Influence of yarn count, yarn twist and yarn technology production on yarn hairiness

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Abstract: *Yarn hairiness is one of important yarn parameters, which is used for yarn production quality control. It is usually characterized by the amount of free fibers (fibre loops, fibre ends) protruding from the compact yarn body towards the outer yarn surface. The first question can be if hairiness is really important and why? The reason is obtaining deeper information about yarn structure and its changes during processing. Thanks to detailed knowledge it is possible predict to yarn behaviour and design fabric and textile products precisely in the way the customers demand. Yarn hairiness and its determining is important because it influences the post spinning operation and parameters of textile product (porosity, permeability, transport of moisture, comfort, aesthetic properties and hand). The main factors influencing hairiness are: type of fibres, yarn twist, yarn count, blending ratio, yarn technology production, approach to yarn hairiness observation and measurement condition. This paper concentrates on the influence of yarn construction parameter (yarn count, yarn twist) and technology of production (ring comb and carded, experimental and open end). In this case, the Uster Tester 4 and the new optical approach for yarn hairiness investigation is applied. Results for experimental sets of yarn will be shown.*

Key words: *Yarn hairiness, yarn diameter, yarn count, yarn twist*

Introduction

Yarn hairiness is an important parameter because it gives us the information about the arrangement and behaviour of fibre in hairiness sphere. The study of yarn structure and fibre arrangement allows to understand the spinning process deeply way and describe the yarn parameters changes during yarn processing. This information can be used for precise predicting of the yarn behaviour and designing the textile structures according to the customer's demand. Yarn is a compact complex, which can be intuitively divided in to two parts – core and cover. A strict border doesn't exist and therefore the hairiness can be characterized only in connection with using convention for yarn diameter as a periphery line of yarn surface. Number of fibres and packing density in compact part of yarn is higher than in hairiness area. The arrangement of fibres in yarn core is much better than in yarn cover. It is assumed, that in the compact yarn body mechanical rules are valid because of the number of contacts among the fibres and fibre mechanical properties (rigidity, friction, shape factor). By contrast, only probability patterns in the hairiness sphere are valid because of lower number of fibres. The arrangement of fibres is related to the technology of production, construction of yarn and type of fibre.

There are two yarn geometrical parameters influencing yarn hairiness significantly. It is yarn count and yarn twist. Helical model is usually used for describing idealized fibre assembly in yarn structure. During twisting of the yarn some fibres are displaced from their central position to the yarn surface (migration effect). The hairiness depends on fibres on the periphery layer of yarn. The distribution of hairs is related to the arrangement of fibre in yarn. The simplified convention is usually used for hairs definition. It is supposed that hairs have their ends in yarn body and the reversal fibre ends are neglected because of their scarcity.

It is generally accepted that hairiness increases when the yarn count increases and it decreases when yarn twist increases. The influence of yarn count is in connection with number of fibres in yarn cross-section. The probability of fibre occurrence in hairiness sphere is higher when the number of fibres in yarn cross-section is higher and that means higher yarn count. The hairiness sphere consists of short fibre ends, fibre loops and long flying fibres. The number of fibre loops represents the major part of hairs in case of cotton yarns produced by classical technology. The increase in yarn twist can reduce the number of fibre loops and their dimension. The fibre loops formation is affected thanks to forces action during sliver formation and yarn twisting [1], [2].

The influence of yarn technology production and its investigation is more complicated. There are a lot of factors, which can affect the fibre arranging, yarn structure and yarn parameters. The main factors, in case of classical ring spinning process, are type of production equipment, type of mechanism and it’s setting. Other factors are for example type, weight and shape of travellers, type and eccentricity of spindles, ring size, type of balloon separator and many others. Pre-spinning operation in terms of sliver and roving preparation is very important for classical spinning process. Higher number of draw-frame passages causes greater parallelization of fibres and reduction of hooks number. Higher differences in hairiness can be found out if the higher draft for obtaining optimal yarn count and twist level is necessary. The number of marginal fibres increases when the double roving is used as well as the higher draft has to be used for achieving the given yarn count and twist level. Greater draft leads to higher hairiness because of potential higher yarn mass irregularity. Type of drawing system and control of fibres influence the arranging of fibres. The new systems use the condenser for improving fibres control during drafting. These systems prevent the marginal fibres and reduce yarn hairiness. Carding as a step of classical spinning process influences hairiness because of reducing short fibres and better arranging of fibres. The distribution of fibre length is more uniform after this operation but long fibres on the surface can influence the occurrence of long flying hairs.

The influence of open-end spinning system on yarn hairiness was studied by many researches. This type of yarns is less hairy than classical ring yarns. The nature of this phenomenon is hidden in the different structure of open-end yarn. The fibres are better controlled inside the rotor as far as possible. For this reason, in this type of yarn, short fibre ends predominate over long hairs and the structure and dimension of fibre loops is more closed. Belt fibres, more closed and disordered internal structure are characteristic for these yarns. Main factors influencing hairiness are: rotor surface, its diameter and speed. The accumulation of impurities in rotor during spinning of yarn is problematic, mainly in case of using cotton and other natural fibres. This difficulty influences yarn hairiness, it causes the increase of yarn end-breakage, decrease of yarn abrasion resistance as well as decrease of yarn tensile strength [1].

Methodology for yarn hairiness observation

In the last few years, yarn hairiness has attracted increasing practical interest because of the commercialisation of some instruments that enable it to be measured. There exist a lot of physical principles for observing yarn hairiness (optical, photographic, and photoelectric methods, methods based on the application of laser rays, etc.). The otherness among the methodology is in connection with various approaches to yarn detection. The way of yarn profile obtaining is related to demandingness of measuring equipment, various parameters used for yarn hairiness describing (cumulative index of hairiness H, length of hairs L_i or number of fibres in length category defined as a distance from yarn body N_i, ...) and differ precision of results. The measurement precision and possibility of using results for prediction is related to measured length of yarn and ability of detection device.

There are two approaches commonly implemented to commercial instruments. The first type of testing devices observes only the sphere of hairiness and the output is the number of hairs in length category or an index based on this information. The advantage is the information about hairs length distribution. An example of this type of instrument is Zweigle hairiness tester. Criter Dum II, Shirley hairiness Meter, Hairiness Counter and Toray F index tester, gives similar information. The other type of testing equipments observes the yarn as a complex for example its longitudinal profile and the output is cumulative hairiness index. Uster Tester and analogy system Premier Tester 7000 are well known. The additional information like yarn diameter and yarn unevenness can be obtained optically for example thanks to Kaisokki Laserspot LST.

Each type of instruments has its own limitations. The Uster tester with additional hairiness sensor, Premier Tester 7000 and Kaisoki Laserspot give nothing more than a cumulative scalar characteristic, but it is possible to obtain raw data of measurement from the hairiness diagram. The Zweigle hairiness tester and Criter Dum II neglect the presence of hairs near the yarn surface but S_3 value give the information about the hairs exceeding the 3mm length. Both of outputs omit the important spatial information.

The reason of yarn hairiness measurement is related to the way of judgement and evaluating this parameter. The cumulative characteristic is sufficient in case of routine testing for quality control. From the point of view of suggesting the complex criterion based on yarn geometrical and mechanical properties, which is used for yarn usability assessment for given kind of textile application, the cumulative parameter is more advantageous. Detailed information describing the yarn is essential for studying the yarn structure and it is important for more precise prediction of yarn behaviour.

Professor Neckar introduced an original theoretical model of hairs distribution and a new methodology for yarn hairiness determination was found and firstly presented in about 2000 [3, 4, 5]. Since that time, the measurement methodology and the way of data processing was modified. This approach to the yarn hairiness assessment allows us to obtain deeper information about two significantly different components of hairiness. Data are processed relatively easily but the time for testing is too high for practical using. On the other hand this method can be prepared for using in practice. The methodology will be described only basically. The last version of data processing is precisely explained in [6].

Experimental technique is based on scanning images of yarn longitudinal view by the special equipment developed by Laboratory Imaging. Imaging system consists of CCD Camera, microscope or macro scope, optical fibres lighting and PC. A special device allows to set the yarn under the microscope or macro scope and to move the yarn manually. After capturing and saving 800 colour images, these files are processed in Matlab programming language. Colour images are transformed through grey-scale to binary image by using suitable threshold [7]. The next step is determination of yarn axis. The histogram of occurrence "yarn" pixels is used for the first estimation of yarn axis position. Problem is with loops and wild fibres near the yarn body, which enlarged the yarn body. Therefore fibres belonging to hairiness sphere are eliminated by morphological operation. Yarn axis is marked as a middle pixel of longest pixels area of yarn body. When the difference between the first and the second axis estimation are higher than the used convention, the first estimation is used.

Dissimilarities between estimation of yarn axis position are caused by the algorisms of erosion.

Hairiness function as an experimental curve is determined as a relative frequency of “yarn” pixels occurrence. It is possible to determine four parameters describing the internal yarn structure. These parameters are obtained from the experimental results using statistical regression technique and mathematical optimisation by applying double exponential Neckar’s model. In addition to the function representing “total” hairiness, it is also possible to obtain two other functions representing the two significantly different hairiness components. The first component of hairiness can be formed from small fibre loops or short fibre ends etc. It takes a high value near the yarn surface, but it decreases quickly with the distance away from the yarn surface. These hairs influence comfort properties of textiles (hand value, etc.) and they are called “dens” hairs. The second component of hairiness, which may be formed from relatively long fibre ends, often creates troubles in post-spinning operations (winding, weaving, etc.). The second component does not take a high value near the yarn surface, but it decreases more slowly with the distance away from yarn surface and the long hairs are called “loose” hairs. The integral characteristics indicate the areas under the hairiness curves integrated from yarn radius. The area under the total hairiness curve is marked as $I_{c\ dens}$, and areas under “dens” and “loose” component curves are marked $I_{1\ dens}$, $I_{2\ dens}$. The procedure for finding yarn diameter used two conventions. There are the cover and the dens convention and the second one is more preferable because it takes the mechanical interaction among fibres in yarn into consideration. Yarn cover diameter is defined as a double distance from yarn axis corresponding to 50% of hairiness function. For determining yarn dens diameter respectively yarn dens radius from the hairiness function the convention that yarn packing density is equal to 0,11 is used (for more information see [3]).

Experimental results

The relation between yarn structure and technology of production can be found thanks to laboratory analysis of yarns. This article concentrates on the relation among yarn hairiness, yarn geometrical parameters and technology of production. The idea of this experiment was to prepare yarn by various technologies in comparable condition with similar geometrical parameters from the same material in order to eliminate influencing factors. Practically, it is a little bit problematic because of the nature of spinning process. The advantage of open-end spinning technology is the shorter pre-spinning process without roving preparation and possibility of producing quality yarns from less quality fibres. Demands on the cotton fibres for classical spinning technology are higher in terms of fibre length, maturity ratio, fibre fineness and uniformity of these parameters. Open-end spun yarns can be produced at the same level of quality from not so costly fibres. Yarns for our experiment were produced from the same material (cotton mixing) in respect to the technology. It means that each yarn counts in each level of yarn twist coefficient for given yarn technology was prepared from the same cotton fibre mixing. From the point of view of pre-spinning operation, in case of classical and experimental technology, the sliver was prepared in respect to the range of yarn count. The number of draw-frame passages was applied according to the given yarn count. It was higher for finer yarns and lover for coarser yarns.

A set of 100% cotton yarns was used for the experiment. The yarns were produced thanks to cooperation with the university IIT Delhi India and Textile Research Centre of Cotton Fibres Czech Republic. A set of classical ring yarns was spun with five levels of yarn count (14,5tex, 19,5tex, 25tex, 29,5tex, and 37tex) and three levels of T. M. twist coefficient ($3{,}7\mathrm{Ne}^{1/2}\mathrm{in}^{-1}$, $4\mathrm{Ne}^{1/2}\mathrm{in}^{-1}$ and $4{,}3\mathrm{Ne}^{1/2}\mathrm{in}^{-1}$) in two variants – combed and carded. A set of open-end yarn was spun with five levels of yarn count (14,5tex, 20tex, 35,5tex, 50tex and 72tex) and three levels of Phrix twist coefficient (70ktex$^{2/3}$m^{-1}, 85ktex$^{2/3}$m^{-1} and 100ktex$^{2/3}$m^{-1}). The new technology Novaspin was used for producing the set of combed yarns with five levels of yarn count (7,4tex, 10tex, 12tex, 16tex and 20tex) and three levels of Phrix twist coefficient (38 ktex$^{2/3}$m^{-1}, 56ktex$^{2/3}$m^{-1} and 81ktex$^{2/3}$m^{-1}). This new experimental technology is based on classical spinning process, only the production is higher and it can be compared to production of open-end spinning technology. The influence of yarn count, yarn twist and technology of production was observed and the relation among the hairiness parameters and geometrical characteristic is shown in figures. The generally known results were established. The increase of yarn count is followed by hairiness increase and the increase of yarn twist coefficient causes the decrease of hairiness. The relation between hairiness parameters and yarn twist are shown because of the nature of T. M. twist coefficient definition. This type of coefficient isn't constant for the whole range of yarn count.

The figure 1a shows the relationship between cumulative hairiness index *H* and yarn count *T* together with 5%, 50% and 95% qualitative lines of Uster Statistic. Experimental points of open-end yarns are placed in the area delimited by 5% and 50% quality lines. Hairiness of classical combed and carded yarns are comparable to 50% of world yarn production. Hairiness of experimental Novaspin yarns is comparable to classical yarn in two levels of twist coefficient. Yarns produced by the lowest twist coefficient are more hairy than the classical yarns. The figure 1b shows the relation between cumulative hairiness index *H* and yarn twist and it can be seen that hairiness of experimental Novaspin yarn decrease more quickly than classical yarn and the hairiness decrease of open-end yarn is very slow.

The dependence of integral hairiness characteristic and geometrical parameters of yarn is shown in figures 2, 3 and 4. Figures 2a, b describing the relation between "total" hairiness characteristics and geometrical yarn parameters give similar results as figures 1a, b. Typical trends for all types of yarns can be found but the open-end yarn trend is a little bit dissimilar. The figures 3 and 4 give interesting information about fibre segments arrangement. The dependent variable in figure 3a, b is the first component of hairiness and it can be seen that the trends of open-end yarn are the highest. It means that this type of yarns has the highest number of short fibres and closed fibre loops on the yarn surface in comparison with other tested yarns. Yarn count is a significant factor influencing hairiness in case of combed and carded classical yarns and open-end yarns. The significance of yarn count influence in case of experimental Novaspin yarn is lower. The reason can be the smaller steps in yarn count and the preparing of yarn thanks to prototype device. The twist coefficient is a less significant factor in case of open-end yarn and the solution of this phenomenon is hidden in structure of these yarns. The influence of yarn count and yarn twist on the second hairiness component is shown in figures 4a, b. The occurrence of long fibres and more open fibre loops is affected by the geometrical yarn parameters changing only in case of combed and carded classical yarns and experimental Novaspin yarns. The influence of yarn count and yarn twist changing is less significant in case of open-end yarn.

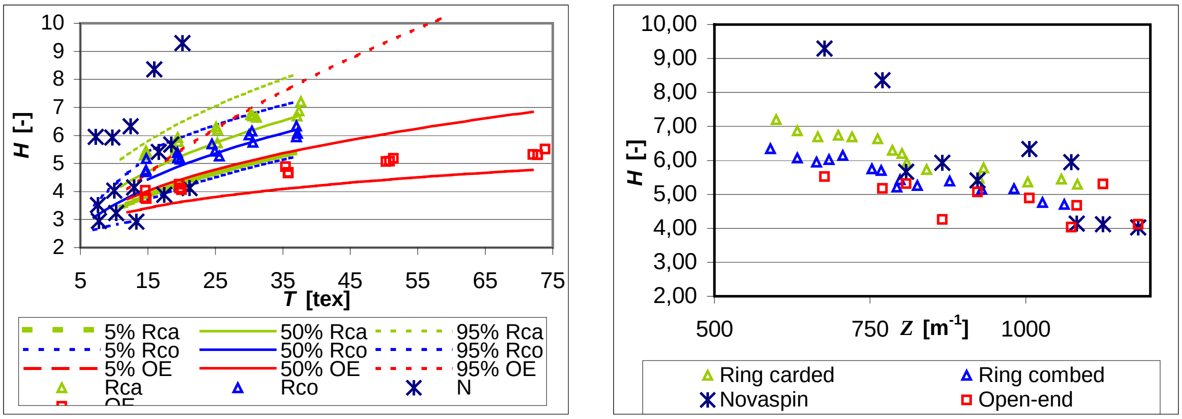

Fig. 1 a, b: Relation between cumulative hairiness index and geometrical yarn parameters

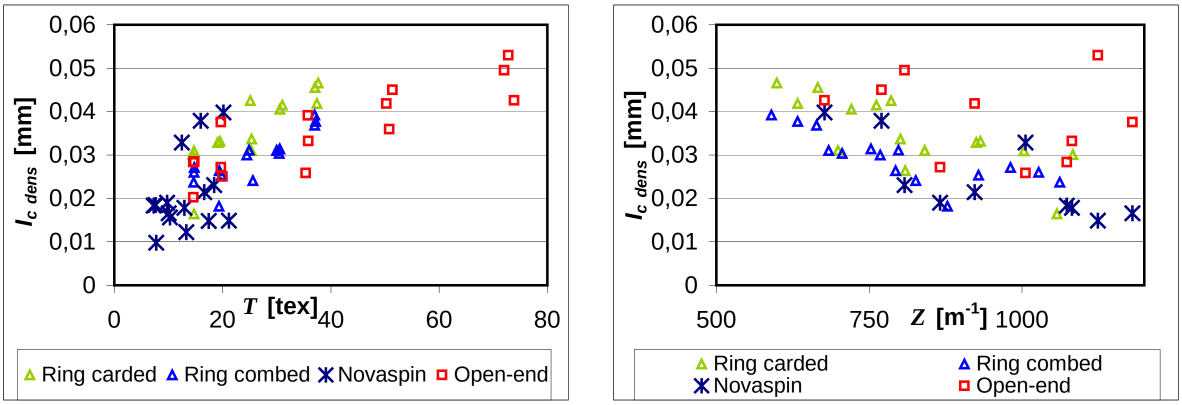

Fig. 2 a, b: Relation between integral characteristics and geometrical yarn parameters ("total hairiness)

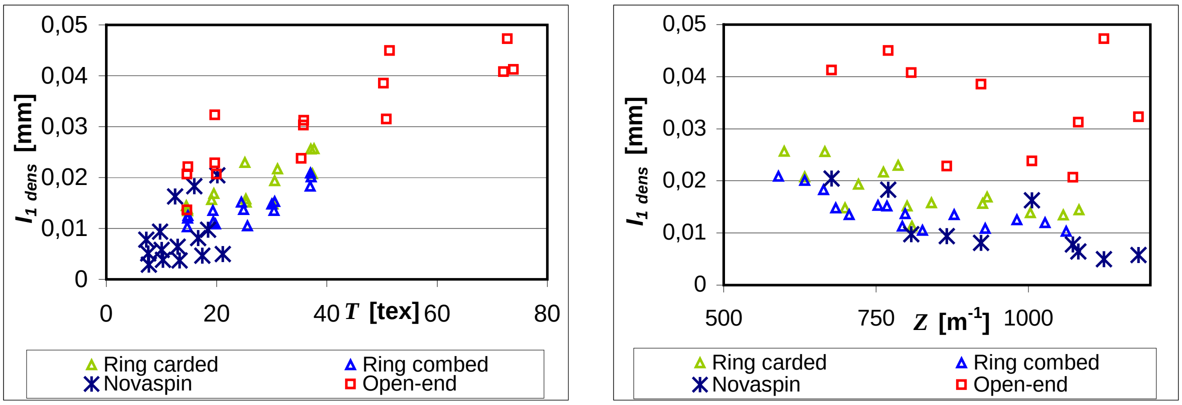

Fig. 3 a, b: Relation between integral characteristics and geometrical yarn parameters (first component of hairiness)

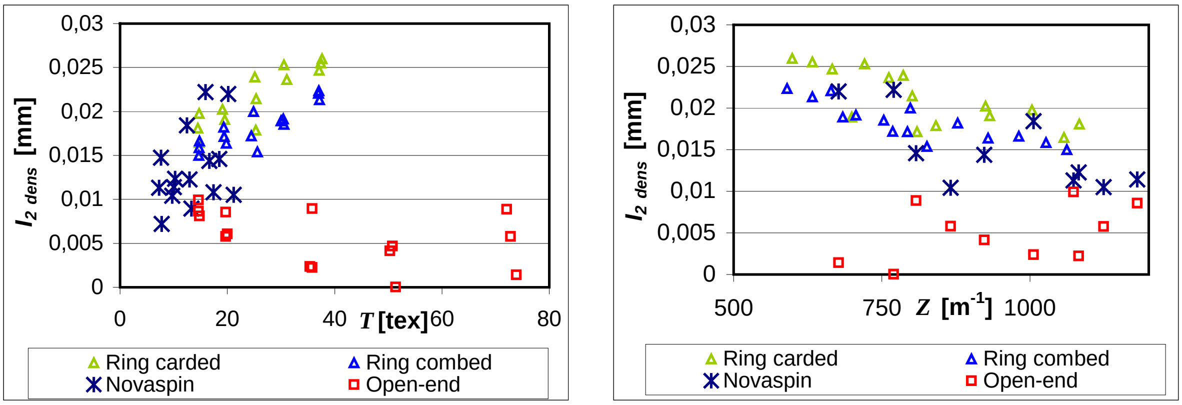

Fig. 4 a, b: Relation between integral characteristics and geometrical yarn parameters (second component of hairiness)

Thanks to multivariate data analysis it was found that the yarn count, yarn twist and technology of production are important factors influencing yarn hairiness. The standard or powerful statistical methods allow the prediction model creation. This approach is limited in case of hairiness parameter prediction because of factor mutually connection (multicolinearity), factor limited range and proper selection of technological yarn creation parameters (interdependence yarn count, yarn twist).

Multi-regression models, which take these factors into consideration, for all types of yarns can be established in following forms $Hairiness=aT+bZ+c$, $Hairiness=aZT+b$, $Hairiness=aZT+ bT +cZ+d$, $Hairiness=aT+ b$, $Hairiness=aZ+ b$. The first type of model neglects the relation between these two geometrical parameters. The second model is based only on the type of yarn forming (twist coefficient). The third version of prediction model assumed that the influence of yarn count and yarn twist is complex. The last two models omit the influence of the second factor. Specific coefficient *a*, *b*, *c* used for prediction of yarn hairiness can be find for complex hairiness index *H* and integral hairiness parameter $I_{c\ dens}$, $I_{1\ dens}$. The estimation of the second component of hairiness $I_{2\ dens}$ is less reliable. The MEP and Acaice criterion of regression was evaluated together whit multi-regression coefficients, regression coefficient and regression prediction coefficient. Multi-regression coefficients are higher than 80% and the regression coefficients of determination are higher than 65% in cases of ring and open-end yarns by using the first three model variants. Hairiness prediction of Novaspin yarns is problematic because of its higher variability. Higher variability of experimental yarn can be connected with the system, these yarns was prepared on prototype device, which was firstly tested. Better results are obtained by the four equation, because the regression coefficients are higher than 95%, the regression coefficients of determination are higher than 85% - 90% a prediction correlation coefficient is about 75% - 80% in case of ring and open-end yarns. The comparison among the experimental and predict integral parameters is shown in figures 5a, b and 6. It can be summarized that the regression model can be successfully applied for combed and carded yarn as well as for open-end yarn in case of the “total” and the first component of hairiness prediction. The summarization of prediction model for estimation cumulative hairiness index *H* and total integral hairiness characteristic $I_{c\ dens}$ are shown in the table 1 and 2. Selected models whit better prediction ability are marked bold.

Tab. 1: Summarization of prediction model for cumulative hairiness index *H*

N	R	R^2	R_p	MEP	AIC	estimation of a	estimation of b	estimation of c	estimation of d
1	**0,8969**	**0,8044**	**0,4342**	**1,1671**	**1,9754**	**-0,0005**	**0,5140**	**0,0015**	**3,7124**
2	0,8154	0,6649	0,1724	2,0013	8,0544		-0,0041	-0,0071	9,9054
BD									
1	0,9921	0,9842	0,9249	0,0129	-70,5066	0,0000	0,0094	-0,0009	4,8569
2	**0,9903**	**0,9808**	**0,9323**	**0,0116**	**-69,5668**	**0,0135**	**-0,0008**	**4,8656**	
3	0,9551	0,9123	0,7769	0,0400	-48,7931		0,0261		3,6367
P combed									
1	0,9535	0,9091	0,6412	0,0476	-49,4426	7,1306	0,0000	0,0352	-0,0022
2	**0,9513**	**0,9050**	**0,6635**	**0,0443**	**-50,7775**		**0,0122**	**-0,0027**	**7,3863**
3	0,9160	0,8390	0,6136	0,0518	-44,8608		0,0569		4,0943
P carded									
1	0,9659	0,9330	0,7719	0,0442	-47,6862	-0,00005	0,0603	-0,0017	6,9598
2	**0,9635**	**0,9283**	**0,8041**	**0,0376**	**-48,6800**		**0,0326**	**-0,0022**	**7,1611**
3	0,9493	0,9013	0,7596	0,0468	-45,8770		0,0713		4,3432

Tab. 2: Summarization of prediction model for total integral hairiness characteristic $I_{c\,dens}$

N	R	R^2	R_p	MEP	AIC	estimation of a	estimation of b	estimation of c	estimation of d
1	**0,8247**	**0,6802**	**0,1626**	**0,000045**	**-151,4068**	**-0,0000024**	**0,0026**	**0,000010**	**0,0090**
	0,7290	0,5315	0,0621	0,000057	-147,6797		0,0001	-0,000016	0,0391
2	0,3979	0,1583	0,0300	0,000089	-140,8929		0,0008		0,0105
BD									
1	0,8661	0,7501	0,2474	0,000044	-152,9949	0,0000003	0,0002	-0,000004	0,0228
2	0,8601	0,7397	0,2944	0,000040	-154,3856		0,0004	-0,000001	0,0231
3	**0,8596**	**0,7389**	**0,4237**	**0,000030**	**-156,3384**		**0,0004**		**0,0209**
P combed									
1	**0,8984**	**0,8071**	**0,5085**	**0,000009**	**-172,5442**	**-0,0000021**	**0,0020**	**0,000033**	**-0,0051**
2	0,8403	0,7061	0,3487	0,000013	-168,2323		0,0007	0,000004	0,0092
3	0,8396	0,7050	0,3771	0,000012	-170,1715		0,0006		0,0142
P carded									
1	0,8098	0,6558	0,1131	0,000041	-153,4425	0,0000005	0,0006	0,000001	0,0080
2	0,8080	0,6529	0,1750	0,000036	-155,3164		0,0060	0,000910	0,00001
3	**0,8070**	**0,6512**	**0,2838**	**0,000029**	**-157,2469**		**0,0008**		**0,0149**

From the point of view of yarn complex hairiness index *H* prediction, the Uster Static can be used, but this regression equation is build only in respect to the yarn count. This type of model gives the sufficient result from the point of view of prediction ability. The other way of hairiness prediction is using Neckar’s model, which takes into consideration type of fibre in terms of fibre equivalent diameter, the internal yarn structure and the characteristic parameters of yarn (half decrease interval of number of protruding fibres, packing density of hairs).

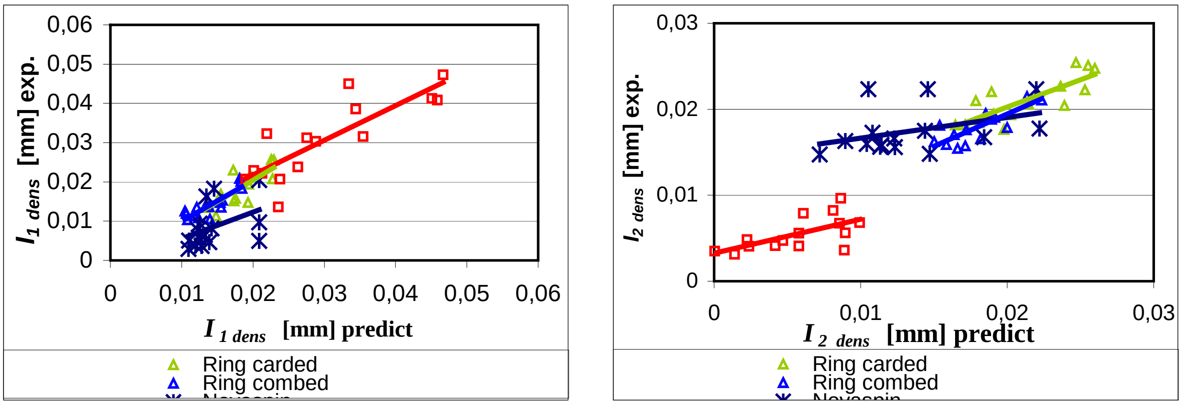

Fig. 5 a, b: Relation between experimental and predict integral characteristics (the first and the second component of hairiness)

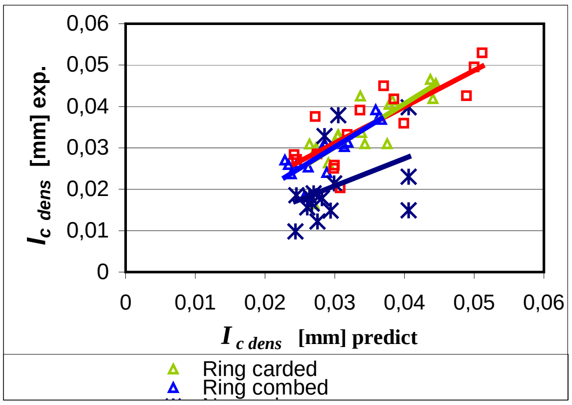

Fig. 6: Relation between experimental and predict integral characteristics („total“ hairiness)

Conclusion

The main aim of this article was to verify the influence of geometrical parameters and technology of yarn production on yarn hairiness. The Uster Tester and the new optical methodology based on scanning longitudinal view of yarn were used. The generally known results could be expected. The hairiness increases when the yarn count increases and yarn twist coefficient decreases. The open-end yarns are less hairy than the ring or experimental yarns. Hairiness of carded ring yarn is higher than hairiness of combed ring yarns. Experimental Novaspin yarns produced by low twist coefficient show higher hairiness than ring yarns. This phenomenon can be advantageous for some kinds of using where the open and bulky structure is demanded. It can be summarized that open-end yarn has characteristic closed structure with belt fibres and smallest hairiness. Disordered internal structure usually leads to the smallest strength. The ring yarn has more arranged structure with higher hairiness and maximal strength. The experimental yarns have similar internal structure as ring ones. The main differences are in hairiness and looser arrangements in subsurface layers resulting in slightly lower strength.

The interesting information was obtained thanks to Neckar’s model. The double exponential model of yarn hairiness was applied to the experimental hairiness curve and the information about two hairiness components was obtained. Open-end yarns have the highest number of fibres and the closed fibre loops on the surface. This fact corresponds with the structure of open-end yarn. From the point of view of yarn hairiness prediction it is possible to find the typical trends for all tested yarn sets. The hairiness prediction, of experimental yarns is less reliable and the solution is preparing additional set of these yarns. The regression model based on geometrical parameters (yarn count, yarn twist) or the Neckar’s model can be successfully applied.

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