2 – tie-in thread (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master's Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E)

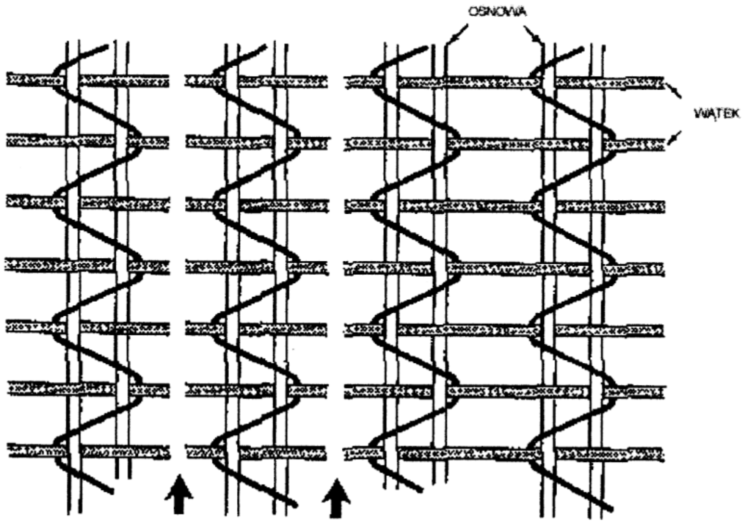
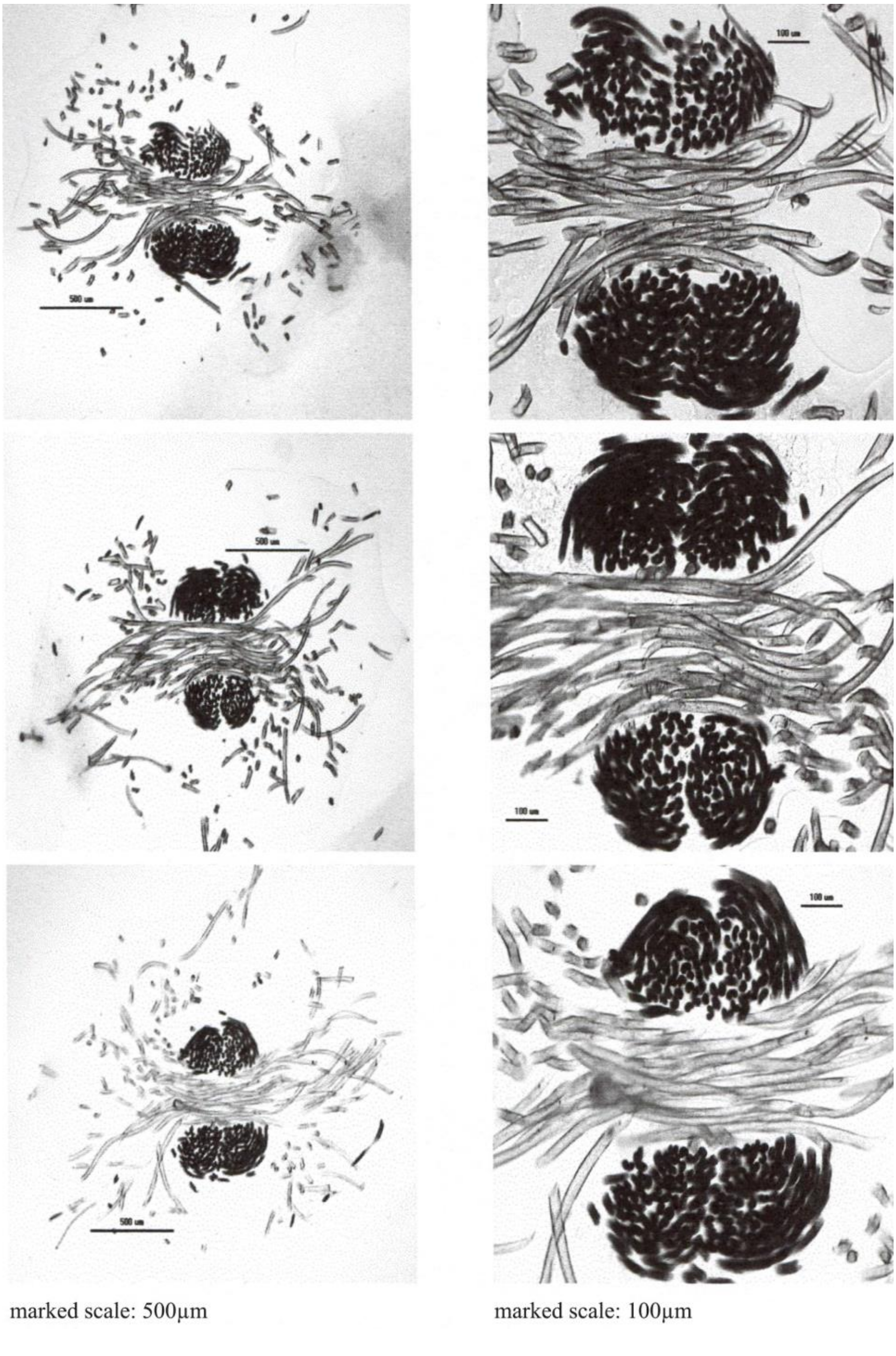


Fig. 44. Construction of the chenille thread produced with the use of the weaving method: 1 – pile, 2 – tie-in thread (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master's Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E)

There are also two other methods of production of the chenille thread, which are considered the oldest and very inefficient. They are the weaving method and the knitting method. Both of those methods consist of producing a flat textile product and cutting it along the warp threads. This way, the weft threads constitute the hair pile of the chenille thread and the warp threads are the so-called core threads that support the whole structure of the chenille thread. Research was conducted on the structure of the chenille thread and the significance of technological parameters of the production process on the properties of the chenille thread (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master's Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E).



marked scale: 500μm

marked scale: 100μm

Fig. 45. Cross-sections of the chenille thread (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master’s Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E)

Statistical models were determined that describe the influence of:

- the linear density of the core yarns on the final linear density of the chenille thread:

  $$y = 1.81x + 179;\ R^2 = 0.98 \tag{17}$$

  where:

  y – final linear density of the chenille thread [tex],

  x – linear density of the core threads [tex]

- twist of the chenille thread on its linear mass:

  $$y = 0.14x + 317.9;\ R^2 = 0.98 \tag{18}$$

  where:

  y – final linear density of the chenille thread [tex],

  x – twist of the chenille thread [t/m]

- linear density of the core threads on the thickness of the chenille thread:

  $$y = 0.0014x + 2.02;\ R^2 = 0.6 \tag{19}$$

  where:

  y – thickness of the chenille thread [mm],

  x – linear density of the core threads [tex]

- linear density of the core threads on the breaking force of the chenille thread:

  $$y = 17.9x - 16.8;\ R^2 = 0.98 \tag{20}$$

  where:

  y – breaking force of the chenille thread [cN],

  x – linear density of the core threads [tex]

- twist of the chenille thread on the breaking force of this thread:

  $$y = -1.48x + 2366.4;\ R^2 = 0.98 \tag{21}$$

  where:

  y – breaking force of the chenille thread [cN],

  x – twist of the chenille thread [t/m]

- linear density of the core threads on the elongation of the chenille thread:

  $$y = 0.07x - 11.41;\ R^2 = 0.98 \tag{22}$$

where:

y – elongation of the chenille thread [%],

x – linear density of the core threads [tex]

- twist on the breaking elongation of the chenille thread:

$$y = 0.008x - 14.04;\ R^2 = 0.98 \quad (23)$$

where:

y – elongation of the chenille thread [%],

x – twist of the chenille thread [t/m]

- linear density of the chenille thread on the strength of the chenille thread:

$$y = 0.02x + 2.55;\ R^2 = 0.98 \quad (24)$$

where:

y – breaking strength of the chenille thread [cN/tex],

x – linear density of the core threads [tex]

- twist on the strength of the chenille thread:

$$y = -0.004x + 5.77;\ R^2 = 0.98 \quad (25)$$

where:

y – breaking strength of the chenille thread [cN/tex],

x – twist of the chenille thread [t/m].

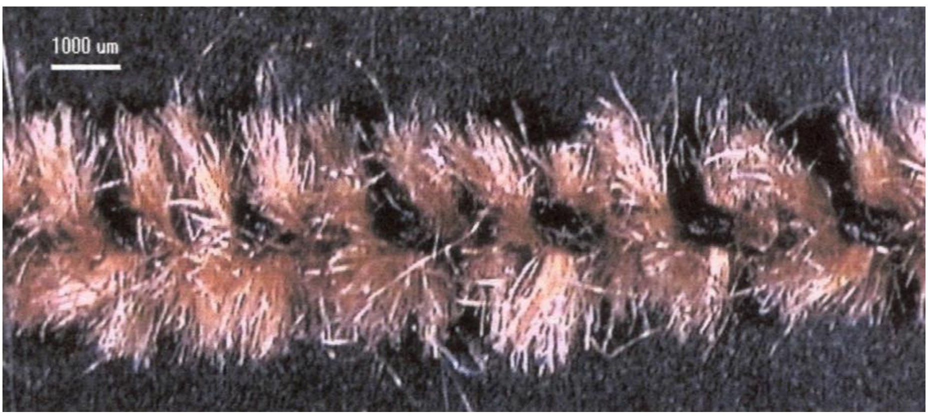


Fig. 46. Chenille thread produced with the use of the spinning method (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master's Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E)

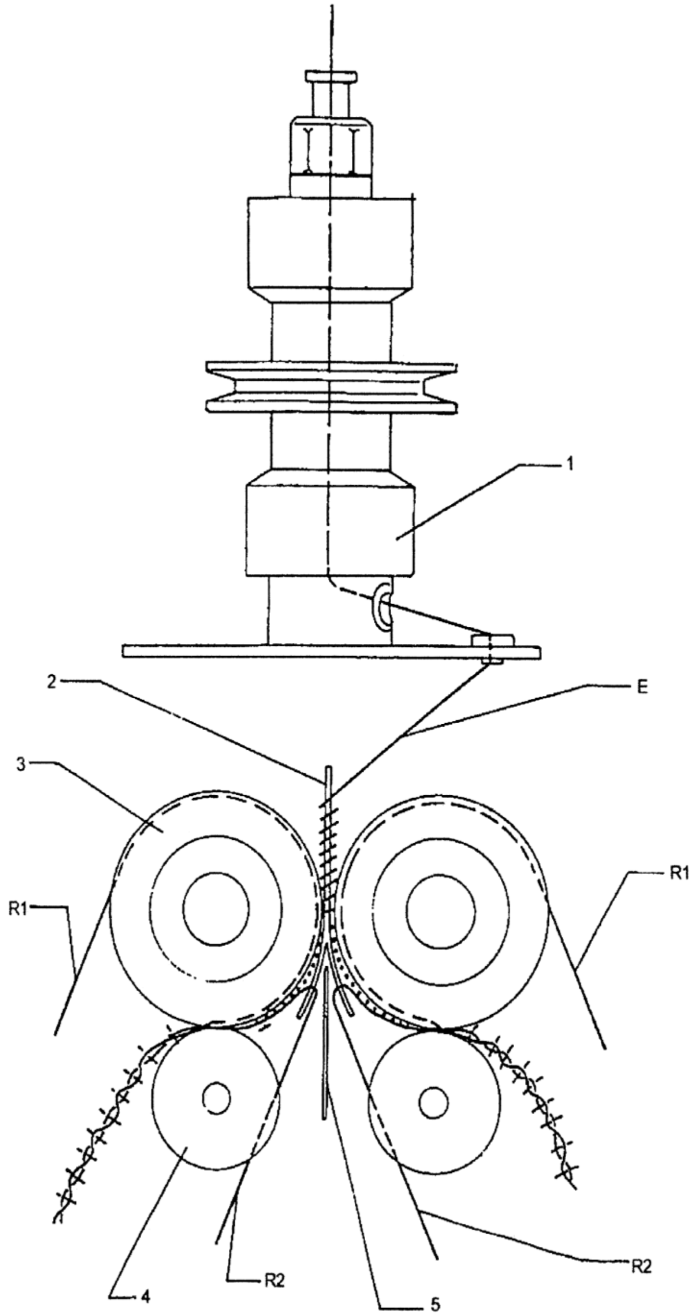


Fig. 47. Spinning frame used for the production of chenille yarns: 1 – spinning head, E – multifilament thread, 2 – calibrator, 3, 4 – rollers feeding component threads, R1, R2 – component threads, 5 – cutter (source: Wojewódzka J., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej typu chenille* [Production Methods and Functional Properties of Chenille Fancy Yarn], Master's Thesis, Lodz University of Technology 1999, Supervisor: Grabowska K.E)

On the basis of the analysed statistical models, we can draw the conclusion that there is little influence of:

- the linear density of the core threads on the thickness of the chenille thread, because it is the length of the segmental fibres that decides on the thickness of the chenille thread,
- the twist on the breaking elongation of the chenille thread,
- the twist on the strength of the chenille thread, because there is a significant negative influence of the twist of the chenille thread on the breaking force and a significant, directly proportional influence of the twist on the linear density of the chenille thread (opposing directions of the influence of twist on the numerator and denominator of tenacity cause the elimination of the influence of twist on the strength of the chenille thread).

7.1.3. Loop threads

Loop threads belong to the group of multi twist threads with continuous effects. Those threads are characterised by a lack of continuity of contact between the effect components and the core yarn that occurs periodically within a given length characteristic of the diameter of the loop. The coefficient of shape of the spiral threads is always lower than the liminal value, i.e.:

$$K < K_{gr} = d_{R0}/D_{sE0} \tag{26}$$

where:

K_{gr} – liminal value of the coefficient of shape of the multi twist decorative thread,

d_{R0} – diameter of the core yarn [mm],

D_{sE0} – external diameter of the helix formed by the outer edge of the effect thread in the loop thread [mm].

Such a low value of the coefficient of shape conditions the formation of overfeed of the effect thread and its bulging as well as the loss of contact with the core thread. The lower the value of the shape coefficient, the stronger the tendency to form clearly rounded loops. In other words, the lower the value of the coefficient of shape, the bigger the needed overfeed of the effect thread. All loop threads are also characterised by the fact that the smallest number of yarns and component threads is three (as distinct from the spiral threads, where the smallest required number of component yarns is two). For the production of loop threads we need a core yarn, an effect yarn, and as an essential element, the so-called tie-in thread, which fixes the design effects obtained as a result of the use of overfeed of the effect thread. Usually, the tie-in thread is very fine, almost invisible, and in modern systems of the twisting process, the package of the tie-in thread is mounted on the top of the hollow spindle. That way, the production of loop threads with the use of a hollow spindle-type machine is single-stage (as opposed to the ring twisting frame method, where the process of tying the loops in takes places after the process of their formation as a separate production stage). The hollow spindle machine guarantees a high effectiveness of production and repeatability of effects of the loop thread. Usually, the core thread and the effect thread are characterised by a twist opposing to the direction of spinning of the hollow spindle. It prevents snarls from forming, and at the same time, leads to untwisting of the above-mentioned yarns. Rarely, the loop yarn is subject to the process of thermal stabilisation of twist, due to the fact that it makes the production process more costly. Research was conducted which aim was to check, whether loop threads made of the same raw material, but with the use of two different production methods, i.e. with the use of the hollow spindle method and the ring twisting frame method, are characterised by the same structure and mechanical properties. The result of research led to the conclusion that despite of the use of the same machine settings, twist and overfeed, and the use of the same component yarns, loop threads produced with the aforementioned production methods differed significantly. The most significant difference were detected between (Wieczorek, *Porównanie właściwości nitek pętelkowych i frotowych oraz tkanin i dzianin z nich wykonanych* (Comparison of Properties of Loop Threads and Terry Threads as Well as Woven and Knitted Textiles of Them), Engineer's Thesis, Łódź University of Technology, 2002, Supervisor: Grabowska K.E.):

- linear densities,
- distances between the loops,
- heights of loops,
- breaking forces,
- specific tenacity,
- relative elongation.

The causes of those differences come from different types of stimulators of tension of the component threads fed into the twisting zone. The two above-mentioned basic machines that are used in the production of fancy threads are characterised by different types of devices that are used to feed the component threads into the twisting zone. In the case of the ring twisting frame, it is a system of the so-called mechanical working beams, which stimulate different tension of the component threads before they are fed into the twisting-winding device. In turn, in the case of the hollow spindle, the overfeed and tension of the component threads are computer-controlled as a result of changes in the speed of feeding them into the twisting zone. In other words, it is the tension of individual component threads that are generated at the stage of feeding them into the twisting zone what decides on the kind of produced fancy thread in a significant way. The speed of delivery rollers (hollow spindle twisting frame) and mechanical working beams (ring twisting frame) control the tension and speed of feeding of the component threads into the twisting zone.

Also differences that occur in fabrics made of the loop thread used as weft, which differ in terms of the production technique, were studied. It was verified that fabrics made with the use of the same weave, but differing in terms of weft used in the production process (loop threads that came from two different twisting frames, i.e. the hollow spindle and the ring spinning frame with the same settings and component yarns were used) differ from each other in terms of structure (Olejnicka, *Analiza porównawcza nitek pętelkowych wytwarzanych metodą skręcarki obrączkowej oraz metodą wydrążonego wrzeciona* [Comparative Analysis of Loop Threads Produced with the Use of Ring Twister Method and Hollow Spindle Method], Master's Thesis, Łódź University of Technology 2000, Supervisor: Grabowska K.E.). The fabrics made of loop thread produced with the use of the hollow spindle method are characterised by bigger and more pronounced loops than the ones made of loop thread produced with the use of the ring twisting frame method.

Loop threads are characterised by greater unevenness of structure than spiral threads. The group of loop threads includes terry thread and bouclé thread. Terry thread has half-loops on its surface and is characterised by a smaller overfeed of the effect yarn than the bouclé thread, on the surface of which there are clear circular loops. The core thread should be characterised by an adequately high coefficient of friction, which would allow for an initial mount of the effect yarn in the form of loop on the surface of the core yarn, and it should be resistant to breaking due to the fact that it was precisely this thread that transfers the biggest tensile stress. Usually, the core yarn or the tie-in thread breaks first, due to the fact that both are fed into the twisting zone without any overfeed.

The tensile stress of the core yarn is the function of the force of friction generated between fibres in the component threads, which is the function of the coefficient of shape of the decorative thread, according to the following formulas:

$$S_R = \frac{R_R(1-F_s)l_h \cos\beta_{wR}}{Tt_{fR}\left(l_{\max}^2 - l_{\min}^2\right)^2}\left\{l_{\max}^4 - 4l_h l_{\max}^3 + 8\left(l_h^2 l_{\max}^2 - l_h^3 l_{\max}\right) + \frac{48}{15}l_h^4\right\} \qquad (27)$$

$$R_R = \frac{u_R \mu_R 10^5 \gamma_{fR} T_0 d_{R0}}{2Tt_R\left(KD_{sE0} - d_{R0}\right)\sqrt{1+\left(KD_{sE0} - d_{R0}\right)^2 \pi^2 T_0^2}} \cdot$$
$$\cdot\left\{2d_{E0}\left(1+e_{Er}\right)Tt_E S_E \sin 2\beta \sin\beta + \pi\left(1+e_{Br}\right)\left(KD_{sE0} - d_{B0}\right)Tt_B S_B \sin 2\gamma\right\} \qquad (28)$$

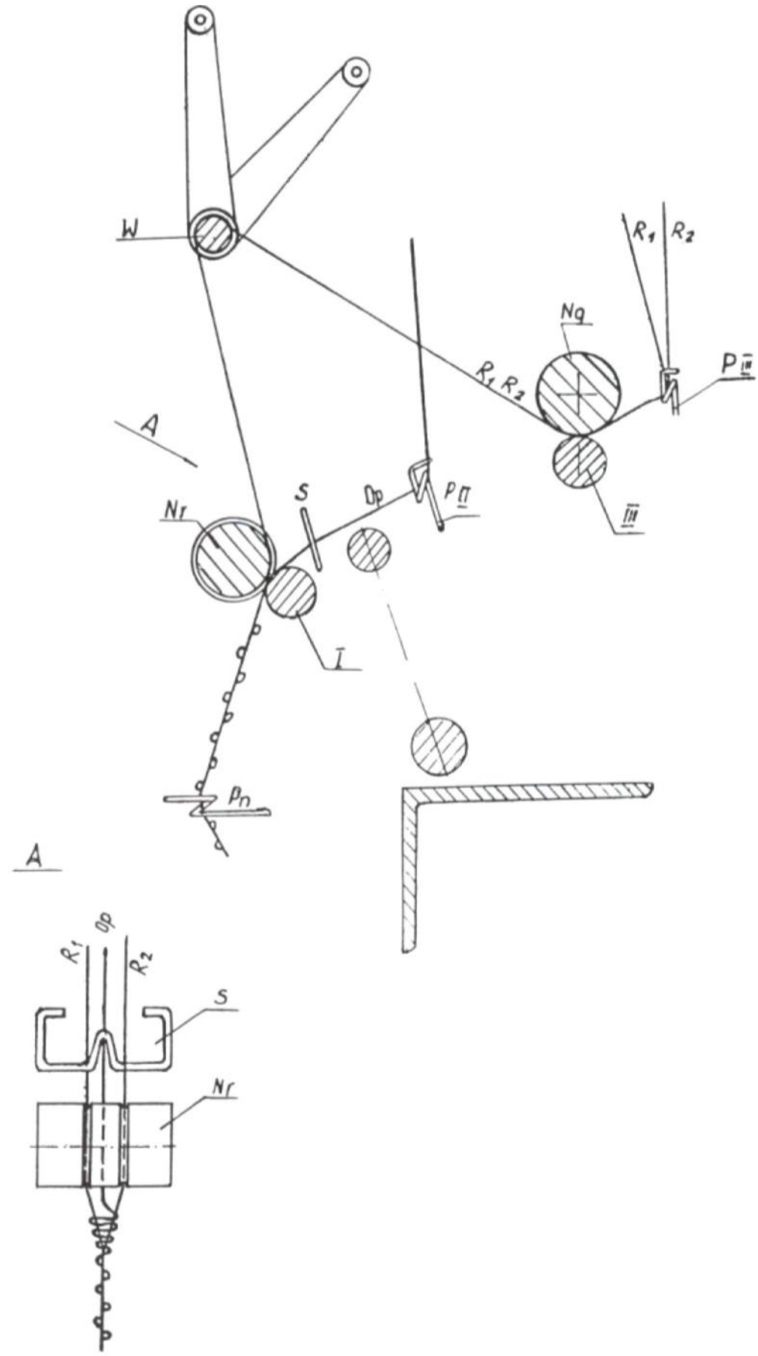


Fig. 48. Scheme of twisting the loop thread with the use of a yarn ring twisting frame: R_1, R_2 – core threads, P_{III} – component thread guide, N_q – top roller, III – guide roller for core yarns, W – working beam to control the movement of core threads, P_{II} – effect yarn guide, O_p – effect yarn, S – effect yarn guide, N_r – top delivery roller, I – bottom delivery roller, P_n – lap guide

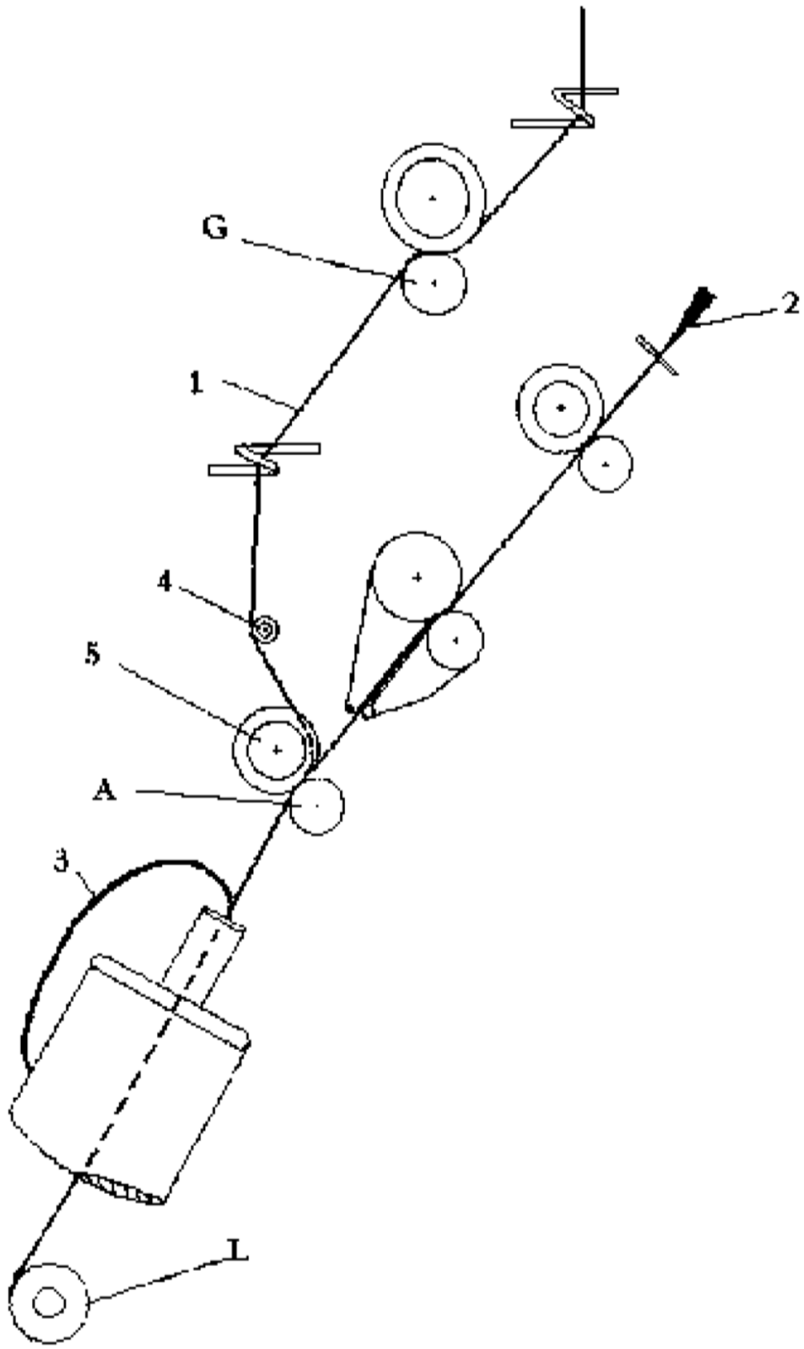


Fig. 49. Scheme of the production of loop thread with the use of the ESP-SX hollow spindle spinning frame: 1 – core component, 2 – braid component, 3 – tie-in component, 4 – regulating screw, 5 – effect regulator

where:

S_R – axial tension of the core yarn [cN/tex],

R_R – force of friction between fibres of the core yarn [cN/mm],

F_s – share of staple fibres shorter than the minimum length of fibres in the sliver,

l_h – hampering length of staple fibres in the component yarn [mm],

β_{wR} – angle of inclination of staple fibres in the outer layer of the core yarn,

l_{max} – maximum length of staple fibre in the component yarn [mm],

l_{min} – minimum length of staple fibre in the component yarn [mm],

Tt_{fk} – linear mass of a single staple fibre that forms the component yarn of the loop thread [tex],

u_R – diameter of a single fibre in the core yarn [mm],

μ_R – coefficient of friction between staple fibres,

γ_{fR} – specific density of fibres that form the core yarn [g/cm^3],

T_0 – twist of the plied thread under the preload [t/m],

d_{R0} – diameter of the core yarn that forms part of the decorative thread under the preload [mm],

Tt_R – linear density of the core yarn [tex],

K – coefficient of shape of the loop thread,

D_{sE0} – external diameter of the helix formed by the effect yarn that forms part of the decorative thread under preload [mm],

d_{E0} – diameter of the effect yarn that forms part of the decorative thread under the preload [mm],

e_{Er} – relative deflection of the diameter of the effect yarn,

Tt_E – linear mass of the yarn that forms effects in the loop yarn [tex],

S_E – axial tension of the effect yarn [cN/tex],

β – angle of inclination of the helix formed by the effect yarn,

e_{Br} – relative deflection of the diameter of the tie-in yarn,

d_{B0} – diameter of the tie-in yarn that forms part of the decorative thread under the preload [mm],

Tt_B – linear density of the tie-in yarn [tex],

S_B – axial tension of the tie-in yarn [cN/tex],

γ – angle of inclination of the helix formed by the tie-in yarn.

In turn, the force of friction generated between the staple fibres of the core yarn is the function of parameters of the structure of core yarn and the axial tension generated in the remaining component yarns of the loop thread, i.e. the tension generated in the effect yarn and the tiein yarn. The scheme of the relationship between the tensile stress of the core thread and the effect thread is described in Figure 50.

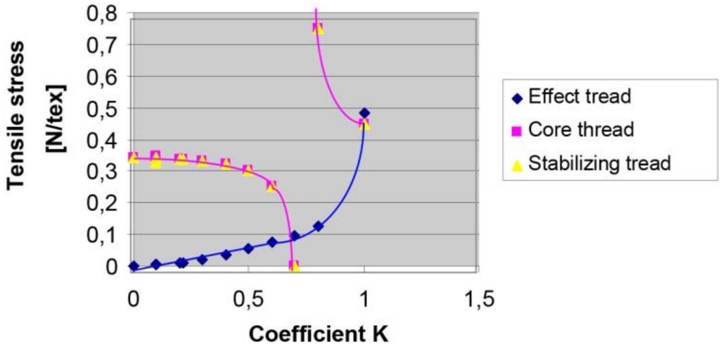


Fig. 50. Relationship between tensile stress of the component threads and the coefficient of shape of the loop thread (K); final twist 200 [t/m]

It was verified that:

- A zero point for the tension transferred by the core thread exists for the value of the coefficient of shape of the decorative thread determined by $K = \frac{d_{R0}}{D_{sE0}}$ (with the fulfilment of the condition assumed during the designing of patterns for the loop thread that all the component threads have the same diameter), i.e. in the area of instability of the core thread.
  The production of loop thread begins for coefficients of shape lower than $K = \frac{d_{R0}}{D_{sE0}}$, which means that in the area of practically realised loop threads there is no possibility to zero the tensile stress of the core thread.
- A vertical asymptote for the liminal value of the coefficient of shape of decorative thread defined by the condition $K = \frac{d_{R0}}{D_{sE0}}$ exists. It means that the greatest tensile stress is transferred by the core thread characterised by a straight structure. Further reducing the value of the coefficient of shape as a result of an increase in the overfeed of the effect thread leads to a formation of loops in the first sinusoidal form.
- A horizontal asymptote defining the equilibrium state of the core thread exists. Increasing the overfeed of the effect thread in such a way that the coefficient of shape assumes values lower than its liminal value will cause such lateral pressure of the effect thread on the core thread that having lost its stability, it will strive to assume a location that would allow further transfer of tensile stress. There are no counteraction forces in the core thread, due to the influence of the tiein thread that binds the structure of the loop thread, which prevents the core thread from the excessive buckling.

7.1.3.1. Terry thread

The first form of the loop thread is the terry thread, in which the initial form of the loop occurs, i.e. the discontinuity of contact between the core thread and the effect yarn is a bulge in the form of a sinusoidal effect yarn. The tie-in thread fits together the effect of half-loop on the core thread. The terry thread is produced with a slight overfeed of the effect yarn. In the production of the terry thread, it is necessary to use a tie-in thread to stabilise the effect of half-loop on the core thread. In its simplest and most frequent form, the terry thread is a three-ply cord built from the core thread, the effect thread and the tie-in thread. The most effective production method of the terry thread is the hollow spindle method. The hollow spindle method guarantees a high level of repeatability of designing effects as well. The hollow spindle is fed with the core thread unwound from a package placed on a bobbin frame and with an assembly of staple fibres delivered from a drawing mechanism in the form of attenuated slubbing or drawing sliver. The tie-in thread is the lightest and finest one (it should be invisible within the structure of the terry thread) and it is unwound from a package placed on the hollow spindle. Research was conducted to determine the significance of influence of the technological parameter that characterise the process of fancy twisting on the structure of the terry thread and its mechanical properties. It was concluded that at the initial stage the value of overfeed of the effect yarn results in an increase of the amplitude of the sinusoid outlined by the effect yarn. Then, when the overfeed of the effect yarn is further increased, the loop closes to its circular form. A further increase in the overfeed of the effect yarn results in an increase of the diameter of loops and an increase in the frequency of their occurrence. Drastically big overfeed of the effect thread coupled with a small linear density of the effect thread causes the formation of snarls: loops achieve a very large diameter, which under the influence of significant susceptibility of the effect thread to twisting (low stiffness of twist and bend of the effect thread) is characterised by a tendency to self twist on the surface of the core thread. [Grabowska, 2001]. Fancy thread with snarls forms a separate group of fancy threads ranked among the group of threads with point effects. It was concluded that an increase in overfeed of the effect thread leads to a decrease in the strength of terry thread (Kryńska M., *Modyfikowanie własności nitki pętelkowej* [Modifying the Properties of Loop Yarn], Master's Thesis, Lodz University of Technology 2005, Supervisor: Grabowska K.E.). It stems from the fact that tenacity is calculated as the quotient of the breaking force of the terry thread divided by the linear density of that thread. In turn, overfeed of the effect yarn does not influence the value of the breaking force of the terry thread, because the value of the breaking force of the terry thread is determined by the strength of the core yarn: during the process of drawing of the terry thread, it is the core yarn that breaks first, then the tie-in thread and the effect yarn as the last one. The overfeed of the effect yarn stimulates an increase in the linear density of the terry thread in a very significant way. Thereby, an increase in the overfeed of the terry yarn does not cause an increase in the numerator of the formula that determines the breaking strength of the terry thread.

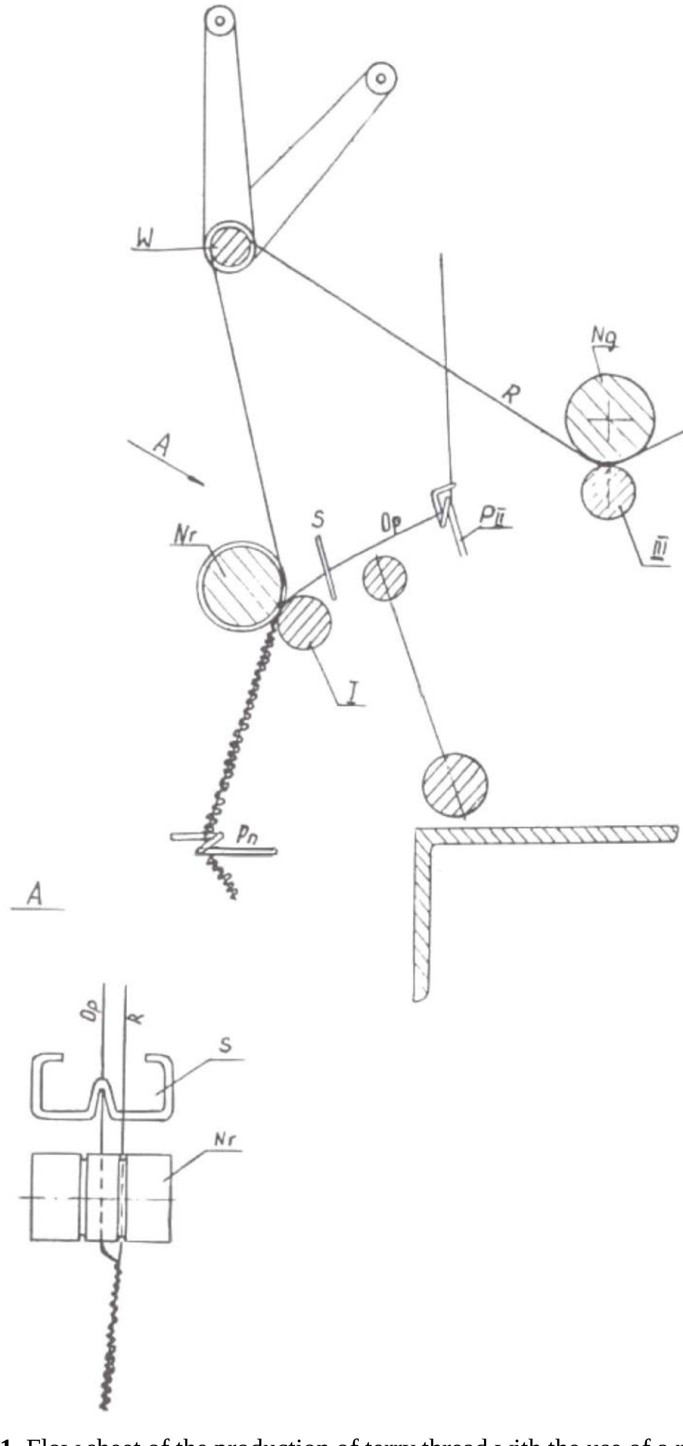


Fig. 51. Flow sheet of the production of terry thread with the use of a ring twisting frame: P_{III}, P_{II}, P_n, S – thread guides, N_g, N_r – top rollers, III – feeding rollers of the component threads, W – working beam, R – core thread, O_p – braid thread

In turn, the overfeed of the effect yarn influences the increase in the denominator of the formula that determines the tenacity of the terry thread. This way, together with the increase in overfeed of the effect yarn, the tenacity of the terry thread decreases in a significant way. An increase in the twist of the terry thread significantly influences the value of the breaking force and its elongation that occurs in the process of drawing of the terry thread: together with the increase in the twist of the terry thread, the breaking force of this thread increases as well as its breaking elongation. Upon defining the breakage of the terry thread equivalent to the breakage of its first component, it has to be stated that the overfeed of the effect yarn does not have any influence on the value of elongation of the terry thread during the process of drawing this yarn, because it does not determine its breakage. Simultaneously, both the twist of the terry thread and the overfeed of the effect yarn significantly influence the final value of the linear density of the terry thread: together with the increase in twist and overfeed, the linear density of the terry thread increases as well. Together with the increase in the twist of the terry thread, the value of the amplitude of the sinusoid gen- erated by the effect thread decreases. The most beautiful effects of the terry thread are achieved as a result of the use of fine components of this thread. The delicate sinusoidal pattern formed by the effect yarn is generated with the use of a minor overfeed and twist of the fine effect yarn. The terry thread is used in knitted products characterised by a minor twist of yarns and high drapability as well as low stiffness of bend. Simultaneously, it was verified that the use of the terry thread as the main ingredient in the production of knitted fabrics forces the use of even knitting stitches in such a way that an elaborate structure of the terry thread and an extended surface of the knitted fabric would not overlap.

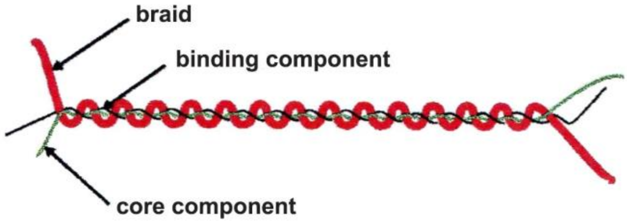


Fig. 52. Construction of the terry thread (source: Kujawa K., *Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych* [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

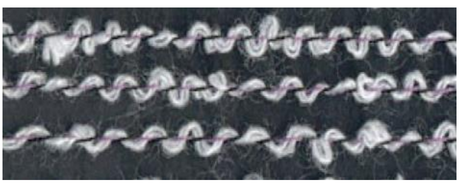


Fig. 53. Wavy terry thread (source: Grabowska K.E., *Modelowanie własności wybranych liniowych wyrobów włókienniczych o rozbudowanych powierzchniach* (Modelling of Properties of Choesn Linear Textile Products with Expanded Surface Area), Habilitation Dissertation, Lodz University of Technology, 2006)

7.1.3.2. Bouclé thread

The bouclé thread is a variation of the loop thread, in which there are full, rounded loops. The production of bouclé thread is determined by the overfeed of the effect yarn, which has to be bigger that the overfeed used in the production of terry thread. The bottom limit of the overfeed of the bouclé thread is determined by the overfeed of the terry thread and the top limit of the overfeed is determined by the overfeed of the effect yarn characteristic for the thread with snarls. In its simplest form, the bouclé thread is a three-plied cord built from the effect yarn, the core yarn and the tie-in thread. Pretty, circular loops on the bouclé thread are obtained with the use of fine component yarns characterised by a high susceptibility to bending. High level of repeatability of effects and their even, circular shape determine the quality of the bouclé thread. Research was conducted on how the technological parameters of the twisting process determine the structure of the bouclé thread. It was concluded that an in increase in the overfeed of the effect yarn influences, above all, the diameter of the loop, i.e. together with the increase in the overfeed of the effect yarn, clear loops with the big diameter are generated. At the same time, it was concluded that an increase in the overfeed of the effect thread causes a decrease in the distance between emerging loops, i.e. together with the increase in the overfeed of the effect yarn, the frequency of the occurrence of loops along the length of the bouclé thread ncreases as well. The research on the influence of the twist of the bouclé thread on the distance between the loops proved that an increase in twist causes a decrease in the distance between loops (Wieczorek K., *Porównanie właściwości nitek pętelkowych i frotowych oraz tkanin i dzianin z nich wykonanych* (Comparison of Properties of Loop Threads and Terry Threads as Well as Woven and Knitted Textiles Made of Them), Engineer's Thesis, Łódź University of Technology, 2002, Supervisor: Grabowska K.E.). A multidimensional regression model was used in order to estimate the statistical significance of the influence of the twist value of the bouclé thread and the overfeed of the effect yarn on the distance between the loops (Ciszewska T., *Metody wytwarzania i właściwości przędz fantazyjnych pętelkowych* (Production Methods and Properties of Loop Fancy Yarns), Master's Thesis, 1998, Lodz University of Technology, Supervisor: Grabowska K.E.):

$$l_B = -0.05t_B - 0.02N_B + 20.6 \quad (29)$$

where:

l_B – distance between the loops [mm],

N_B – overfeed of the effect yarn.

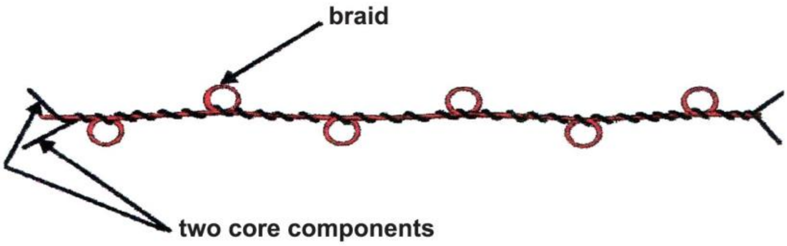


Fig. 54. Construction of the bouclé thread (source: Kujawa K., Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz Universityof Technology, Supervisor: Czekalski J.)

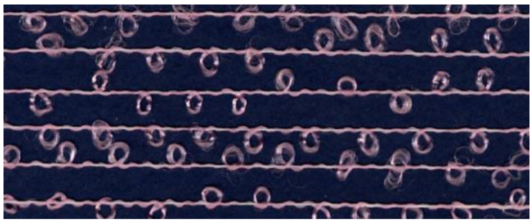


Fig. 55. Bouclé thread (source: PAFA Construzioni Machine Tessili)

The high value of the coefficient of regression proves the correctness of the model construction.

The research on the influence of the twist value of the bouclé thread on the height of the generated loops allowed for the use of multidimensional regression and estimation of the statistical model. The influence of the twist of the bouclé thread on the height of the generated loops is linear, inversely proportional and can be formulated as:

$$h_B = -0.03\, t_B + 10.6 \qquad (30)$$

where:

h_B – height of the loops [mm],

t_B – twist of the bouclé thread [t/m].

For this approximation, a high value of the coefficient of correlation $R^2 = 0.88$ was achieved, which is indicative of a good adjustment of the statistical model to the results of experiments. It has to be inferred on the basis of this model that an increase in the twist of the bouclé thread causes a slight decrease in the height of snarls. A model of regression describing the significance of the influence of the value of twist of the bouclé thread and the overfeed on the linear mass of the bouclé thread was estimated as well:

$$Tt_B = 0.1t_B + 0.8N_B + 173.45 \qquad (31)$$

where:

Tt_B – linear density of the bouclé thread [tex],

t_B – twist of the bouclé thread [t/m],

N_B – overfeed of the effect yarn.

The high value of the coefficient of determination $R^2 = 0.97$ proves that the statistical model is correct and indicates that together with the increase in the twist of the bouclé thread and the working-in of the effect yarn, the linear density of the bouclé thread increases. Whereby it has to be pointed out that the influence of the overfeed of the effect yarn on the change in the linear density of the bouclé thread is considerably more significant than the influence of twist.

Research conducted on bouclé threads proved the influence of twist on the value of breaking force of this thread and that the liminal value of twist of those threads is 200 t/m (Kryńska M., *Modyfikowanie własności nitki pętelkowej* [Modifying the Properties of Loop Thread], Master's Thesis, Łódź University of Technology 2005, Supervisor: Grabowska K.E.). After exceeding this value of twist the tenacity of those threads starts diminishing and their stiffness of bend starts increasing significantly. It was also proved that an increase in overfeed of the effect thread influences negatively the strength of the bouclé thread. An inversely proportional linear relationship was discovered:

$$W_B = -0.02N_B + 8.7 \quad (32)$$

where:

W_B – specific tenacity of the bouclé thread [cN/tex],

N_B – overfeed of the effect yarn.

Together with the increase in the overfeed of the effect yarn, the linear density of the effect yarn used in the production of the bouclé thread increases as well and, thereby, increases the linear density of the bouclé thread. It causes an increase in the denominator of the formula that determines the specific tenacity of the bouclé thread. Whereby it has to be pointed out that the overfeed of the effect yarn does not influence the value of the breaking force of the bouclé thread: the effect thread does not transfer the longitudinal tension.

Research was also conducted to discover significant differences between parameters of bouclé threads and terry threads built from the same component threads and characterised by the same values of twist. It was concluded that bouclé threads are characterised by a significantly bigger linear density than the corresponding terry threads. Those differences stem from the fact that a bigger overfeed of the effect yarn is used in the production of bouclé threads. Thereby, bouclé threads are characterised by greater stiffness of bend in relation to the corresponding terry threads. Hence, the popularity of terry threads in the knitting industry is greater than the popularity of bouclé threads, which are often used as the weft in woven fabrics. In turn, knitted fabrics produced with the use of the same stitch from terry threads are finer than the knitted fabrics made from bouclé threads: mass per unit area of the knitted fabrics produced from bouclé threads is bigger than the mass per unit area of knitted fabrics made of terry threads. The amplitude of the sinusoid formed by the effect yarn in the terry thread is always lower than the diameter of the loop formed in the bouclé thread with corresponding parameters describing the technological process. Research on the structure of the bouclé loop thread was conducted with the use of the computer image analysis. On the basis of research conducted on the structure and mechanical properties of the bouclé thread, an artificial neural network was developed, with the so-called teacher and the use of a Levenberg-Marquardt algorithm solver and the error backpropagation algorithm (Stefańska A., *Zastosowanie sieci neuronowych w predykcji własności nitek fantazyjnych* [The Application of Artificial Neuron Networks in Prediction of Fancy Threads Properties], Master's Thesis, Łódź University of Technology 2004, Supervisor: Grabowska K.E.). Neuron networks were used with the aim of predicting the value of breaking force, linear density, height of loops and distance between them (Binienda A., *Przewidywanie własności nitek fantazyjnych za pomocą sieci neuronowej* [Estimated Properties of Fancy Threads with the Help of Neuron Network], Master's Thesis, Łódź University of Technology 2003, Supervisor: Grabowska K.E.). The network is repeatedly used to design the properties of bouclé loop threads [Grabowska, Ciesielska, & Vasile, Fancy yarns-an apprisal, 2009].

7.2. Plied fancy threads with point effects

Fancy threads with point effects belong to the group of threads, which effectiveness of production decreases drastically with an increase in the complexity of their effect. Threads with point effects are fancy threads, in which the decorative effect produced along the thread is formed by separate colour structures in the form of knots and different bulges of a specific thickness, length and shape. In all of the enumerated fancy threads, the point decorative effect is characterised by a specific colour, length and thickness as well as the frequency of occurrence. Having assigned the centre of the point effect and treating it as a point of reference, one can assign a scale of occurrence of point effects [Grabowska, 2010]. The scale of ocurrence of point effects can be regular or irregular.

Due to the shape of the designing effect, fancy threads with point effects can be divided into:

- tuft threads,
- caterpillar threads,
- eccentric threads,
- flame threads (slub threads).

Multi-plied threads with point effects are characterised by a complex construction that consists in twisting together at least three component yarns in such a way that the base yarn and the effect yarn are fed into the twisting zone with a regulated non-constant speed. It means that in the process of twisting together the component yarns, one of the threads is slowed down or even halted, so that the other component yarn, the so-called effect yarn, is twisted or even wound in one point of the base yarn. This way, a tuft of a specific length and thickness is formed. The time intervals between the processes of retarding or halting of the core thread feed to the twisting zone determine the scale of ocurrence of point effects and their shape. The scale of point effects is defined by the time of the core thread feed at a constant speed to the twisting zone. The time allotted to the process of retarding and then accelerating the core yarn feed into the twisting zone determines the length of the point effect. The shape of the point effect is determined by the time of retarding and the time of accelerating the core yarn feed into the twisting zone. The shape of the point effect is also determined by the use of different kinds of effect yarn, i.e. from slubbing to different structural forms of effect yarn. Treating the time allotted to the different stages of the multi twist fancy thread as the input variable and the parameters of shape of the point effect as the output variable, one has to pay attention to the speed of feeding to the twisting zone of individual component yarns, and, thereby, the twist generated between the component yarns, because it is the differentiation of twist, alongside the differentiation of the linear mass of the component yarns in the fancy thread, that determines the shape of the point effect. The third component strand of the fancy twisted thread with point effects fixes the effect on the core thread and is called tie-in thread. Usually, it is a fine, and thereby, an invisible filament thread [Grabowska, Vasile, Van Langenhove, Ciesielska, & Barburski, 2006]. The mechanism that decides about the shape of the effect in a fancy yarn is the operation of the drawing mechanism of the web of fibres feeding the twisting and winding system. If in the process of creating a fancy thread with point effects the drawing mechanism plays an important role, its periodic actions cause a periodic delivery of thicker or finer segments of slubbing to the twisting zone. If, however, the drawing mechanism is excluded from the production process, only the speed of core yarn feed to the twisting zone is regulated by the last pair of delivery rollers. Currently, the most popular production method of fancy twisted threads with point effects is the hollow spindle method. Due to the computer-controlled operating system of the drawing mechanism, one can obtain periodically or stochastically arranged point effects that consist of attenuation or thickening, or that consist of unevenness of twist of the thread with point effects. It has to be pointed out that in case of the thread with point effects that is characterised by unevenness of twist, very often the phenomenon of imbalance of twist along the whole length of the thread occurs, and thereby, such a thread with point effects is characterised by the occurence of a tendency to form snarls. It is a completely negative phenomenon and one that influence the postproduction process, i.e. the productivity of the process of weaving or knitting. That is, why the fancy thread with point effects is subject to the process of steaming in order to stabilise the twist and diminish the tendency to form snarls. It prolongs the production process and increases the production costs. Fancy thread with point effects is characterised by a very interesting structure and the more stochastic arrangement of the point effects in the thread, the better the designing effect is. Thereby, it prevents the forming of the so-called stripe of the pattern in a flat textile product, which is not always a desired effect. Another method of production of fancy twisted threads with point effects is the ring twisting frame method, which currently is not very popular, because it requires a complicated process of feeding the effect thread to the feeding zone with the use of working beams and due to the two-stage production process of such a thread, i.e. during the first stage, the effect yarn is twisted with the core yarn, while during the second stage the constructed combination of threads is subject to twisting with the tie-in thread in the direction opposite to the direction of twist that occurs between the effect yarn and the core yarn. This change in direction of twist during the “tying-in” process of the fancy thread with point effects influences the stabilisation of the twist of the final thread as well. Fancy threads with point effects are characterised by a considerably more extended surface than threads with continuous effects. Unevenness of structure and mechanical properties, which stems from the fact that designing effects are present along the whole length of the thread ina stochastic way, has to be mentioned as the dominant feature of this kind of threads. Due to their unstable structure, fancy threads with point effects are threads that cause certain processing problems that are made apparent already at very early stages of production. Even the process of winding the fancy thread with point effects from yarn packages to weaving or knitting cones can cause multiple breaks, due to the unstabilised tension. Fancy threads with point effects are always fed as the weft thread. The use of a fancy thread with point effects as the warp thread is con- sidered uneconomical and leading to multiple structural disturbances of the flat textile product. Fancy thread with snarls makes up a fancy thread structure that is situated on the border between threads with continuous effects and the group of threads with point effects [Qadir, et al., 2018].

7.2.1. Fancy thread with snarls

Fancy thread with snarls is a thread that is situated in between fancy threads with continuous effects and fancy threads with point effects, because the fancy thread with snarls is formed from bouclé fancy thread, in which a very high value of overfeed is used, as high as to make the resulting loops made of a very tenuous thread begin to break down and twist with one another. That way, in lieu of loops, there form twisted segments of effect thread. The length of those segments is conditioned by the value of overfeed. The principle of production of the thread with snarls is analogous to the principle of production of the loop thread and the difference between them stems from the value of overfeed of the effect thread. The thread with snarls is at least a three-plied cord, due to the need to stabilise the effect. Research concerning the mechanism of formation of yarn snarls was conducted, i.a., by E. Belov et al. [Belov E., Lomov, Truevtsev, & Bradshaw, 2002].

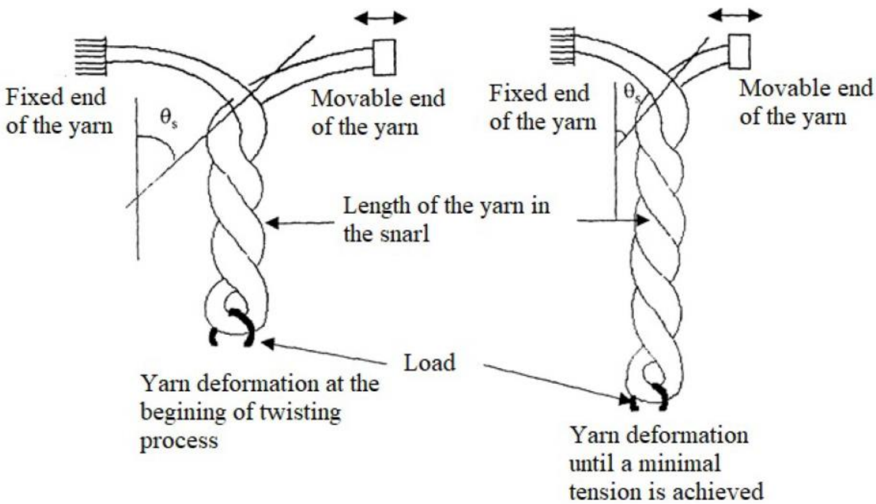


Fig. 56. Mechanism of formation of snarls in yarn (source: Githaiga J.T., *Study of The Dynamic Behaviour of The Weft Yarn at The End of The Weft Insertion in Air-Jet Weaving*, University of Ghent, Faculty of Applied Sciences, Department of Textiles, 2002-2003)

During the process of twisting, both torque and compressive force are applied to the yarn. Stability of the thread with snarls depends on the arrangement of fibres and the yarn geometry. The mechanism of forming snarls is illustrated by the instability of the elastic, cylindrical body of the yarn. During the twisting of the thread, the twisting force increases up to the moment of achieving a certain critical value, after crossing of which a deformation of the yarn occurs and the snarl appears, and the tension present in the yarn diminishes. The mechanism of forming snarls in the thread is described by the following rules:

- while making the twist, the thread is deformed within a certain section, while the rest of the yarn retains its rectilinear form,
- local variation of the rectilinear deformation of stable thread (formation of snarl – loop) is preceded by a loss of stability. This fact is related to the result of theory of elastic rod; the curvature of the axis of the twisted rod has a spiral form,
- if the thread has a structural defect (fault), i.e. a finer place, a deformation of the rectilinear stable thread into a snarl will, with a high probability, occur in this place,
- the spiral deformation (formation of snarl) stabilises the thread, if it is not stable. Loss of stability occurs, when the spiral curls while further twisting,
- the loss of stability consists in a transformation from a spiral bundle to a snarl–loop. It is a shift to a more beneficial energy state. In turn, while the

process of twisting the thread is performed quickly, a quick accumulation of energy occurs and in the moment of loss of stability there appears simultaneous formation of several snarls,

- after the first loop has appeared, further twisting causes formation of further loops – snarls. Thus, the thread is wholly covered in loops,
- further twisting of the thread, as a result of which the loss of stability and the appearance of subsequent series of snarls occurred, in extreme cases can lead to the destruction (breakage) of the yarn.

Fig. 57. Construction of the thread with snarls (source: Kujawa K., *Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych* [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

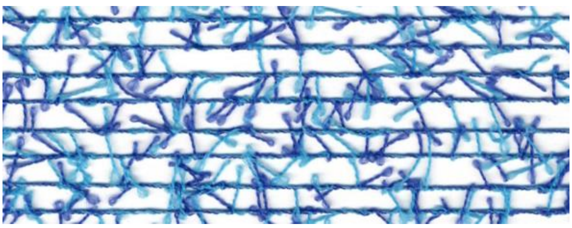


Fig. 58. Thread with snarls (source: Allma Twisting Systems)

Research was conducted on the influence of different parameters of the process of formation of thread with snarls on its structural and mechanical properties (Szwed A., *Ocena właściwości użytkowych i możliwości produkcyjnych procesu dziania z nitki ozdobnej skrętkowej* (Assessment of Functional Properties and Production Possibilities of the Knitting Process of Decorative Snarl Thread), Master's Thesis, Łódź University of Technology, 2005, Supervisor: Grabowska K.E.). It was proved that:

- the twist of the effect yarn influences the final linear density of the thread with snarls:

$$y = 0.025x + 26.86;\ R^2 = 0.8 \tag{33}$$

where:

y – final linear density of the thread with snarls [tex],

x – twist of the effect yarn [t/m]

- the overfeed of the effect yarn and the linear density of the effect yarn influence the final linear mass of the thread with snarls:

$$y = 0.58x + 1.61z + 54.21;\ R^2 = 0.98 \tag{34}$$

where:

y – final linear density of the thread with snarls [tex],

x – overfeed of the effect yarn,

z – linear density of the effect yarn [tex]

- the linear density of the effect yarn influences the length of snarls:

$$y = -0.62x + 30.03;\ R^2 = 0.6 \tag{35}$$

where:

y – length of snarls [mm],

x – linear density of the effect yarn [tex]

- the overfeed of the effect yarn influences the length of snarls:

$$y = 0.03x + 2.26;\ R^2 = 0.75 \tag{36}$$

where:

y – length of snarls [mm],

x – overfeed of the effect yarn

- the twist of the effect yarn and its linear density influences the distance between snarls:

$$y = 0.24x - 10.69z + 377.92;\ R^2 = 0.6 \tag{37}$$

where:

y – distance between snarls [mm],

x – twist of the effect yarn [t/m],

z – linear density of the effect yarn [tex],

- overfeed of the effect yarn influences the distance between snarls:

$$y = -0.08x + 28.04;\ R^2 = 0.75 \tag{38}$$

where:

y – distance between snarls [mm],

x – overfeed of the effect yarn

Fig. 59. Plain weave fabric brocaded with a thread with snarls (source: Kurek E., *Techniki zdobienia tekstyliów z wykorzystaniem nieklasycznych struktur i faktur nitek* [Techniques of Decorating Textiles with the Use of Non-Classical Structures and Textures of Threads], Master's Thesis, 1998, Lodz University of Technology, Supervisor: Masajtis J.)

- twist of the effect yarn and its linear density influences the number of snarls generated in the effect yarn:

  $$y = 0.01x - 0.22z + 6.94;\ R^2 = 0.6 \tag{39}$$

  where:

  y – number of snarls generated in the effect yarn,

  x – twist of the effect yarn [t/m],

  z – linear density of the effect yarn [tex]

- overfeed of the effect yarn influences the number of snarls generated in the effect yarn:

  $$y = 0.09x + 6.46;\ R^2 = 0.69 \tag{40}$$

  where:

  y – number of snarls generated in the effect yarn,

  x – overfeed of the effect yarn.

Conducted research proved that the best visual effects connected with the use of the thread with snarls in both woven and knitted fabrics were achieved with the use of a thread with snarls characterised by long and frequent snarls.

7.2.2. Tuft threads

Tuft as a designing effect was defined in the spinning industry as a short local bulge generated as a result of a concentration of the effect strand on the core strand as a result of a local increase in twist. There are four basic shapes of tufts, i.e.: spherical, ellipsoidal, conical and biconical. The spherical tuft is formed as a result of quick, i.e. brief, successive stages of retardation of core yarn feeding into the twisting zone, followed by a quick and brief acceleration of core thread feeding. That way, the incremental oval of the tuft is formed on its left side (retardation of the core yarn feeding, and thereby, local winding of the effect thread) and the decreasing oval of the tuft is formed on its right side as a result of a quick and brief acceleration of base yarn feeding to the twisting zone. After that process, one should retain a constant speed of core yarn feeding to the twisting zone for a specified time interval, so that evenness of twist of the tuft thread could be retained within a specified length defined as the scale of designing effects in the tuft yarn. With regard to the shape of the tuft, we can distinguish tuft fancy yarns with spherical tufts, ellipsoidal tufts, conical tufts and biconical tufts. The spherical tuft is formed in case of very short and quickly successive times of retardation and acceleration of the process of tuft yarn feeding to the twisting zone. In the case of generating ellipsoidal tufts, the times of retardation and acceleration of the tuft yarn feeding to the twisting zone are the same, but considerably longer than in the case of production of spherical tufts. The processes of retardation and acceleration of the core yarn feeding into the zone of twisting with the effect yarn are rather mild so that the effect thread is wound evenly on the core yarn both during the retardation and the acceleration of the core yarn. The ellipsoidal tuft is often identified with the twisting flame. The twisting caterpillar is defined in a similar way. Both names are used to denote design effects of the tuft thread. Frequently, both in the industry and trade, different names of the tuft thread are distinguished, based on the specific shape of the tuft, i.e. eccentric thread and caterpillar thread. It has to be borne in mind that both the aforementioned types of the fancy thread concern the tuft thread. A different situation takes places in the case of conical and biconical tufts. The process of acceleration of the core yarn is ended by an abrupt halt in the twisting zone and then a quick process of acceleration. That way, tufts in sharp shapes, which resemble cones, are formed. The difference between a conical and a biconical tuft is the result of different times of retardation and acceleration of the core yarn in the zone of twisting with the effect yarn. The biconical tuft is formed in the case of use of the same time of acceleration and retardation, if the core yarn fed into the zone of twisting with the effect yarn, taking into account the short time of halt of the core yarn in the twisting zone. In turn, the conical tuft is formed as a result of differentiation of times of retardation and acceleration so that the peak point of the tuft, which is identified with the moment of halting the core yarn in the twisting zone, does not correspond to the centre of the tuft (Cal I., *Metody wytwarzania i właściwości przędz fantazyjnych pęczkowych* [Productions Methods and Properties of Fancy Tuft Yarns], Master's Thesis, Łódź University of Technology 1998 Supervisor: Grabowska K.E.).

Fig. 60. Construction of the tuft thread (source: Kujawa K., *Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych* [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

Research was conducted on the properties of the tuft yarn. Homogenous research material was used: polyester filament thread under the trade name of Torlen and with the linear density of 16.7 tex was used as the core thread and the binding thread. Polyacrylonitrile yarn with a variable linear mass, i.e. 32x2 tex, 32x4 tex, 32x6 tex, 32x8 tex, was used as the effect yarn. The aim of the research was to determine the influence of the linear mass of the effect thread and the working-in of this yarn in the tuft thread on the appearance and the mechanical properties of the tuft thread. Finally, the research material was composed of 16 kinds of tuft thread. The results of the conducted research and the statistical analyses proved the significance of the influence of (Cal I., *Metody wytwarzania i właściwości przędz fantazyjnych pęczkowych* [Productions Methods and Properties of Fancy Tuft Yarns], Master's Thesis, Lodz University of Technology 1998 Supervisor: Grabowska K.E.):

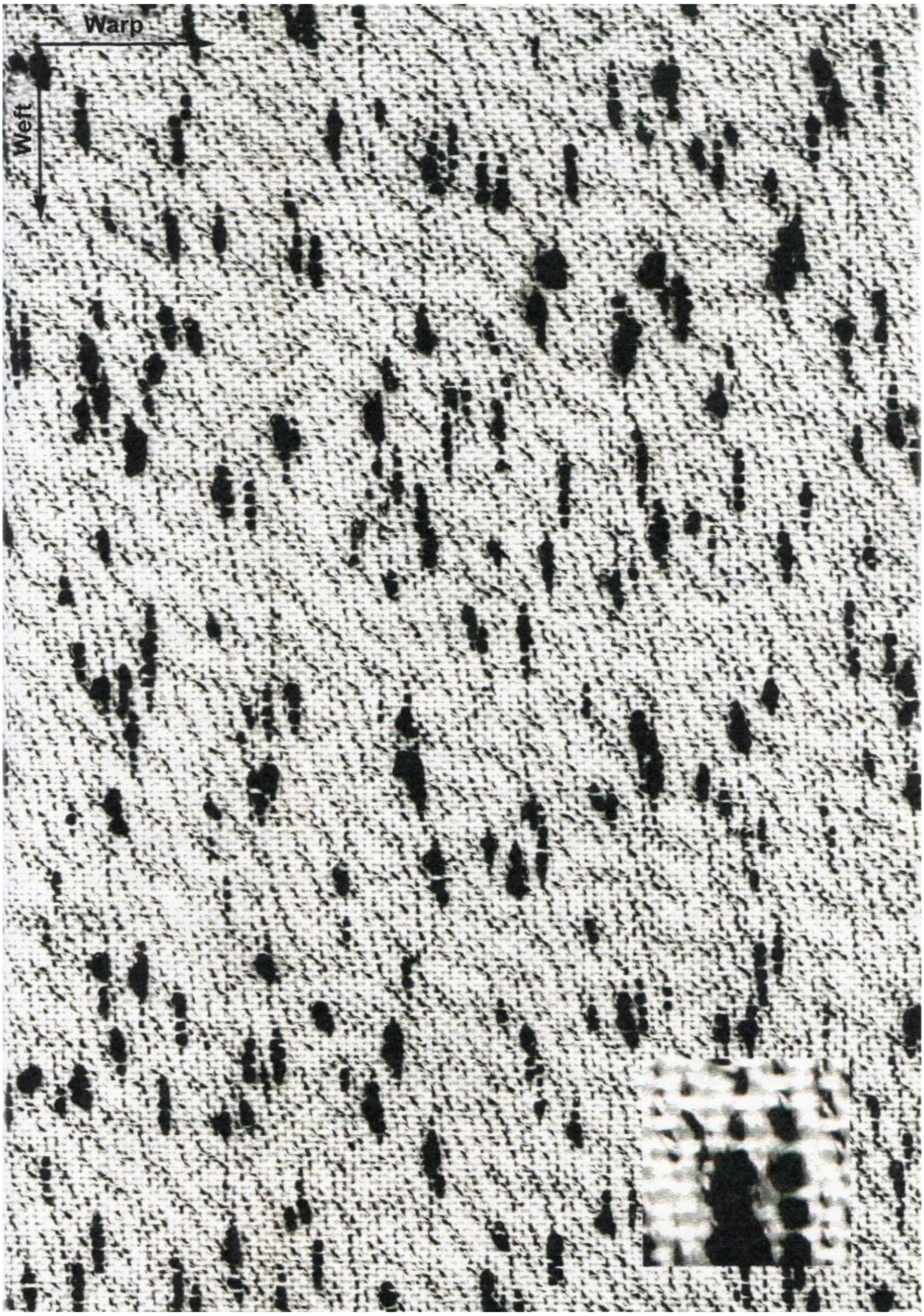


Fig. 61. Plain weave fabric with tuft thread used as weft (source: Kurek E., *Techniki zdobienia tekstyliów z wykorzystaniem nieklasycznych struktur i faktur nitek* [Techniques of Decorating Textiles with the Use of Non-Classical Structures and Textures of Threads], Master's Thesis, 1998, Lodz University of Technology, Supervisor: Masajtis J.)

- the overfeed of the effect yarn in the tuft thread on the final linear mass of the tuft thread: an increase in the linear density of the tuft thread takes places together with an increase in the overfeed of the effect yarn in the tuft thread,
- the linear density of the effect thread on the strength of the tuft thread: it is an inversely proportional relationship, which means that together with an increase in the linear mass, the strength of the tuft thread decreases. This relationship is the implication of the formula that allows us to estimate the strength of the thread as the quotient of the breaking force and the linear density of the thread: the bigger the final linear density of the thread, the lower its strength.

  The regression equation that determines the influence of the linear density of the effect yarn on the strength of the tuft thread defines a small influence of the linear density on the strength of the tuft thread (nevertheless, the influence is significant as a phenomenon):

  $y = -0.01x + 6.1; R = -0.94$ (41)

  where:

  y – breaking strength of the tuft thread [cN/tex],

  x – linear density of the effect yarn [tex],

  R – coefficient of correlation,

- influence of the overfeed of the effect yarn in the thread on its strength. It is an inversely proportional relationship, i.e. together with an increase in the overfeed of the effect yarn in the tuft thread, its breaking strength decreases. The explanation of this phenomenon is analogous to the analysis of the formula of strength of the thread, because together with an increase in overfeed of the effect yarn in the tuft thread, the final linear density of the tuft thread increases,
- influence of the effect thread on the elongation of the tuft thread: a minor influence of the increase in the linear density of the effect yarn on the increase in the strain of the tuft thread was detected, only up to the value of double linear density of the effect yarn. Any further increase in the linear mass of the effect thread has no influence on the change in the elongation of the tuft thread.

  Regression equation: $y = -0.0001x + 0.07; R = 0.61$ (42)

  where:

  y – strain of the tuft thread,

x – linear density of the effect yarn [tex],

R – coefficient of correlation,

- influence of the overfeed of the effect yarn in the tuft thread on its elongation: in the case of use of effect yarns with small linear density it was detected that an increase in the overfeed of such yarns in the tuft thread causes a decisive and significant increase in the strain of that thread. In turn, in case of the use of effect yarns with bigger linear density of the overfeed of the effect thread it does not have any influence on the final strain of the tuft thread,

- influence of the linear mass of the effect yarn on the length of the tuft: no influence of the linear mass of the effect yarn on the length of the tuft was detected (R = 0.03),

- influence of the overfeed of the effect yarn on the length of the tuft: influence of the linear mass of the effect yarn on the length of the tuft was detected. After exceeding the overfeed by about 80%, the overfeed of the effect yarn in the tuft thread does not have any influence on the length of the tuft,

- influence of the linear mass on the thickness of the tuft in the tuft thread: a mild (but statistically important) influence of the linear density of the effect yarn on the thickness of the tuft was detected for the value of overfeed that does not exceed 130%. In case of higher values of overfeed of the effect yarn in the tuft thread, no significant influence of the linear density in the effect thread on the thickness of tuft was detected.

  Regression equation: $y = 0.001x + 1.6$; $R = 0.83$ (43)

  where:

  y – thickness of the tuft [mm],

  x – linear density of the effect yarn [tex],

  R – coefficient of correlation,

- influence of the linear density of the effect yarn on the distance between the tufts: significant influence of the linear density of the effect yarn on the distance between the tufts was detected only in the case when the value of overfeed of the effect yarn in the tuft thread did not exceed 100%. In the case of higher values of overfeed of the effect yarn in the tuft thread, no significant influence of the linear density of the effect yarn on the distance between tufts was detected.

  Regression equation: $y = -0.01x + +61.77$; $R = -0.7$ (44)

where:

y – distance between tufts [mm],

x – linear density of the effect yarn [tex],

R – coefficient of correlation,

- influence of the overfeed of the effect yarn in the tuft thread on the distance between tufts: in the case of effect yarns with small linear mass the increase in the overfeed of the effect yarn in the tuft thread has a decisive and significant influence on the diminishing of distance between the tufts. In turn, in the case of using effect yarns with big linear mass, a lack of any significant influence of the overfeed of the tuft yarn on the distance between the tufts was detected.

7.2.2.1. Caterpillar thread

Fancy twisted threads with decorative effects in the form of caterpillar belong to the group of decorative thread characterised by designing effects with point effects. As a caterpillar we understand a local cylindrical bulge along the length of the thread, created by an evenly condensed concentration of the effect component over the core thread. This concentration is formed as a result of retardation and then feeding of the core thread to the twisting zone that is constant over time and a quick acceleration to the primary speed of feeding of the core thread to the twisting zone. Along the length of the tuft formed in the shape of a caterpillar, there occurs an even binding of the effect thread in the form of coil by coil, i.e. with a very strong twist that stems from the retardation of feeding of the core thread into the feeding zone. What is more, in order to achieve an enriched designing effect, very often in the case of the production of the caterpillar thread the method or alternating change of core function and effect is used, i.e. the core and effect yarn periodically change roles, so by using yarns that differ in colour or linear mass as core and effect yarns, one can achieve design effects in the form of caterpillar that differ in size or colour.

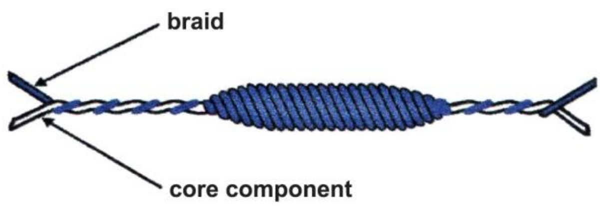


Fig. 62. Caterpillar thread (source: Kujawa K., *Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych* [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

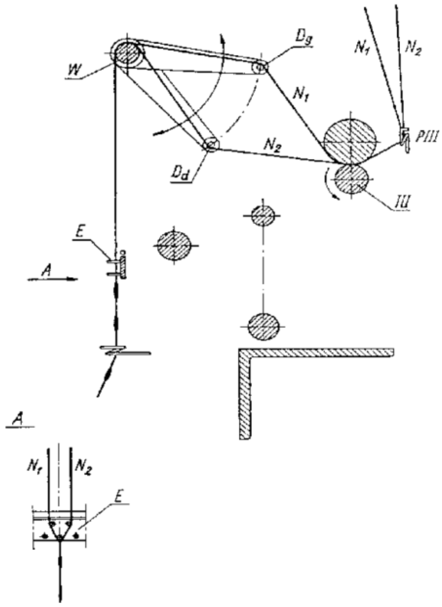


Fig. 63. Scheme of twisting of the caterpillar thread on a ring spinning frame: N_1, N_2 – component threads, PIII – guide, III – feeding rollers, D_d, D_g – arms of the working beam, W – roller propelling the working beam, E – guide pegs

Research was conducted on the structure and properties of the caterpillar thread. Twenty kinds of the caterpillar thread were produced with the use of the ring twisting frame, polyacrylonitrile yarn with the linear density of 32x2 tex was used as raw material, and metallic filament thread as the core and effect strands and the tie-in thread. The caterpillar threads were produced according to the assumed full experiment plan: the set twist between the effect yarn and the core yarn as well as the speed of the working beams that determined the speed of retardation and acceleration of feeding the core yarn into the twisting zone were used as input variables. From the produ ced caterpillar threads 15 kinds of samples of fabrics were made that differed in terms of weave, i.e. three samples of plain weave fabrics, three twill weave fabrics and three satin weave fabrics. Caterpillar threads were used as weft and polyester thread with the linear density of 15x2 tex as warp. Similarly, 16 samples of knitted fabrics that differed in terms of the used caterpillar thread and stitch (RR, RL and LL stitches were used) were produced with the use of a flat knitting machine.

The influence of the used twist of the caterpillar thread on the final linear density of this thread was studied.

A regression equation in the following form was obtained:

$$y = 0.52x + 52.9; R^2 = 0.87 \quad (45)$$

where:

y – final linear density of the caterpillar thread [tex],

x – twist used in the production of the caterpillar thread [t/m],

R^2 – coefficient of determination.

The high coefficient of determination indicates that as much as 87% of changes in the linear density of the caterpillar thread is defined by the change in twist between the effect yarn and the core yarn. It follows from the regression equation that on one unit of increase in twist falls the average increase in the linear density by 0.52 unit.

It was analysed what factors influence the thickness of effects in the caterpillar thread. A regression model in the following form was developed:

$$y = 0.003x + 0.02z = 0.124;\ R^2 = 0.97 \qquad (46)$$

where:

y – thickness of effects on the caterpillar thread [mm],

x – speed of the working beam,

z – distance between effects [mm],

R^2 – coefficient of determination.

It was concluded that together with the increase in the speed of the working beam and the distance generated between the effects, the thickness of design effects in the caterpillar thread increases as well. What is more, 97% of changes in the thickness of design effects of the caterpillar thread are caused by changes in the speed of the working beam and the distance between the effects.

It was studies what factors influence the length of the effect formed in the caterpillar thread. A regression model in the following form was developed:

$$y = 0.03x - 1.47;\ R^2 = 0.9 \qquad (47)$$

where:

y – length of effect on the caterpillar thread [mm],

x – speed of the working beam,

R^2 – coefficient of determination.

The derived regression model proves that together with the increase in the speed of the working beam, the length of the design effect produced in the caterpillar thread increases as well, and that 90% of changes in the length of the effect are explained by the speed of the working beam.

It was also studied, what factors influence the strength of the caterpillar thread. A regression equation in the following form was determined:

$$y = 0.004\,x - 0.014\,z - 0.003t - 0.16\mathrm{w} + 5.9;\ \mathrm{R}^2 = 0.97 \qquad (48)$$

where:

y – breaking tenasity of the caterpillar thread [cN/tex],

x – breaking force of the caterpillar thread [cN],

y – final linear density of the caterpillar thread [tex],

t – nominal twist of the caterpillar thread [t/m],

w – length of the produced effect [mm],

R^2 – coefficient of determination [Grobelna M., *Właściwości nitki gąsieniczkowej oraz tkanin wykonanych z tej nitki* [Properties of Caterpillar Thread and Fabrics Made of It], Master's Thesis, Łódź University of Technology 2001, Supervisor: Grabowska K.E.].

Fig. 64. Caterpillar thread (source: Grobelna M., *Właściwości nitki gąsieniczkowej oraz tkanin wykonanych z tej nitki* [Properties of Caterpillar Thread and Fabrics Made of It], Master's Thesis, Lodz University of Technology 2001, Supervisor: Grabowska K.E.)

Fig. 65. Plain weave fabric with the caterpillar thread fed as weft (source: Grobelna M., *Właściwości nitki gąsieniczkowej oraz tkanin wykonanych z tej nitki* [Properties of Caterpillar Thread and Fabrics Made of It], Master's Thesis, Lodz University of Technology 2001, Supervisor: Grabowska K.E.)

On the basis of the analysis of the developed regression model, it was concluded that the length of the created effect in the caterpillar thread has the biggest influence on the breaking strength and tenacity: the longer the caterpillar in the decorative thread, the weaker the decorative thread is. It has to be pointed out that along the length of the decorative effect of the caterpillar fancy thread there is an unstable, very high twist, much higher than the liminal value, i.e., after the crossing of which a drastic fall in tenacity occurs. Also the linear mass of the caterpillar thread has a significant influence on the strength of this thread. The negative relationship between the final linear density of the caterpillar thread and it's strength stems from the analysis of the formula of tenacity, which is the quotient of the breaking force and the linear density of the decorative thread. In turn, the averaged value of twist of this thread has only a minor influence on the strength of this thread. It stems from the fact that the twist of the caterpillar thread is diversified along its length. The high value of the coefficient of determination proves that 97% of changes in the tenacity od the caterpillar thread can be explained with changes in the linear density, length of the effect, breaking force and twist. In order to produce a strong, i.e. resistant to breaking, caterpillar thread, one has to use fine filament threads resistant to breaking and design the structure of the thread with short caterpillars.

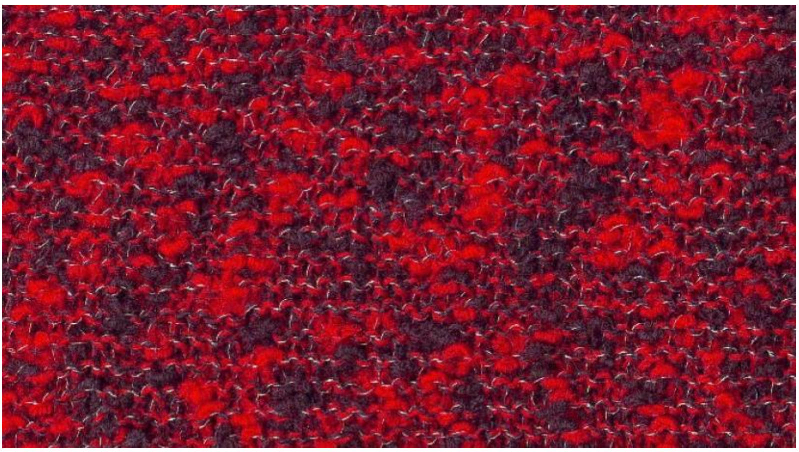


Fig. 66. LL knitted fabric with the use of the caterpillar thread (source: Grobelna M., *Właściwości nitki gąsieniczkowej oraz tkanin wykonanych z tej nitki* [Properties of Caterpillar Thread and Fabrics Made of It], Master's Thesis, Lodz University of Technology 2001, Supervisor: Grabowska K.E.)

The structure of fabrics produced from the caterpillar thread used as weft was analysed (the fabrics differed in terms of weave). The satin weave fabric was distinguished by the fact that the design effects in the form of caterpillars were sparsely visible despite the fact that the relative cover with the weft was very big and the surface mass of the fabric was bigger than that of the plain weave fabric. In turn, in the twill weave fabric, caterpillars are clearly visible and accumulate to form stripes in the shape of waves and skew lines. Nevertheless, the fabric is relatively soft and drapable. In the plain weave fabric, caterpillars are often covered with warp threads and the fabric is hard to the touch, stiff and rough, which is caused by the high twist of the caterpillars. In turn, the surface mass of this fabric and its thickness were the lowest among the produced fabrics. A similar analysis was used to analyse knitted fabrics produced with the use of a flat knitting machine. The produced fabrics were soft and drapable. In the knitted fabric produced with the use of the RR stitch, the caterpillars arranged themselves into the form of zigzags. Very often, due to the unstabilised twist of the caterpillar thread there were problems with feeding machines with that thread and the phenomenon of coiling of the edges of the produced knitted fabric took place.

7.2.2.2. Eccentric thread

Twisting flame is a design element of a plied decorative thread that belongs to the group of tuft threads. The twisting flame differs from the caterpillar in that its shape is streamlined and resembles a spindle. It means that the process of variations in speed, i.e. retardation and acceleration of feeding the core yarn into the zone of twisting with the effect thread are implemented in a gentle way, i.e. without abrupt shifts in the tension of the core yarn. Research on the structure of the eccentric thread was conducted in order to determine, how the interlacing of the component threads between the pegs of the calibrating machine of the ring twisting frame influence the structure and properties of the eccentric thread. A relaxed, fluffy polyacrylonitrile filament thread (32x2tex) and a polyester filament thread with the linear mass of 15tex were used to produce eccentric thread, the latter one used as the tie-in thread that stabilised the designing effect. In sum, 16 variants of the eccentric thread were produced and examinated. The full plan of experiments was implemented. The variable angle of rotation of coupling propelling the working beam, which causes the retardation and acceleration of feeding the core yarn into the zone of twisting with the effect yarn and four different variants of interlacing of the core yarn and the effect yarn between the pegs of the calibrating mechanism of the ring twisting frame were used as input variables. The statistical analysis was conducted on the basis of Student t-test. In all the analysed variants, the normality of distribution of data and lack of significant differences between variations were tested (Dziakiewicz H., *Własności nitki płomykowej oraz tkanin i dzianin wykonanych z tej nitki* [Properties of Eccentric Thread as well as Woven and Knitted Textilest Made of It], Master's Thesis, Lodz University of Technology 2003, Supervisor: Grabowska K.E.)

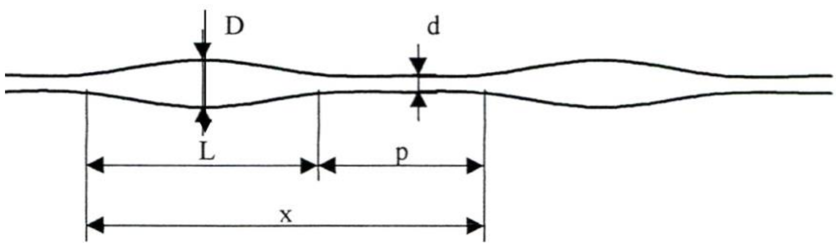


Fig. 67. Structural parameters of eccentric thread: D – maximum diameter of effect (flame), d – minimum diameter of eccentric thread, p – distance between effects, L – length of effect (flame), x – repeat of effects of eccentric thread

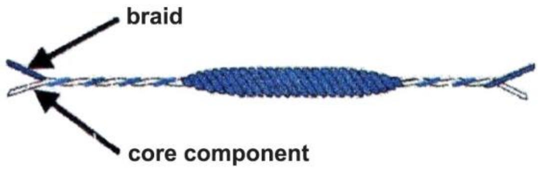


Fig. 68. Construction of eccentric thread (source: Kujawa K., *Zaprojektowanie i wykonanie płaskiego wyrobu włókienniczego z przędz fantazyjnych o efektach punktowych* [Designing and Making a Flat Textile from Fancy Yarns with Point Effects], Master's Thesis, 1999, Lodz University of Technology, Supervisor: Czekalski J.)

It was concluded that:

- eccentric threads produced with different kinds of interlacing of the core yarn and the effect yarn between the pegs of the calibrating mechanism, but within the same range of relative rotary speed of the working beam differ from one another in terms of linear density. Thereby, it was demonstrated that the angle inclination between the core yarn and the effect yarn influences the final linear mass of the eccentric thread. Small angle inclination between the core yarn and the effect yarn results in an increase in the linear density of the eccentric thread. Use of big angle inclination between the core yarn and the effect yarn results in smaller linear density of the eccentric thread,
- eccentric threads produced with the same kind of interlacing of the core yarn and the effect yarn between the pegs of the calibrating guide, but with a variable relative rotary speed of the working beam differ from one another in terms of final linear density. It was concluded that an increase in the speed of the working beam influences the increase in the final linear density of the eccentric thread,
- eccentric threads produced with the use of one and the same speed of the working beam, but with different kinds of interlacing between the pegs of the calibrating rail of the ring twisting frame differ from one another in terms of length of the flame. Use of big angle inclination between the core yarn and the effect yarn caused an increase in the length of the flame. It was concluded that a big angle inclination between the core yarn and the effect yarn causes a decrease in the dynamics of the twisting process and the resulting flames are very precise. The shortest flames are produced with the smallest angle inclination between the component threads,
- eccentric threads produced with the use of the same interlacing between the pegs of the calibrating rail, but with different speed of the working beam differ from one another in terms of length of the flame. The longest flames are formed with the smallest rotary speed of the working beam. It is caused by the slow raising movement of the working beam and the small speed of feeding the component yarn by the delivery roller into the twisting zone. The slow feeding of the component yarns into the twisting zone makes the process of flame forming take place within a long segment of the core yarn,

- eccentric threads produced with the use of the same rotary speed of the calibrating working beam, but with different kinds of interlacing between the pegs of the calibrating rail do not differ significantly from one another in terms of thickness of the flame,
- eccentric threads produced with the use of the same kind of interlacing between the pegs of the guide but with different rotary speed of the working beam differ significantly from one another in terms of thickness of the flame: the smaller the angle inclination between the component yarns, the bigger the differences in thickness of the flame (the flame is thicker),
- eccentric threads produced with the use of different types of interlacing of the component yarns between the pegs of the guide but with the same rotary speed of the working beam differ from one another in terms of distance between the flames,
- eccentric threads produced with the use of the same arrangement of interlacing of the component yarns between the pegs of the calibrating rail, but with different rotary speed of the working beam differ from one another in terms of, distance between the flames: the distance between the flames decreases with the increase in rotary speed of the working beam. It happens that way, because when the rotary speed of the working beam is higher, the amount of the core yarn fed to the zone of twisting with the effect yarn increases, which causes a reduction in yarn tension in this zone. In turn, faster upward movement of the working beam causes a multiplication of the produced flames,
- eccentric threads produced with the use of different kinds of interlacing of the component yarns through the calibrating rail of the ring twisting frame, but with the use of a constant rotary speed of the working beam differ from one another in terms of the breaking force, because, as was demonstrated, different kinds of interlacing of the component threads between the pegs of the calibrating rail cause the formation of different flames. It was concluded that the eccentric threads produced with the use of a very complex model of interlacing of the component threads between the pegs of the calibrating rail are characterised by the smallest breaking force,
- eccentric threads produced with the use of the same interlacing of the component threads between the pegs of the calibrating rail but, with different rotary speed of the working beam differ from one another in terms of breaking force: the higher the rotary speed of the working beam, the bigger the breaking force of the eccentric thread. The reason for the occurance of this phenomenon is the tension of the component yarns during the twisting process: at a low rotary speed of the working beam the core yarn is fed considerably slower than at a high rotary speed of the coupling. In turn, the rotary speed of spindles remained unchanged, which caused an increase in tension generated inside the core yarn. As a consequence, it causes a damage of staple fibres of the component yarns already at the stage of twisting,

- eccentric threads produced with the use of different kinds of interlacing of component threads between the pegs of the calibrating rail, but with the same rotary speed of the working beam do not differ significantly from one another in terms of breaking elongation: the interlacing of the component yarns between the pegs of the calibrating rail does not have any significant influence on the value of breaking elongation of the eccentric thread,
- eccentric threads produced with the use of the same interlacing of the component threads between the pegs of the calibrating rail but, with different rotary speed of the working beam differ from one another in terms of breaking elongation: the rotary speed of the working beam has influence on the breaking elongation of the eccentric thread. With the increase in the rotary speed of the working beam, the breaking elongation of the eccentric thread increases as well,
- eccentric threads produced with the use of different models of interlacing of the compo- nent threads between the pegs of the calibrating rail but with the same rotary speed of the working beam differ from one another in terms of specific breaking strength: it was proven that the eccentric threads characterised by smaller thickness of the flame were charac- terised by greater specific breaking strength. It stems from the analysis of the formula of specific breaking strength of the thread, because together witht the increase in thickness of the flame, the final linear density of the thread increases as well and, thereby, the specific breaking strength of the thread decreases,
- eccentric threads produced with the use of the same interlacing between the pegs of the calibrating rail, but with different rotary speed of the working beam differ from one another in terms of specific tenacity: together with the increase in the speed of the working beam, the tenacity of the eccentric thread increases as well. The increase in the rotary speed of the working beam causes a decrease in tension of the core yarn during the twisting process.

An analysis of multidimensional regression was conducted allowing for an estimation of the significance of the influence of individual input variables on:

- the linear density of the eccentric thread:

$$y = 23.8x + 117.3;\ R^2 = 0.84 \quad (49)$$

where:

y – linear density of the eccentric thread [tex],

x – thickness of the flame [mm],

R^2 – coefficient of determination.

It means that the unit of increase in the thickness of flame causes an average increase in the linear density of the eccentric thread equal to 23.8 units.

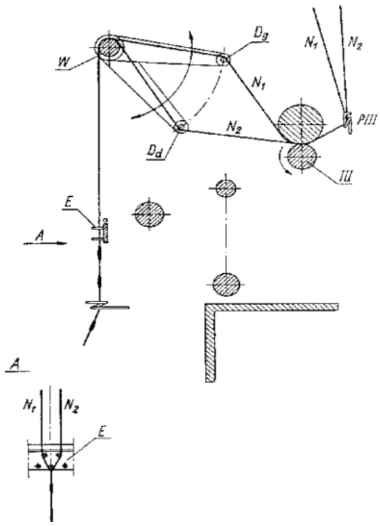


Fig. 69. Scheme of eccentric thread twisting on a ring twisting frame: N1, N2 – component threads, E – guide below which the twisting the of threads takes place, W – shaft of the working beam, Dg counter faller wire that crosses the upper arms of the working beam, Dd – counter faller wire that crosses the lower arms of the working beam, PIII – first thread guide, III – feeding roller

The research proved as well that the value of linear density of the eccentric thread depends predominantly on the smallest possible angle of flare of the component yarns fed into the twisting zone.

- the length of the flame:

$$y = 30.13 + 6.76x - 0.2z - 2.35t;\ R^2 = 0.93 \quad (50)$$

where:

y – length of the flame [mm],

x – thickness of the flame [mm],

z – rotary speed of the working beam,

t – kind of interlacing of the component threads through the pegs of the calibrating rail,

R^2 – coefficient of determination.

The research proved that the increase:

- in the thickness of the flame by one unit causes a decrease in the length of the flame by 6.76 units,
- in the speed of the working beam by one unit causes a decrease in the length of the flame by 0.2 unit,

– change in the interlacing of the component threads of the eccentric flame on the pegs of the patterning rail causes a decrease in the length of the flame by 2.35 units.

- the thickness of the flame:

$$y = 0.96x + 1.03;\ R^2 = 0.8311{,}8 \qquad (51)$$

where:

y – thickness of the flame [mm],

t – kind of interlacing of the component threads through the pegs of the calibrating rail,

R^2 – coefficient of determination.

The analysis of the model shows that the way the component threads are interlaced through the pegs of the patterning rail has an influence on the thickness of the flame: a change in the interlacing of the component yarns through the pegs of the patterning rail causes an increase in the thickness of the flame by 0.96 unit.

- the distance between the flames:

$$y = 55.9 - 0.48x + 4.01z;\ R^2 = 0.9 \qquad (52)$$

where:

y – distance between flames [mm],

x – rotary speed of the working beam,

z – kind of interlacing of the component threads through the pegs of the calibrating rail,

R^2 – coefficient of determination.

The analysis of the model shows that together with the increase in the rotary speed of the working beam by unit, the distance between the flames decreases by 0.48 unit of length, and together with the change in the interlacing of the component threads through the pegs of the calibrating rail, the distance between the flames increases by 4 units of length.

- the breaking strength of the eccentric thread:

$$y = 999.36 + 5.4x;\ R^2 = 0.74 \qquad (53)$$

where:

y – breaking strength of the eccentric thread [cN],

x – speed of the working beam,

R^2 – coefficient of determination.

The analysis of the model indicates that an increase by one unit of speed of the working beam causes an increase by 5.4 units of breaking force of the eccentric thread. The increase in the speed of the working beam causes an increase in the speed of the roller controlling the feeding of the component yarn into the twisting zone. If the rotary speed of the spindles remains unchanged, then by increasing the speed of feeding the component yarns into the twisting zone, we decrease the tension of those yarns in the process of twisting and increase the averaged twist of the component yarns occurring between the flames, which causes an increase in the breaking force of the eccentric thread.

- the breaking strain of the eccentric thread:

$y = 47.9 + 0.04x;\ R^2 = 0.48$ (54)

where:

y – breaking elongation of the eccentric thread,

x – breaking strength of the eccentric thread [cN],

R^2 – coefficient of determination.

The breaking force of the eccentric thread has the biggest influence on the value of the breaking elongation of this thread and an increase by one unit of breaking strength of the eccentric thread causes an increase in the breaking elongation by 0.04 units. Knowing that the speed of the working beam has a positive influence on the breaking strength of the eccentric thread, we can draw conclusions about the influence of the speed of the working beam on the elongation of the eccentric thread.

- specific tenacity:

$y = 7.87 + 0{,}06x + 0.007z;\ R^2 = 0.96$ (55)

where:

y – specific tenacity [cN/tex],

x – linear density of the eccentric thread [tex],

z – breaking strength of the eccentric thread [cN],

R^2 – coefficient of determination.

An increase by one unit of the linear density of the eccentric thread causes a decrease in the specific tenacity of this thread by 0.06 unit. An increase in the breaking force of the eccentric causes an increase by 0.007 units of specific tenacity of this thread. The result of the analysis of the statistical model is compatible with the analysis of the physical model describing the tenacity of the eccentric thread.

Fig. 70. Plain weave fabric made with the use of flame thread as weft (source: Wójcik M., *Modelowanie faktur i własności tkanin wątkiem* [Modelling Textures and Properties of Fabrics with Weft], Master's Thesis, Lodz University of Technology 2003, Supervisor: Masajtis J.)

Research aimed at demonstrating the differences in the construction of fabrics made from the eccentric thread used as the weft were conducted. Three groups of fabrics were produced with the use of the following weaves: plain, twill and basket. Polyester filament thread with the linear density of 15x2 tex was used as warp.

The research checked the significance of differences in:

- surface mass: it was concluded that the fabrics made from different variants of the eccentric thread used as weft differ significantly in terms of the areal mass. The study on those differences involved fabrics made according to a specified variant of the eccentric thread within one kind of weave. All of the eccentric threads differed significantly in terms of the linear density. It implies differences in the surface mass of the fabrics produced from those threads. Those fabrics that were made with the use of the plain weave showed a great variability in the surface mass. Apart from that, the fabrics made with the use of the plain weave were characterised by the lowest values of the surface mass. Those fabrics that were made with the use of basket weave showed the greatest values of the surface mass.

- linear density of weft determining the concentration of fabric with the arrangement of weft threads expressed in the form of the number of weft threads per 1dm of fabric (the number of picks was constant and equalled 250 threads per 1dm): the conducted statistical analysis showed that there are no significant differences in terms of the number of picks of weft in fabrics made with the use of the same weave that differ in the variant of the eccentric thread used as the weft. In turn, upon analysing the number of ends of the weft of fabrics that differ in weave, significant differences were discovered: the lowest linear density of weft was shown by the fabrics made with the use of plain weave and the highest number of ends of weft was shown by the fabrics made with the use of basket weave,
- working-in of the weft in fabrics, which constitutes the difference in the length of the straight thread and the length of the corresponding woven product, out of which a thread related to the length of the segment of the fabric was extracted: significant differences in terms of working-in of the weft were discovered between fabrics that were made with the use of the same weave, but different in terms of the used variants of the eccentric thread. Similarly, differences were discovered in case of the analysis of the influence of the kind of weave on the working-in of the weft in fabrics: the lowest values of working-in of the weft were discovered for plain weave fabrics and the highest values for basket weave fabrics,
- working-in of the warp in fabrics: it was concluded that there are statistically significant differences between fabrics made from different variants of eccentric threads as far as the working-in of the weft is concerned. The values of working-in of the warp depended on the thickness of the eccentric thread: in the case, when the warp met a thick flame, the working-in of the warp increased. In turn, no significant differences in the working-in of the warp were discovered in case of fabrics made with the use of different weaves: working-in of the warp in plain weave, twill weave and basket weave fabrics did not differ in any significant way,
- thickness of fabrics: the occurrence of differences depending on the kind of eccentric thread used as the tweft were discovered to depend on the kind of weave used. The thickness of a plain weave fabric from the eccentric thread depends significantly on the structural parameters of that thread. Also the number of interlacings has a significant influence on the thickness of the fabric: with a big number of interlacings, the effects of the eccentric thread become crushed, which results in a decrease in the thickness of the fabric. Plain weave fabrics were characterised by the lowest thickness, while basket weave fabrics showed the highest thickness,

- relative cover with the weft, warp and both weft and warp simultaneously that took into ac- count the count and thickness of threads in the fabric. Relative cover with the weft and warp simultaneously determines the relative value of clearance: relative cover measures the air permeability of a given fabric. It was proven that fabrics made from different variants of the eccentric thread differ significantly as far as the relative cover with the weft is concerned. Similarly, fabrics that differed only in terms of weave differed also in terms of relative cover with the weft: the lowest values of relative cover with weft were shown by plain weave fabrics and the highest values of relative cover with weft were shown by basket weave fabrics. In turn, the statistical analysis did not show any differences in relative cover with weft and warp simultaneously in the case where the influence of the weave type was analysed.

Analogous research conducted in the case of the produced 9 course knitted fabrics that differed in type of the eccentric thread and stitch used: 3 RL knitted fabrics, 3 LL knitted fabrics and 3 RR knitted fabrics.

The research checked the significance of differences in:

- areal mass of the produced knitted fabrics: knitted fabrics made from different variants of the eccentric thread differed significantly in terms of the surface mass. The smallest surface mass characterised the knitted fabrics made with the use of the RL stitch and the biggest areal mass characterised the knitted fabrics made with the use of the RR stitch,
- the length of the thread in a loop. Knitted fabrics produced with the use of the RL stitch and the LL stitch from different variants of the eccentric thread showed a significant difference in the length of the thread in a loop. In turn, knitted fabrics made with the use of the RR stitch did not show significant differences in the length of the thread in a loop depending on the eccentric thread used. With the round shape of the loop (RL stitch and LL stitch), stiff effects of the eccentric thread caused a flattening of the arc,
- the coefficient of working-in of the eccentric thread. Stitch density, the type of the pro- cessed thread and its susceptibility to deflection decide about the value of the coefficient of working-in. We can distinguish course and wale take-up, calculated as the quotient of the length of the thread and the height of the course or the width of the wale. Knitted fabrics made from different kinds of eccentric thread were characterised by a lack of significant differences in course and wale take-up. Whereby, the lowest values of the course take-up were shown by the knitted fabrics made with the use of the RR stitch and the highest values of the course take-up were shown by the knitted fabrics made with the use of the LL stitch. An inversely proportional relationship was discovered in case of wale take-up: the lowest values of wale take-up were discovered in case of the group of the LL knitted fabrics and the highest values of wale take-up were

discovered in case of the RR stitch [Dziakiewicz H., *Własności nitki płomykowej oraz tkanin i dzianin wykonanych z tej nitki* (Properties of Eccentric Thread as Well as Woven and Knitted Textiles Made of It), Master's Thesis, Lodz University of Technology 2003, Supervisor: Grabowska K.E.].

7.2.2.3 Flame thread (slub thread)

Flame thread is another example of fancy twisted thread with point effects produced as a result of the introduction at regular time intervals of slubbing between two component threads twisted with each other. It has to be pointed out that in the case of the flame thread, apart form the effect there are two core yarns, which stabilise the construction of the decorative thread. The name of the thread comes from the intensive colour of the effect, which takes the form of segments of slubbing "thrown" between core threads. However, it is not a rule and many times a flame thread is characterised by a unicoloured, extended structure. Flame thread is produced with the use of the ring twisting frame method or the hollow spindle method. The core threads are fed on equal rights through the feeding rollers and guides to the twisting zone. In turn, the slubbing is fed by guides to the lifting rollers of the roller-apron drawing mechanism. As a result of variations in the rotary speed of the lifting, intermediate and delivery rollers, the slubbing is attenuated. The speed of the rollers of the drawing mechanism is computer-controlled, so at specified time intervals expending of slubbing, attenuated to a specific value, in the form of a tuft of staple fibres to the twisting zone takes place. In the twisting zone, i.e. inside the hollow spindle, twisting of the segment of slubbing inserted between two core spun yarns with filament thread reeled out from the hollow spindle takes place. Having passed through the whole length of the hollow spindle, all the components of the flame thread pass through a false twist hook and then, they are coiled around the taking-off rollers that take off the ready flame thread. Typically, the twisting-spinning frame with a hollow spindle is equipped with two drawing mechanisms, which enable it to feed alternately two slubbings that are different in terms of colour. A similar principle of production of flame thread applies in the ring twisting frame equipped with the drawing mechanism. Core yarns separated by a separating ring are fed to the shaft of the working beam into the grooves of the top roller and directly to the eye of the guide situated over the spindle. In turn, the slubbing is reeled off the package, fed into a funnel-shaped guide that guides the slubbing directly into the area between the grooves of the top roller. It means that the slubbing is fed directly between two core spun yarns even before the stage of twisting them into the form of a flame thread. If the pair of feed rollers II (delivery rollers) is spinning and, at the same time, feed rollers are halted, only core yarns without slubbing are fed into the twisting zone. The activation of the feed rollers causes the slubbing to be fed into the zone of the drawing machine and inserted between two core spun yarns. After the main process of creating the flame thread with the use of the ring twisting frame method, retwisting of flame thread with a filament thread occurs, which strengthens the designing effect. Stabilising twisting with the filament thread takes place with the use of a ring twisting frame in the direction reverse to the direction of twist of the flame thread. Stabilizing twisting, apart from stabilising the structure of the thread, aims at stabilising the twist so that the flame thread would not generate the snarl effect, while being reeled out from the package.

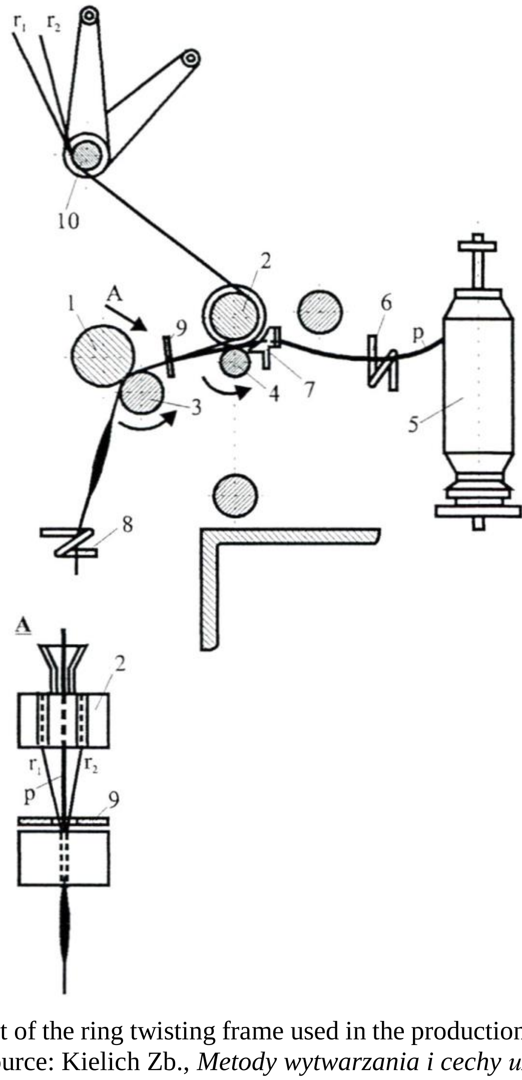


Fig. 71. Flow sheet of the ring twisting frame used in the production of thread fluffed with slubbing (source: Kielich Zb., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej napuszanej niedoprzędem* [Productions Methods and Functional Properties of Slub Fancy Yarn], Master's Thesis, Lodz University of Technology 1999 Supervisor: Grabowska K.)

There has been research conducted on the structure and properties of the flame thread (Kielich Zb., *Metody wytwarzania i cechy użytkowe przędzy fantazyjnej napuszanej niedo-przędem* [Productions Methods and Functional Properties of Slub Fancy Yarn], Master's Thesis, Łódź University of Technology 1999

Supervisor: Grabowska K.). Fifteen variations of the flame thread were produced that differed from one another in terms of linear density of the slubbing introduced between the core yarns and the twist generated between the core yarns. Statistical methods were used to analyse the influence of:

- the linear density of the slubbing on the breaking force of the flame thread:

  $y = -0.05x + 2074.9;\ R = -0.79$ (56)

  where:

  y – breaking force of the flame thread [cN],

  x – linear density of the slubbing [tex],

  R – coefficient of correlation.

  It has been concluded that an increase in the linear mass of the slubbing introduced be- tween two core yarns produces a slight fall in the value of breaking force of the flame thread. It is explained by a rule that a radical change in the thickness of the thread is where a potential thread breakage may occur.

- the twist of the flame thread on the force breaking the thread:

  $y = 0.73x + 1740.4;\ R = 0.9$ (57)

  where:

  y – breaking force of the thread [cN],

  x – twist of the flame thread [t/m],

  R – coefficient of correlation.

  A substantial influence of the value of averaged twist of the flame thread on the value of the breaking force of the thread was discovered. The rationality of the statistical model is explained by the rule that determines the increase in breaking force together with the increase in the twist of the thread, up to reaching the critical value of twist.

- linear density of the slubbing introduced between core yarns of the flame thread on the length of the breaking strain:

  $y = – 0.002x +21.6;\ R = – 0.73$ (58)

  where:

  y – strain of the flame thread,

  x – linear density of the slubbing [tex],

  R – coefficient of correlation.

Despite the fact that the significance of the influence of the linear mass of the slubbing intro- duced between core yarns was proven, the influence turned out to be minor and negligible.

- averaged twist of the flame thread on the value of the elongation of the thread:

$y = 0.02x + 15.6; R = 0.99$ (59)

where:

y – breaking elongation of the flame thread,

x – averaged value of the twist of the flame thread [t/m],

R – coefficient of correlation.

The significance of value of the averaged twist of the flame thread on the breaking elongation of the thread was proven. However, the influence of the twist of the flame thread on the elongation is minor, since an increase of one unit of twist of the flame thread causes an increase by 0.02 unit of elongation of this thread.

- linear density of the slubbing on the specific tenacity of the flame thread:

$y = -0.007x + 14.6; R = -0.97$ (60)

where:

y – specific tenacity of the flame thread [cN/tex],

x – linear density of the slubbing inserted between core yarns [tex],

R – coefficient of correlation.

Despite the significance of the influence of the linear density of the slubbing inserted between core yarns, the influence is negligibly small, since an increase in the linear density of the slubbing by one unit generates reduction in the tenacity of the flame thread by only 0.007 unit.

- averaged twist of the flame thread on the specific tenacity of the thread:

$y = -0.004x + 11.8; R = -0.71$ (61)

where:

y – specific tenacity of the flame thread [cN/tex],

x – averaged twist of the flame thread [t/m],

R – coefficient of correlation.

Similarly, the influence of the twist of the flame thread on the specific tenacity up to the breaking point is minor, since an increase by one unit of twist of the flame thread causes a fall in tenacity by 0.007 unit.

- linear density of the slubbing inserted between core yarns of the flame thread on the averaged final linear mass of this thread:

  $y = 0.16x + 129.4;\ R = 0.99$ (62)

  where:

  y – averaged final linear density of the flame thread [tex],

  x – linear density of the slubbing inserted between core yarns [tex],

  R – coefficient of correlation.

  The significance of the influence of the linear density of the slubbing introduced between core yarns was demonstrated: it is logically justified and the model built allows for a prediction of the variable descriptive value.

- averaged twist of the flame thread on the final linear density of the thread:

  $y = 0.22x + 139.8;\ R = 0.91$ (63)

  where:

  y – final linear density of the flame thread [tex],

  x – averaged value of twist of the flame thread [t/m],

  R – coefficient of correlation.

  The significance of the influence of the twist of the flame thread on the final linear density of that thread was demonstrated: an increase in the twist causes an increase in the linear density of that thread.

- linear density of the slubbing inserted between core yarns on the length of the designing effect of the flame thread:

  $y = 0.003x + 5.51;\ R = 0.99$ (64)

  where:

  y – length of the designing effect of the flame thread [mm],

  x – linear density of the slubbing [tex],

  R – coefficient of correlation.

  The significance of the influence of the linear mass of the slubbing on the length of the designing effect was demonstrated. Nevertheless, it was demonstrated that the influence of the change in the linear mass of the slubbing on the length of the designing effect is minor.

- averaged twist of the flame thread on the design effect of the thread:

  $y = 0.22x + 139.78;\ R = 0.13$ (65)

where:

y – length of the designing effect of the flame thread [mm],

x – averaged value of twist of the flame thread,

R – coefficient of correlation.

The minor value of the correlation effect proves there is no significant influence of the twist of the flame thread on the length of the designing effect of that thread.

- linear density of the slubbing on the distance between designing effects:

$$y = -0.005x + 17.14; R = -0.99 \tag{66}$$

where: y – distance between design effects [mm],

x – linear density of the slubbing [tex],

R – coefficient of correlation.

Despite the fact that statistically significant influence of the linear density of the slubbing on the distance between the designing effects was verified, the influence of the linear density of the slubbing on the distance between the effects is negligibly small.

- averaged twist of the flame thread on the distance between the designing effects of the flame thread:

$$y = -0.006x + 16.3; R = -0.9 \tag{67}$$

where:

y – distance between designing effects [mm],

x – twist of the flame thread [t/m],

R – coefficient of correlation.

The demonstrated statistical significance of the influence of the averaged twist of the flame thread on the distance between the effects causes a minor influence of the descriptive variable on the described variable.

- linear density of the slubbing on the thickness of the design effect of the flame thread

$$y = x + 1.17; R = 0.94 \tag{68}$$

where:

y – thickness of the designing effect [mm],

x – linear mass of the slubbing introduced between core yarns,

R – coefficient of correlation.

Significance of influence of the linear density of the slubbing introduced between core yarns was detected and it was demonstrated that an increase by one unit of linear density of the slubbing causes an increase by one unit in thickness of the designing effect.

- averaged twist of the flame thread on the thickness of the designing effect:

y = -0.002x + 1.46; R = -0.6 (69)

where:

y – thickness of the designing effect [mm],

x – averaged value of twist of the flame thread [t/m],

R – coefficient of correlation.

The significance of the influence of the twist of the flame thread on the thickness of the designing effect is negligibly small.

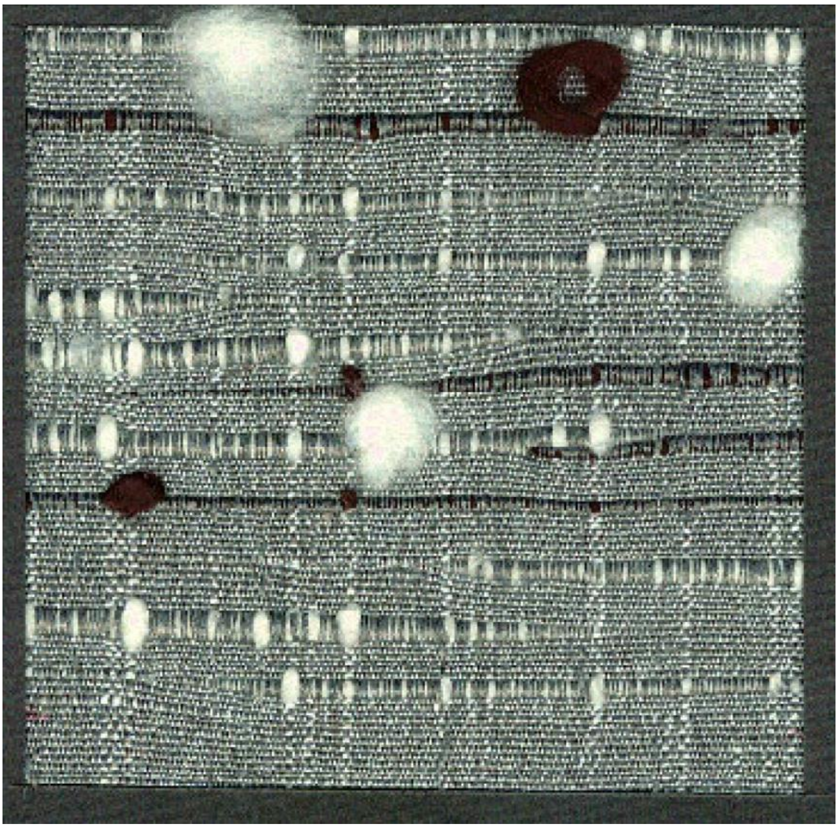


Fig. 72. Fabric made with the use of plain weave of slub fancy twisted yarn (source: Wójcik M., *Modelowanie faktur i własności tkanin wątkiem* (Modelling Textures and Properties of Fabrics with Weft), Master's Thesis, Lodz University of Technology 2003, Supervisor: Masajtis J.

8. Summary

The presented research results concerning the structure, properties and production methods of fancy threads do not exhaust the subject, not only because of the dynamic development of new research methods, but also because of the fact that almost every day new types of decorative threads are produced. It depends on the so-called creative fantasy or the designers' creativity. As has already been stated in the introduction to the present work, fancy threads, besides be- ing the creation of an engineer, are influenced by the designer to a large extent, as far as their properties and structure are concerned. The process of conscious creation of new structures of decorative threads requires engineering knowledge in the field of different spinning or twisting techniques. Furthermore, knowledge in the field of textile materials properties is necessary. In the case of consumers of ready-made textile products, above all, the appearance of the thread is crucial, and consequently, its colour, shine, uneven structure and thickness. From the producer's perspective, in turn, one of the decisive factors is the production turnout. The turnout is measured with the number of thread breaks during spinning, twisting, knitting or weaving. However, in the automatic world of computer-controlled machines, production stoppages that result from eliminating thread breaks do not occur, yet the great ends down of linear textile products determines the quality of products. Of course, the indicators that predispose the yarn to break are a group of parameters describing the mechanical properties of threads. This group include: the breaking strength, breaking force, elongation at break. All of those indicators are a derivative of the structure of thread and the type of textile raw material used in the production. As the indicators describing the structure of the decorative thread we understand its thickness, linear density, coefficient of thickness variability, direction of twist of single thread, coefficient of single thread twist variability and final twist as well as the number of component threads. It can be easily noted that the number of tools at the disposal of a textile engineer and thread designer is very big, the more so if one takes into account the number of possible combinations and potential correlations between all of the parameters listed above. The present publication brings the properties of decorative threads closer to the reader, not only in the context of mathematical relations, but it also defines the production strategy in the aspect of different possible settings of spinning or twisting machines. The preparation of this publication gave a lot of satisfaction to its author, since it made it possible to gather research material from the period of ten years of work and document the results of analyses in the form of a single monograph. The author is a textile engineer by education, which allowed for a development of statistical models of regression that characterise the properties of decorative threads. The need for an elaboration of research results in the form of technological recommendations stemmed from a lack of a cohesive compendium on that topic. The production methods used in the industry are the effect of many years of work of technologists in spinning mills. Undoubtedly, they are the greatest experts on the subject, thanks to all the years of practice. In the monograph, the author wanted to present a broad spectrum of possibilities of production of fancy yarns and decorative threads, which a conscious designer should use, while composing new, even more complex structures. The task is not easy if one takes into account the wide array of textile raw materials with diverse parameters that characterise their properties. In the present work, statistical models developed on the basis of a rich research material are presented. All statistical models were prepared for the full plan of experiments and they are reliable for a restrictive coefficient of reliability (0.05) and with a high correlation of variables. The models help one to understand the relations between the structure of decorative threads and various types of machines and settings that are characteristic of them. Such models, despite their high statistical reliability, should be used as a guideline as to the direction of changes that will take place in the output variable as a result of value change of the input variable, taking into account the pertinence of this influence as well (analysis of value of the parameter describing the input variable). The work also presents a proprietary classification of plied threads on the basis of mathematical models derived on the basis of the analysis of phenomena that occur during the drawing process up to the breakage of a plied thread. The characterised shape parameter of K thread describes well the structural changes that take place within the thread during the multiplication of the value of overfeed of the effect thread. The work also presents other classifications of decorative yarns and, as can be easily noted, in case of threads with point effects, those classifications are not fully authoritative, which results in blurring the answer to which group of decorative threads one should assign a given thread, in which, for example, the shape of the tuft is impossible to precisely describe with precision. Despite such deficiencies, the work clearly defines the limits of a key division between decorative yarns and fancy threads, the first of which are a result of the spinning process, while the latter one are an effect of the process of multi twisting of component threads with one another. The division between threads and yarns with continuous effects on the one hand, and threads and yarns with point effects on the other is clear as well. Only when one descends one step lower in this classification, there begin problems with a precise identification of threads. Problems at that stage stem from the diversity of creative possibilities of designers, both in terms of structure and properties of the raw materials used for the production of decorative threads. On the other hand, this diversity is a value that identifies the group of decorative threads as beautiful elements, comparable to jewellery, which are not introduced into the structure of a flat textile product in excess, but quite the contrary: as a note or phrase that systematically (or randomly) compromises the even structure of a given woven or knitted fabric. The work presents a rich photographic material that defines the use of decorative threads in the production of decorative woven or knitted textiles. Also, it characterises different weaves and stitches, which show the designing effect of decorative thread in different ways. Of course, apart from the type of weave characteristic of different types of woven textiles (e.g. plain, twill or satin weave as well as combined weaves) or type of stitch characteristic of different types of knitted textiles (e.g. course stitches: RR stitch, LL stitch, RL stitch, interlock stitch or wale stitches), the intensity of the introduction of decorative thread as weft is crucial from the point of view of the designer. The thesis that the decorative thread cannot dominate the structure of a flat textile product has been repeatedly proven right, because apart from the designing effects it defines also the stiffness of the fabric and its drapability, which is extremely important upon each subsequent process of designing fully fashioned garments.

The author hopes that the present monograph will allow people to understand the phenomena that take place during the process of creation of different decorative threads as well as facilitate work of designers in terms of creating new structures of woven and knitted textiles and clothing products in which decorative threads were used. Apart from the scientific and substantive side of work, it was the author's aim to emphasise the aspect of beauty of the creation process of new textile structures, which greatly strengthens the consumers' expectations within the scope of creating new fashion trends. Surely, the subject within this field has not been exhausted, but let this insufficiency remain an inspiration for the generations of artists, engineers and designers to come.

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