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Comparative Analysis of the Ring Spinning Process, Both Classic and Compact: Theoretical Reflections. Part 1: Elaboration of the Statistical Model Based on Multiple Regression

Abstract
The analysis of the parameters of the spinning process was conducted of the quality of the yarn and the efficiency of the production, and it was confirmed that the percentage of noils and the metric coefficient of the twist were important factors. The analysis of the simultaneous influence of both factors on the chosen properties of classic cotton yarns, and of the nominal linear density 20 tex of compact yarn, was conducted by means of statistical models based on multiple regression, after conducting two total experiments of the type 5×5. The verification of proposed models will be presented in the second part of the article.

Key words: *classic yarn, compact yarn, percentage of noils, twist factor, Rieter company spinning plan, total experiment, double classification, multiple regression.*

Introduction

Until the early 60s, the main type of spinning machines were ring spinning frames, which were used in all types of spinning systems. In the 70s, open end spinning was developed, mainly rotor spinning, with reference to cotton and cotton-like yarns [10]. However, ring spinning frames are still competitive in relation to rotor spinning machines, and in some systems they are impossible to replace [10]. The barrier to technological progress in the ring spinning system, is the necessity of keeping the rotational motion of the bobbin in order to twist the yarn. Consequently, the values of the bobbin and the speed of the spinning, result in the rate of production being limited [10, 12]. In the mid 90s, the unsatisfactory structure of the O-E yarn made of short fibres, cotton and cotton-like fibres, reversed the trend in developing new designs of machines. The specific character of the ring spinning system forced the machine producers to develop new techniques to improve the quality, even if lowering the rate of production [1]. In the classic type of spinning system, while twisting the stretched sliver, a spinning triangle of considerable dimensions occurs, causing great hairiness and also strength. Further development of ring spinning was adjusted to decrease the spinning triangle by using other systems, including the compact system [32].

Factors which were introduced led to the rise of new techniques in spinning, in particular, the ring compact technique. Tests focused on compact spinning were being carried out in foreign countries [3, 26 – 28, 35, 36] and in Poland [4, 5, 11, 13 – 18, 21, 22, 39].

The technological identification of ring spinning, both classic and compact

one of the factors essentially connected with the quality of the yarn, as well as the efficiency of the spinning process, is the spinnability of fibres, and many working parameters of the spinning machines are applied in the individual technological operations [12]. However, there is also a group of technological parameters which are characteristic to the individual technological operations of the spinning process [12, 23].

In the case of combers, the characteristic parameters are the length of the linear feeding – F, and the sorting zone – S, directly influencing the percentage of noils – p_w. The percentage of noils is directly dependent on the length of the sorting zone. This determines the length of fibres combed out from the sliver, and thus influences the efficiency and the quality of the combed sliver, and the percentage quantity of noils. The size of the sorting zone also indirectly influences the production of the comber because, with the enlargement of the zone, the efficiency of the combed sliver changes. Following traditional symbols applied in the textile industry, the term percentage of noils – p_w in % will be used in the rest of the article.

The percentage of fibres removed from the noils influences the tenacity of the combed cotton yarn [12]. However, investigations relating to the simultaneous influence of the number of twists and the percentage of noils on the physical proprieties of analysed yarns were not carried out. The metric coefficient of the twist of roving, and parameters which are crucial to the composition of the roving package, are characteristic technological parameters in the case of the roving frame. The characteristic technological parameters of the work relating to the ring spinning frame are the metric coefficient of the twist of the yarn – α_m, and parameters which are crucial to the composition of the yarn package. The coefficient – α_m is one of the innumerable parameters influencing the quality of the yarn, particularly its strength, and the efficiency of the spinning process. The parameters mentioned determine this if the yarn is designed to the weaver's aims, if the yarn is to be knitted, and also if it is to be hand knitted. The metric coefficient of the twist of the yarn – α_m directly influences the efficiency of the spinning process [23].

In the opinion of L. Beltran, L. Wang and X. Wang, [2] the size of the ring, the mass of the traveller, and the rotary speed of the spindles, influence the spinnability and the physical proprieties of ring spun yarns. It was confirmed in the cited reference, that the most important parameters influencing the quality of the produced yarn and the efficiency of the spinning process are p_w and α_m. Enumerated pa-

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rameters were used in the design of the plan of the experiment. In order to fulfil the requirements of the comparability of both techniques of ring spinning, i.e. classic and compact, the remaining parameters, including both kinds of applied fibres, their physical proprieties, and the settings for the work of spinning frames, were accepted as constant sizes.

Design of the plan of the experiment

The forecast of spinnability and the physical proprieties of yarns can be carried out using mathematical formulas, based on the theoretical and physical knowledge of the process. The comprehensive information about the process itself in this case, accessible through the possibility of using physical, chemical, and mechanical equations, gives the user a thorough insight into its course. However, as a result of the huge size of the input vectors and the exit vectors, relating to the process of the production of yarn and its interactions, the exact mathematical model of spinning frame has not been worked out so far, and it is hard to believe that such a model will ever be constructed [33].

Analysis of published reports [24, 30], proves that one can also carry out programming of investigations enabling modelling of the process of spinning, using the statistical model relating to statistical regression. The programming of investigations relating to linear regression, enabling analysis of the separate influence of every one of the factors, has small advantages and is insufficient [30]. The definite change of a labile entrance only makes sense when it is considered in connection with a different labile entrance [25]. The danger exists that the separate investigation into the influence of the elimination of an individual labile entrance can, thanks to the lack of significance, affect the analysed process or phenomenon *a priori*. However, when they are considered simultaneously, they can then turn out to be essential [25]. Analysis of published reports also indicates that the programming of investigations enabling modelling of the spinning process, can also be carried out using statistical models based on statistical regression. The programming of investigations based on linear regression, enabling assessment and analysis of the separate influence of every one of the factors, has small advantages and is insufficient [30]. Changes of the definite input variables only make sense when they are considered in connection with different input variables [25]. The danger exists that the separate investigation of the influence of individual input variables, can cause their elimination *a priori*, thanks to the lack of significance. On an analysed process or phenomenon, however, when they are considered simultaneously, they can then turn out to be essential [25]. In the case of the programming of investigations with the use of orthogonal regression, the configuration of the matrix of the experiment has to be programmed in such a way that the values of the input variables distribute themselves along the main diagonal of this matrix, or after the block of these diagonals [6]. Orthogonal regression is useful to investigation cases enabling analyses of the simultaneous influence of many factors on the size and physical proprieties of yarns. By using this, one can formulate orthogonal equations of the regression, determine the coefficients of the correlation, and estimate their significance. Orthogonal regression also allows the determination of the intensity of the influence of individual input variables on the size of the studied feature. However, orthogonal regression has a series of disadvantages [6, 37].

One can also carry out the programming of investigations enabling modelling of the spinning process using multiple regression, and designing appropriate plans of the experiment. Taking these considerations into account, it was decided that the description of the correlation between the parameters of the spinning process, represented by the metric coefficient of the twist -α_m, the percentage of noils - p_w, and the physical proprieties of yarns, the multiple regression method will be applied, and *a posteriori* the use of linear square polynomials:

$$\begin{aligned}\hat{Y}_i = B_0 + B_1 \cdot \alpha_m + B_2 \cdot p_w + \\ + B_{11} \cdot \alpha_m^2 + B_{22} \cdot p_w^2 + B_{12} \cdot \alpha_m \cdot p_w\end{aligned} \quad (1)$$

where:

$[B_0; B_1; B_2; B_{11}; B_{22}; B_{12}]^T$ – the vector of the coefficients of the function of the regression,

$\hat{Y}_i$ – the value of the function of the regression calculated for *i*, the physical parameter of the yarn.

Two total experiments of the type 5 × 5 were conducted, with the aim of accomplishing the profound penetration of the space of input sizes, comprising 50 tests altogether (see ***Figure 1***).

Design of an adequate plan of the spinning, making it possible to carry out the total experiment

The plan of the spinning of cotton yarns, both classic and compact, was introduced in the form of the flowchart in ***Figure 2*** (see page 22). The experiment was divided into two parallel phases, making 50 tests altogether.

Subject of examinations

The object of the investigations was combed cotton yarns, both classic and compact, with linear density of about 20 tex. These yarns were produced in the spinning factory Zawiercie S.A. in Zawiercie city [39]. The raw material used in this experiment was average-fibrous cotton Strict Midling about $1^{3/32}$ “ ÷ $1^{1/8}$” in length and 144 mtex ÷ 157 mtex in thickness.

Methods of the analysis of experimental data

Basic statistical parameters were assigned to every analysed physical parameter of the yarn, including average value, stand-

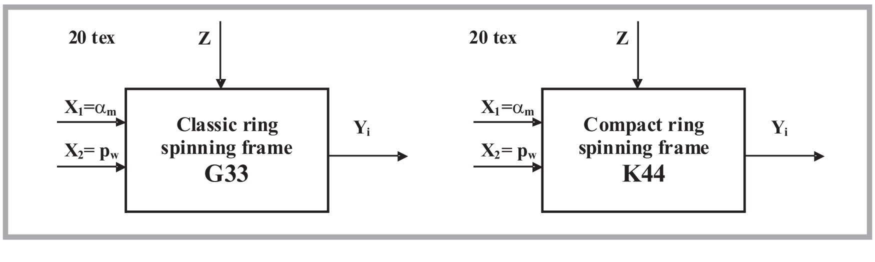

Figure 1. *The total experiment 5 × 5 applied to the investigations of physical properties of analysed yarns [39].* ***Legend:*** $X_1 = \alpha_m = [90\ 100\ 110\ 120\ 128]^T$, $X_2 = p_w = [8\ 10\ 14\ 18\ 20]^T$ *(%),* Y_{11} *– coefficient of mass variation –* CV_m, Y_{12} *– hairness of the yarn – H,* Y_{13} *– number of thins per 1000 m of yarn – thins*$_{-50\%}$, Y_{14} *– number of thicks per 1000 m of yarn – thicks*$_{+50\%}$, Y_{15} *– number of neps per 1000 m of yarn – neps*$_{+200\%}$, Y_{16} *– breaking tenacity –* R_H, Y_{17} *– breaking elongation –* ε_r, *Z – non-measurable disturbances of the spinning process.*

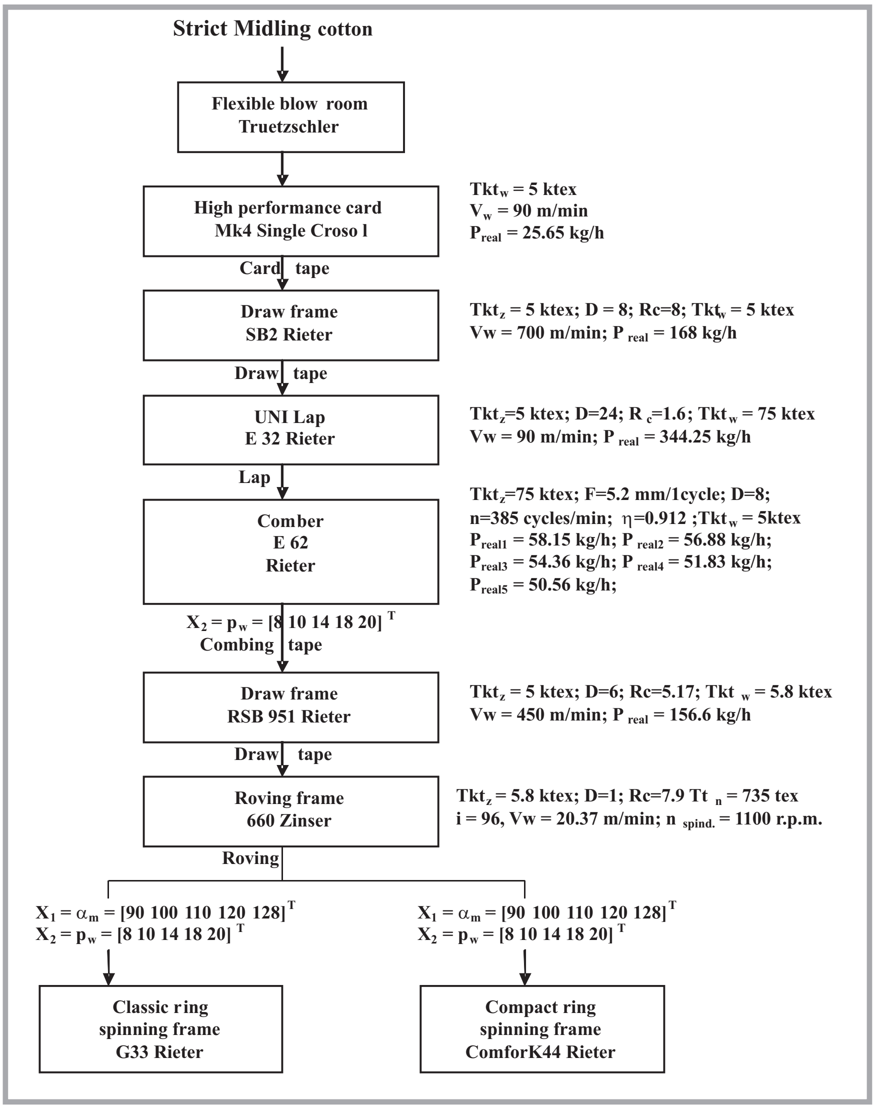

Figure 2. *Plan of the spinning of cotton yarns, both classic and compact [39].* ***Legend:*** *Rc – total draft, D – doublings, T_{ktz} – linear mass of slivers (ktex), V_w – the linear speed of the machine (m/min), n_{spind} – the rotating speed of spindles, P_{real} – real productivity per machine, F – linear feed (mm/1 cycle), η – efficiency, i – the number of outlets (delivery points).*

ard deviation and the coefficient of variation. In order to carry out a comparative assessment of the physical proprieties of classic cotton yarns produced on a ring spinning frame G33, with compact yarns produced on a spinning frame K44, absolute and relative differences of the average values of individual parameters were calculated. The processes of the production of the yarn on ring spinning frames, both classic and compact, were treated as processes which sent random stationary ergodic signals, because they were holding the stabilised work of both spinning frames [12]. To assess the results of the simultaneous influence of the α_m and p_w parameters on the average values of the physical proprieties of analysed yarns, the test of the variance analysis according to double classification was applied [9, 34], followed by the multiple regression method *a posteriori*, together with determining the appropriate functions with approximate linear square polynomials [24, 34]. For statistically adequate models, suitable graphs of the regression function were prepared, considerably facilitating the interpretation of the studied phenomena, together with designating the technological parameters of the spinning process. In order to prove if a correlation exists between the chosen proprieties of cotton yarns, both classic and compact, the matrix of the correlation was created, enabling the calculation of the coefficients of Pearson's correlation and the estimation of their significance [34]. The detailed methodology of the analysis of the data was also described in articles [19-20]. The algorithm of modelling the process of the production of cotton ring yarns, both classic and compact, using multiple regression, is presented in ***Figure 3***.

The total quality of ring spun yarns, both classic and compact, depended on various of their features, so it is difficult to find an objective estimation of the quality of analysed yarns, and the assessment of their technological usefulness. A final estimation of the quality of yarns can be done analytically or synthetically. It is relatively easy to find the usefulness of the examined product by considering one of the features. In this case, it is sufficient to judge the given feature through its measurements. The situation becomes very complicated when the need to perform multi criterion assessment occurs [7, 38]. One of the main disadvntages of the analytical methods is the need to examine every one of the strength features separately from the others.

Multi criterion assessment of the measurable properties of ring spun yarns, both classic and compact, was done through the application of the General Index of Quality – G_Q, which took into consideration tenacity – R_H, coefficient of mass variation – CV_m, the number of neps per 1000 m – $Neps_{+200\%}$, and hairiness – H. Weights were allocated to enumerated features arbitrarily in the three-stage scale – 1, 2, 3:

- the highest mark of importance – t_{CVm} = 3 and t_H = 3 were allocated to the coefficient of mass variation CV_m and hairiness – H, since these parameters play the most significant part in the latest stages of the technological process, especially from the point of view of undesirable breakage, and the view of the finished article [8].
- the mark of importance – $t_{Neps+200\%}$=2 was allocated to the number of neps per 1000 m. The neps content in yarns is still one of the most important quality parameters in the textile industry, especially in the appearance of fabrics and knitted fabrics, because the consumer considers neps in the end product to be unpleasant. A high content of neps is also connected with considerable processing problems that result in, among other things, high end break rates in the knitting process [29].
- the mark of importance – t_{R_H} = 1 was allocated to the tenacity.

During the tests carried out using the form of the General Index of Quality –

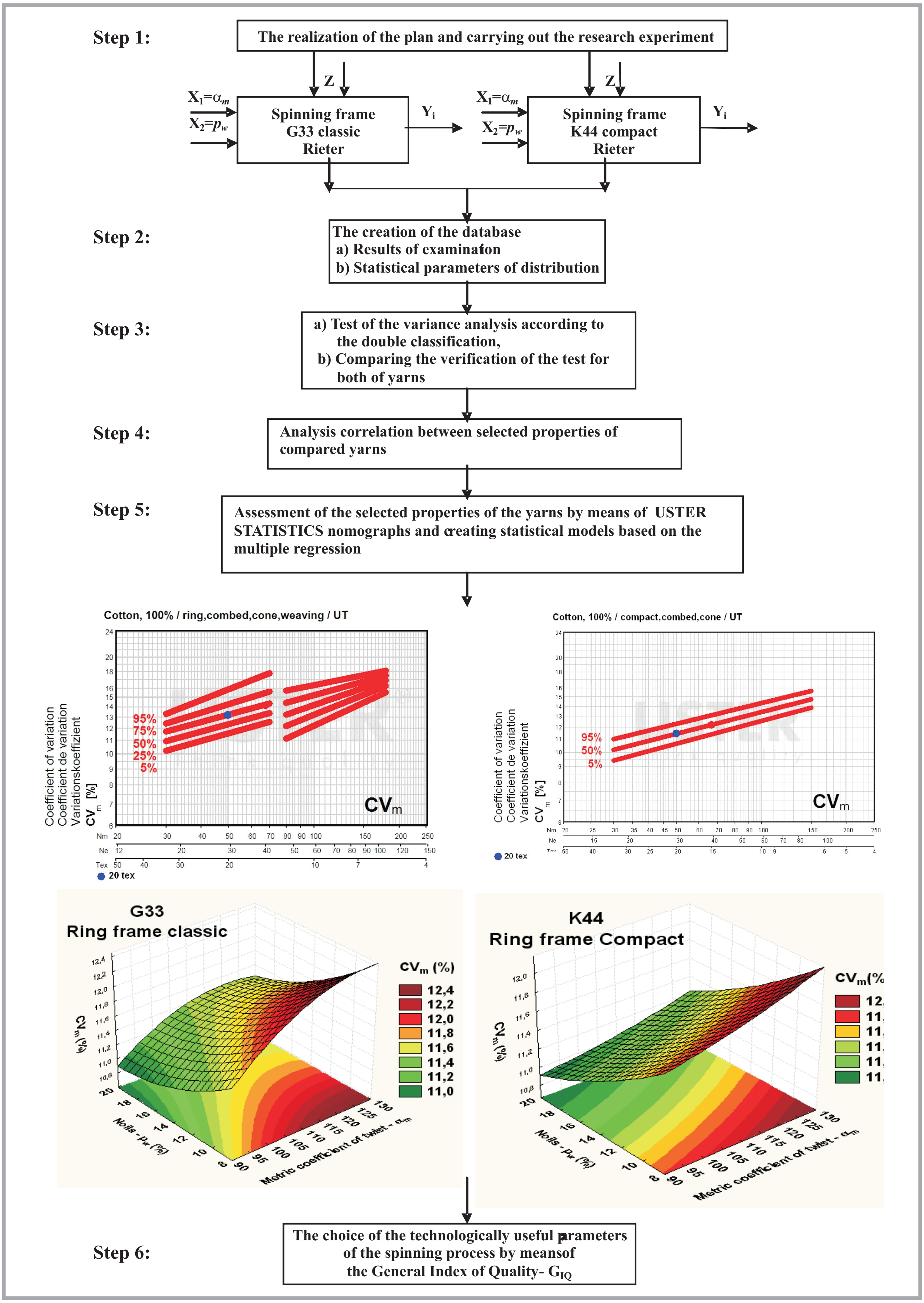

Figure 3. *The algorithm of modelling the process of the production of cotton ring yarns, both classic and compact, using multiple regression.*

G_Q [7, 38], average values of the measurable physical properties of analysed cotton ring spun yarns, both classic and compact, were taken into consideration, as were the minimal and maximum value of these properties, random errors of the properties, and relative indicators of subjected features.

Finally, General Index of Quality – G_Q was expressed in equation 2 where: t_{R_H} − rate of tenacity of analysed yarns, t_{CVm} − rate of coefficient of mass variation – CV_m of analysed yarns, $t_{Neps+200\%}$ − rate of number of neps per 1000 m of analysed yarns, t_H − rate of hairiness of analysed yarns, and t_{CVm} − rate of parameter – CV_m of analysed yarns,

$$W_{i_{R'_H}} = \frac{R_H - (R_{H\min} - U_{R_H})}{R_{H\max} - R_{H\min}}$$ – relative index for breaking tenacity,

$$W_{i_{CV'_m}} = 1 - \frac{CV_{mi} - (CV_{m\min} - U_{CV_m})}{CV_{m\max} - CV_{m\min}}$$

– relative index for coefficient of mass variation,

$$W_{i_{H'}} = 1 - \frac{H_i - (H_{\min} - U_H)}{H_{\max} - H_{\min}}$$ – relative index for hairiness,

$$W_{i_{Neps'+200\%}} = 1 +$$

$$- \frac{Neps_{+200\%i} - (Neps_{200\%\min} - U_{Neps+200\%})}{Neps_{200\%\max} - Neps_{200\%\min}}$$

– relative index for number of neps,

where:
U – absolute random errors of the average values of the individual physical parameters of analysed yarns.

The index G_Q takes into account the individual physical proprieties of yarns with arbitrarily assumed ranks of validity. The value of the General Index of Quality is in the range from 0 to 1, where index $G_Q = 0$ characterises yarns of the lowest quality, and index $G_Q = 1$ characterises yarns of the highest quality. In industrial practice, with the assessment of physical proprieties by means of USTER STATISTICS, an assumption is made that the content of the short-term thick cannot exceed the percentile line – 50%.

Using the above-mentioned information, it was accepted that, if the yarns were of sufficient quality, then the General Index of Quality would fulfil the following condition:

$$G_Q \geq 0.5 \qquad (3)$$

Thanks to the proposed construction of the index G_Q, it is possible to choose the range of the parameters of the spinning process (α_m and p_w), assuring the production of yarns with satisfactory quality if:

$$G_Q = R^+ \cup \{0.5\} \qquad (4)$$

To find the technological parameters of the spinning process (p_w, α_m), enabling the production of yarns with the above-mentioned properties, an analysis of the regression function of the index - G_Q was conducted:

$$\begin{aligned}\hat{G}_Q = {} & B_0 + B_1 \cdot \alpha_m + B_2 \cdot p_w + \\ & + B_{11} \cdot \alpha_m^2 + B_{22} \cdot p_w^2 + \\ & + B_{12} \cdot \alpha_m \cdot p_w \geq 0.5\end{aligned} \qquad (5)$$

Summary

The modern techniques of ring spinning, for classic and compact yarns, make it possible to produce high quality yarns. The disadvantage of compact ring spinning is that the price of the yarns produced is still too high. One can reduce the costs of the production of the yarns by the suitable selection of the technological parameters of the spinning process, which involves the lowering of their quality. It should be remembered, however, that the fundamental aim of the spinning process is getting high quality yarns, whereas the cost of their production is of secondary importance. The considerations presented will make it possible to choose the optimal parameters of the spinning process of yarns in order to fulfil the qualitative requirements recommended in the USTER STATISTICS. This will take place during the execution of the technological verification in the second part of the article.

$$G_Q = \frac{\sqrt{t^2{}_{R_H} + t^2_{CV_m} + t^2_{Neps_{+200\%}} + t^2_H}}{\sqrt{\left(\frac{t_{R_H}}{W_{i_{R'_H}}}\right)^2 + \left(\frac{t_{CV_m}}{W_{i_{CV'_m}}}\right)^2 + \left(\frac{t_{Neps_{+200\%}}}{W_{i_{Neps'+200\%}}}\right)^2 + \left(\frac{t_H}{W_{i_{H'}}}\right)^2}} \qquad (2)$$

Equation 2.

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