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Optimisation of Production Costs and Fabric Quality

Abstract
The influence of the quality characteristics of yarn on the optimum manufacture of fabrics was analysed. Based on yarn properties, an optimal size pick-up which would yield satisfactory fabric quality and optimal yarn breaks on the loom was sought. The correlation between the following parameters was examined: size pick-up, end breaks in weaving, yarn quality according to classes, and breaking force. The tests were carried out on three warps sized with five pick-ups of various sizes and woven in two weaves. The results obtained revealed a certain dependence of the parameters, and the possibility of establishing the optimum costs and quality of the woven fabric.

Key words: *production costs, fabric quality, optimal size pick-up, breaks in weaving, yarn quality according to classes.*

Introduction

In yarn preparation, many parameters influence the quality and efficiency of fabric manufacture, such as the quality and kind of the incoming raw materials and auxiliary agents, modernisation of machinery, the manufacturing process, the human factor, climatic conditions, the supply of spare parts for machinery, and ancillary products in time, storing etc. The quality of the yarn used for manufacturing the fabric is the most influential factor, to which other parameters are added during the manufacturing process. According to the analyses of yarn properties, it is possible, prior to cleaning, to reach a decision on the basis of laboratory analyses as to what degree the yarn can be cleaned to obtain the highest-quality properties. It is important to assess whether this yarn can satisfy a certain purpose, or whether cleaning and sizing can produce an appropriate warp which will yield an optimum frequency of breaks on the loom and a satisfactory fabric quality. To be able to assess the regular degree of cleaning and the optimal size pick-up, it is necessary to know which weak, thick and thin places will remain in the yarn and which are to be eliminated [1 - 4]. The modernisation of the spinning and weaving preparatory machinery as well as of the laboratory equipment makes such an assessment possible. The capability of the machines to clean the yarn according to a preset degree of cleaning on the winding machine, together with yarn splicing and professional control of the machine's operation have considerably contributed to the improvements in yarn quality. Likewise, it is important for the weaving shed to place demands on yarn quality, cleaning and sizing. The minimum and maximum average values of yarn parameters, which will guarantee fabric quality and effectiveness production, should be determined for each fabric.

The course of the weaving process impacts on the final quality and effectiveness. If a yarn which needs no sizing is processed, the manufacture of grey fabric will become considerably cheaper because the sizing process is one of the most expensive in fabric manufacture. If the yarn is made of cotton, and intended for weaving colour fabric, the warp prep-

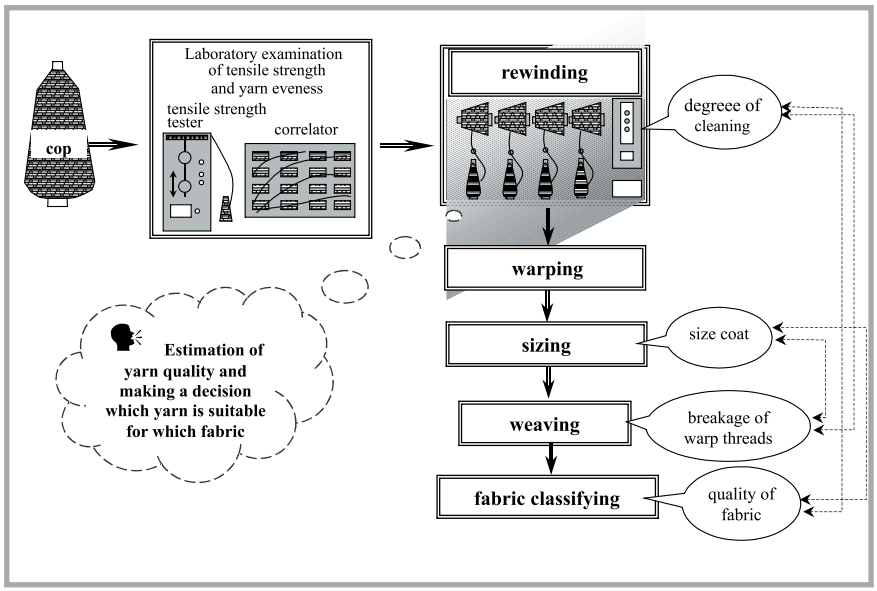

Figure 1. *Course of the production process and the optimisation of fabric quality and cost-effectiveness.*

aration will make the fabric manufacture more expensive, especially if the yarn is dyed on cross-wound bobbins.

The human element is one of the most influential in making a fabric of high quality and cost-effective value, and this affects all the other factors. Due to the modernisation of machinery, the direct influence of human workers on the manufacture is lessening, but its share is still very great from automation and robotisation to control and modernisation, and reaches [5].

Deviation from standard climatic conditions affects material characteristics so that permanent deformations and frequent machine stoppages may be caused.

Ancillary products may affect the final quality of the product, especially if they do not meet the quality and recipe proportions.

In order to manufacture a top-quality and economical fabric, it is necessary to analyse each production stage and its part and impact in the production chain. Figure 1 shows such a circuit of manufacturing steps as well as their mutual influence. The weaving process serves as a basis for optimising fabric manufacture. The impact of individual steps in the weaving process is different; it can be improved by following and analysing them. In order to meet the quality characteristics of the fabric being produced, the properties of the yarn should be examined as well as the maximum quality values expected. In addition to this, it is necessary to optimise the sizing, so that the top quality of sizing is obtained with the lowest costs of energy and agents [6]. Each yarn differs slightly from another, and this difference is frequently not noticed earlier than in the weaving process, although they can have the same properties at the beginning of manufacture. These manifest themselves in various drawing characteristics, different size absorption etc. This indicates that some parameters should sometimes be corrected at the beginning of the manufacturing process: size pick-up, portion of sizing agents, level of yarn cleaning etc. [7-9]. The technologist's proficiency and experience are revealed when he adjusts these parameters. The frequency of end breaks in weaving and fabric quality would be clearly connected with the level of cleaning and the sizing recipe determined and applied.

Theory

Loading the warp yarn during weaving mainly results in irreversible deformation. This deformation depends on yarn strength, the composition of the raw material, the modernisation of the machines for fabric manufacturing, the yarn tension during the manufacture, and manufacturing conditions such as shed height, warp and weft density. Irreversible deformations of threads can be reduced by machinery modernisation and appropriate yarn preparation. On the other hand, this is a problem which influences the utilisation of machines and the quality and durability of a fabric. Weft yarns are less loaded during weaving, so that this thread system can use a yarn of a lower strength than warp yarns, and it is frequently more uneven. For this reason, as well as because fabrics are used more stressed in the warp direction than in the weft direction, this thread system does not cause irreversible deformation. The yarns used as warp are stronger; in most cases they are plied so that they do not need sizing [10-13].

In the weaving process on a medium-modern loom warp, yarns undergo dynamic stresses under which every thread section is subjected to 1000 cycles of stress within a period of 30 minutes, until a mutual balance between the warp and weft is reached, as well as fabric relaxation thereupon [14]. These thread stresses become higher and higher, and they reach their maximum in the heald frames and in the fabric fell when the tensile strengths in the threads sometimes become higher than the average tensile strength of the same yarn. In this case, a break of warp threads occur in weak places, which can be shown as a share of the surface cross-section under the curves of tensile and breaking forces (Figure 2, Equation 1) [15-25]. The accuracy of this statement found in the available literature was confirmed by experimental analyses of yarn breakage based on the length of the tested yarn. According to the results obtained, the rate of warp breakage correlates between the surface cross-section closed by the right part of the Gaussian curve of tensile forces and the left part of the Gaussian curve of breaking forces. The authors analysed the scattering of values according to the Poisson and logarithmic-normal distributions, which show a great correlation of the relationship between the

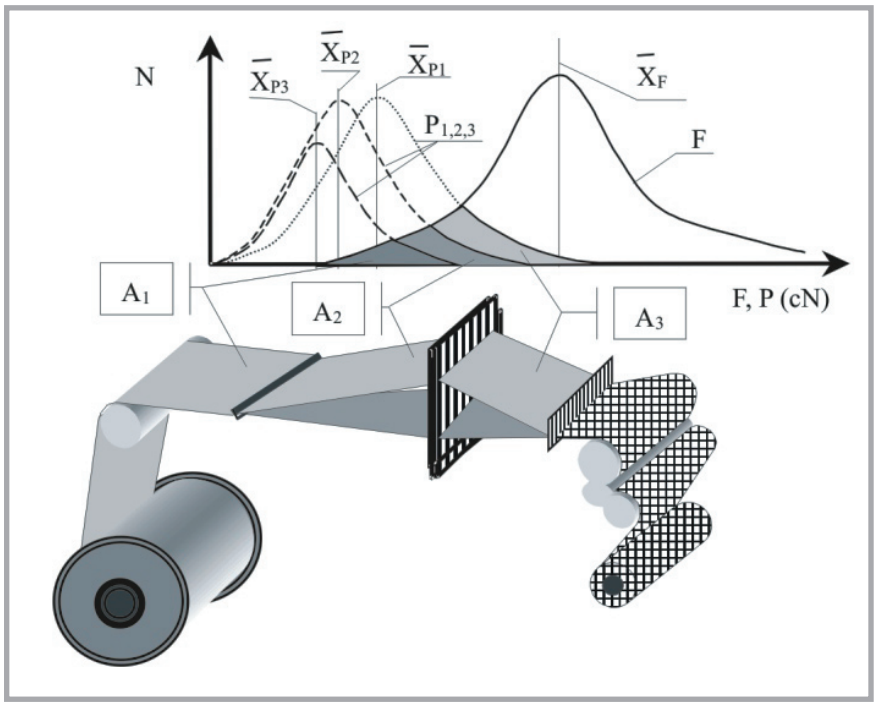

Figure 2. *Share of the warp end breaks according to the position on the loom; N – share of tensile strengths (P) and breaking forces (F) assigned to classes, $X_{F1,F2,F3}$ – mean values of tensile strengths of warp ends according to yarn fineness (cN), X_P – mean value of breaking forces of warp ends (cN), F_1 – scatter plot of tensile strengths of yarn 20×2 tex, , F_2 – scatter plot of breaking forces of yarn 30×2 tex, F_3 - scatter plot of breaking forces of yarn 50×2 tex, P - scatter plot of tensile forces on the loom, $W_{1,2,3}$ - frequency of warp end breaks during weaving according to the positions on the loom, obtained according to equation (1), ×- parameter in equation (1).*

breakage rate and surface cross-section, but the greatest correlation was obtained by normal distribution. Nevertheless, in order to obtain the greatest accuracy of breakage rate for individual warps, it is necessary to take account of the higher breakage rate, or to restrict it to a specific yarn length. This means that the rate of warp thread breakages does not depend only on the stress of warp threads and the frequency of weak places obtained by the surface cross-section under the curves, even in the total number of warp threads. The frequency of yarn breakages will be linked to a specific thread length, and not to the time or the machine used.

The cross-section surface of the curves of tensile and breaking forces has a scattered form, mostly according to Poisson's distribution. The frequency of yarn breakages increases with tensile force until it crosses with the curve of breaking forces, as until then the frequency of breaking forces was lower than that of the tensile forces. Starting from the crossing point, the frequency of breaking forces is greater and exceeds the frequency of tensile forces which have a smaller rate of frequencies, so that the frequency of yarn breakages becomes smaller and smaller.

The weft threads suffer dynamic stress, but it is lower and rarer, and it occurs only once in one weft length; for this reason, the breakage rate is lower. The deformation of warp and weft threads affects the deformation of the fabric and its relaxation.

$$W_t = \int_0^{\infty}\int_0^{x} I_P I_F dx^2 \qquad (1)$$

W_t – end-breakage rate, I_P – relative frequencies of stress forces (P_x) being equal or higher than the absolute breaking forces in integral segment (x), I_F – relative frequencies of breaking forces (F_x) being equal or lower than the absolute breaking forces in the same integral segment (x)

The optimisation of size pick-up is one of the most important tasks in the process of fabric making. Therefore, many systems of regulating size pick-up have been developed [26-30]. Their common disadvantage is that they did not include all the most essential parameters which influence size pick-up. One of the parameters not included in the previous systems, but which fundamentally affects size pick-up, is the entry moisture of the warp before sizing, which is especially reflected in dyed warps on warp beams.

The first author of this paper developed a new system of optimising size pick-up based on substance balance, whereby the parameter's entry moisture is taken into consideration [24, 30].

The constant determination of size pick-up took the following parameters into consideration: entry moisture, exit moisture and concentration, as presented in Figure 3 and by Equation (2) [4,5,9]. This final equation was obtained by analysing the substance balance:

$$S = \frac{W_{h2} - W_{h1}}{\frac{100}{C} - \frac{W_{h2}}{100} - 1} \cdot 100 \quad (\%) \qquad (2)$$

S – size pick-up (%)
W_{h2} – exit moisture of the warp (%)
W_{h1} – entry moisture of the warp (%)
C – concentration of the size (%)

Experimental

Applied materials, test methods, machines and equipment used for testing

The Statimat M strength tester by Textechno was used to determine the physical and mechanical yarn properties: breaking force, breaking elongation. A pre-tension of 0.5 cN/tex was used for testing the yarn; a break happened within 20±3 s, and 100 measurements were carried for each yarn specimen.

The investigations were carried out according to the Croatian standards matched to the DIN and ASTM standards.

Yarn count, number of twists, yarn irregularity and breaking force were tested in the yarn before sizing.

Yarn count was tested by winding 10 specimens on a winch of 10 m each, and the yarn was weighed on a Techtnica 2615 analytical yarn balance, , with an accuracy of 1/1000; then the mean value was calculated in the tex system. The number of twists was determined by unwinding the ply yarn until reaching parallelism on the Huida Hahn KG torque meter. The mean values were determined for 50 test-pieces of each yarn. A 100% cotton yarn with the properties illustrated in Table 1 was used for testing.

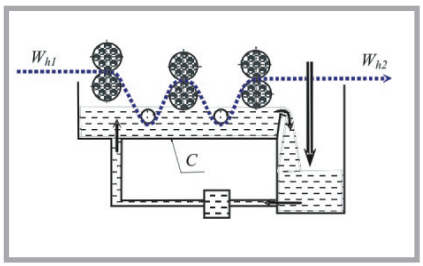

Figure 3. *Scheme of the size box and place of measuring point; W_{h1} – warp entry moisture (%), W_{h2} – warp exit moisture after sizing (%), C – size concentration (%).*

The yarn was sized in an apparatus simulating the size box within the structure of the Schlafhorst section warper (cone warping machine) (Figure 3). The yarn was unwound from the beaming creel, sized in the size box, dried with electrical heaters within the structure of the apparatus, and wound on the warping cylinder. After warping and sizing, all the sections of the yarn was wound onto the warp beam. The yarn was warped and sized in 15 sections with 300 threads in each section, totalling 4500 threads.

All three yarns were sized according to 5 recipes, wound on the cylinder in sections and then together on the warp beam. Three successive sections were sized with the same recipe and they had the same size pick-ups respectively, so that the warp was divided into 5 fields in the width or 5 size pick-ups. Each field contained 900 threads, representing one specimen. This procedure was used to size all three warps and. ply yarn counts respectively (20×2 tex, 30×2 tex and 50×2 tex).

The breakage rate registered in weaving was converted with 900 threads in each specimen to 4500 threads, which would make up the complete warp. Likewise, the number of warp end breaks was recalculated per length unit of warp, namely at a yarn length of 10^5 m. After the weaving faults were registered in the fabric, and based on the number of faults per length unit, the class was determined. Two weave structures were used: plain and twill from three various warps of different counts and each 1000 m long (Table 1). A dobby loom by MAV SACM (France) was used for weaving. The speed of the loom was 230 weft threads/min. The same weft of a count 30×2 tex was used for all specimens of the woven fabric. The weaving conditions were not altered when changing the warp and weave structure.

Test results

Table 1, Figures 4, and 5 show the tested values of breaking forces and size pick-ups, as well as the registered breakage rate and classified quality.

Discussions

The difference among yarn counts was established after testing the breaking force of the unsized yarn. The lowest breaking force was registered in the yarn of count 20×2 tex, amounting to 238 cN, followed by the yarn of count 30×2 tex, amounting to 394 cN, and the highest breaking force was registered in the yarn of count 50×2 tex with 431 cN (Table 1). Increasing the size pick-up increased the breaking force in all specimens. In the yarn of count 20×2 tex, the increase in the breaking force by sizing ranged from 59 cN in the lowest-size pick-up to 120 cN in the highest-size pick-up. An increase in the size pick-up in the yarn of count 30×2 tex caused an increase in the breaking force from 28 cN to 93 cN, and in the yarn of count 50×2 tex from 14 cN to 74 cN. The obtained results demonstrate that the yarn of a lower breaking force before sizing showed an increase in the breaking force by sizing with the same size pick-up.

Increasing the size pick-up reduces the breakage rate of warp ends to a certain extent, and afterwards the breakage rate increases by increasing the size pick-up. According to Table 1, the lowest breakage rate is in the 10% size pick-up in all three yarns; specifically 2.18 breaks/1 machine and 1 hour in the yarn 20×2 tex, 1.74 breaks/1 machine and 1 hour in the yarn 30×2 tex, and 1.53 breaks/1 machine and 1 hour in the yarn 50×2 tex. By a further increase in the size pick-up, a negative effect is caused in weaving plain and twill fabrics, meaning that the size pick-up is higher than necessary. Thus, a size pick-up of 10 or 12% causes an increase in the breakage rate in both weave structures, which is more prominent if the yarn has a lower breaking force.

By altering the size pick-up and the weave structure, the quality of the grey fabric wasalso changed. The fabrics are classified into 4 classes in such a way that the least faulty fabric belonged to the 1st class, and the most faulty fabric belonged to the 4th class. In this examination, the average class was taken for the specific fabric. The development of quality followed the development of the breakage rate during weaving, and a higher breakage rate during weaving resulted in a worse quality. The fabric with a size pick-up on the warp from 10 to 12% had the best quality; the quality worsened with an increase in the size pick-up.

By comparing the plain fabric with the twill fabric, a similar dependence between size pick-up and breakage rate, respectively quality is noticeable. The plain fabric had a slightly higher breakage rate and a worse quality than the twill fabric for the same size pick-up, but the course of the curves is almost identical.

Their interrelationship is noticeable by placing the value of 4 parameters in a coordinate system.

The values of the breakage rate depending on the size pick-up (coordinate systems) represent the lines with the minimum breakage rate obtained with a 10% respectively 12% size pick-up for all three yarns, for the plain and twill weaves.

The coordinate system II, including the breakage rate and classified quality and with the points of measured values, represents the surfaces which are bigger if the scatter of breakage rate and quality is greater. According to Figures 4 and 5, yarn 20×2 tex closes up the biggest surface, followed by yarn 30×2 tex, and yarn 50×2 tex closes up the smallest surface.

The points which represent the relationship among the measured values of classified quality and breaking force of the sized yarn (coordinate system III) represent the surface as well. The size of the surface depends on the scatter of these two parameters, and their difference among the yarns is not perceptible, but there is a certain difference among the weaves. The plain weave has a smaller value scatter than the twill weave which is applied to all yarns.

Breaking force and size pick-up close up the coordinate system IV. Based on the results obtained, an increase in the breaking force in all the yarns is noticeable when the size pick-up is increased. It may be noted that the increase in the breaking force becomes increasingly smaller by increasing the size pick-up, and the difference in the size pick-ups of 12% and 16% is very low, meaning that the warp with a 16% size pick-up reached its maximum breaking force. Since the same-sized yarn was used for weaving plain and twill fabrics, the coordinate system IV is identical for both weaves.

Table 1. *Mean values of the unsized and sized yarn.*

yarn count, tex	20×2				30×2				50×2			
U, twists/m	544				438				344			
F`, cN	328				394				431			
S, %	F, cN	weave	Bp	Q, (1-4)	F, cN	weave	Bp	Q, (1-4)	F, cN	weave	Bp	Q, (1-4)
4	387	p	2.52	2.31	422	p	2.48	2.38	445	p	2.05	2.49
		t	2.41	1.85		t	2.18	2.10		t	2.06	1.74
8	413	p	2.36	1.2	430	p	2.21	2.00	469	p	1.72	1.50
		t	2.08	1.50		t	1.80	1.68		t	1.52	1.20
10	438	p	2.18	1.13	467	p	1.74	1.45	489	p	1.53	1.33
		t	1.67	1.12		t	1.48	1.25		t	1.31	1.14
12	441	p	2.23	1.71	479	p	1.79	1.70	495	p	1.59	1.83
		t	1.65	1.62		t	1.38	1.18		t	1.30	1.75
16	448	p	2.22	1.90	487	p	1.96	2.02	505	p	1.66	1.85
		t	1.95	1.89		t	1.36	2.04		t	1.39	2.02

where: U - number of twists (twists/m), F' - breaking force of the yarn before sizing (cN), S - size pick-up (%), F - breaking force of the sized yarn (cN), Bp - number of warp end breaks at a length of 10^5 m, Q - quality of grey fabric in classes (1-4), p - plain weave, t - twill weave.

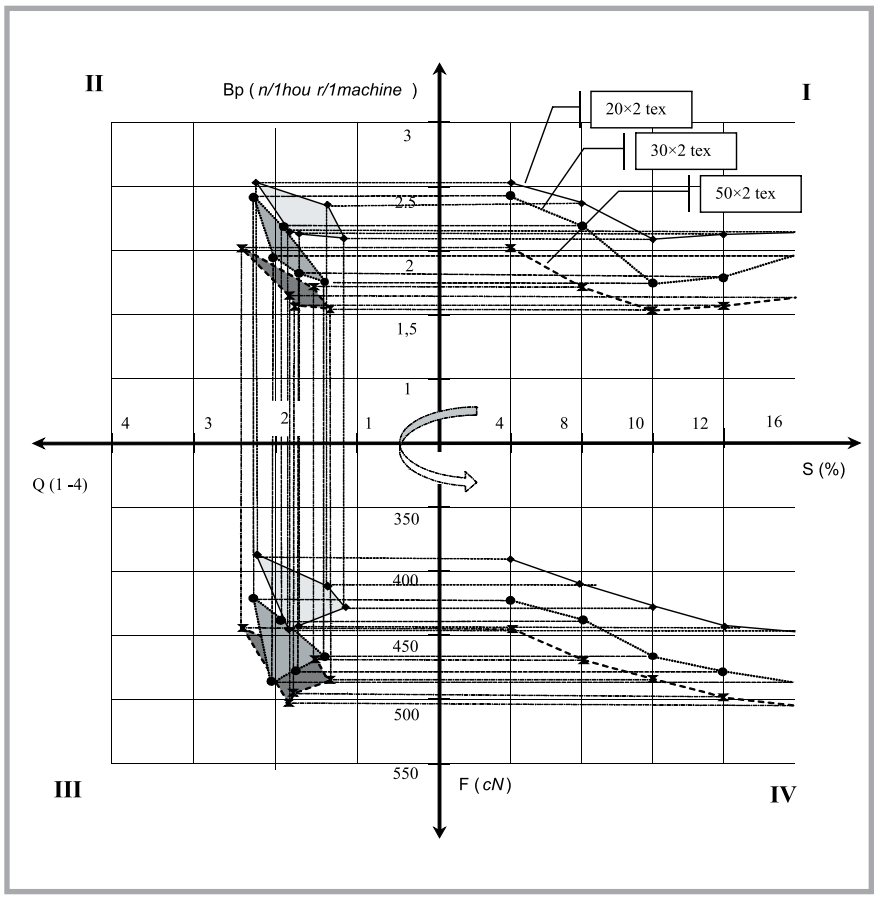

Figure 4. Graphic representation of the interrelationship of the parameters of the warp yarns in weaving the plain weave; S - size pick-up (%), F - breaking force of the sized yarn (cN), Bp - number of warp end breaks at a length of 10^5 m, C - quality of grey fabric in classes (1-4).

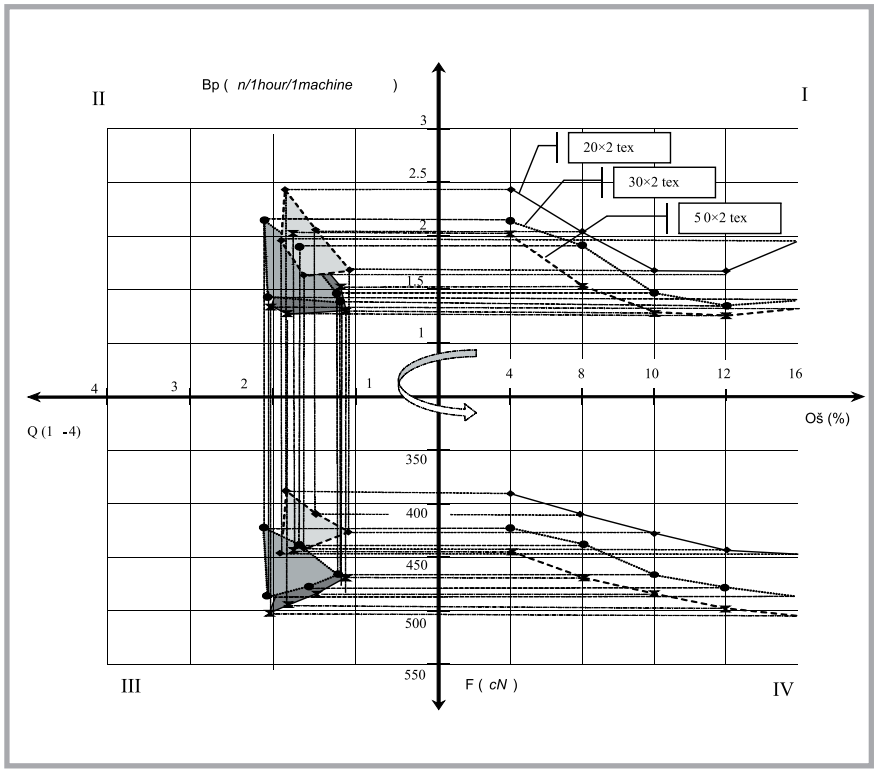

Figure 5. Graphic representation of the interrelationship of the parameters of the warp yarns in weaving in twill weave; S - size pick-up (%), F - breaking force of the sized yarn (cN), Bp - number of warp end breaks at a length of 10^5 m, C - quality of grey fabric in classes (1-4).

Conclusions

The basic task of optimising the fabric manufacture is to reduce production costs and attain a guaranteed quality. Machinery automation, enhancement of raw material quality, and proficiency of the personnel form the basis for attaining the above-mentioned goals.

The aim of this work is to find out the most economical and highest-quality production, and to conduct investigations leading to this aim. Moreover, it is possible to plan the production qualitatively and quantitatively in a time unit. According to the results obtained, the following can be concluded:

- Size pick-up is closely linked with the breakage rate in weaving. The breakage rate decreases by increasing the size pick-up, but only up to a specific limit when the breakage rate begins to rise.
- The relationship between breakage rate, the classified quality changes and the pertaining points creates a specific surface in the coordinate system. This surface depends on the minimum and maximum parameter values. The greater the scatter is, the bigger the surface is.
- The points between the breaking force and the classified fabric quality in the coordinate system also close up one surface. This surface is larger when the deviations of these two parameters are greater. The difference is not perceptible either among the yarns or the weave structures .
- The dependence of the breaking force on the size pick-up is almost linear for all yarns. The breaking force raises increasingly less if the size pick-up is higher than the optimal one.
- The significance of determining the optimum costs and fabric quality is a possibility resulting from qualitative and quantitative production planning in a time unit, besides cost-effective production and competitive quality.

Acknowledgment

The tests were conducted at the Laboratory of the Department of Textile-Mechanical Technology at the Faculty of Textile Technology of the University of Zagreb, Croatia, and at the Tekstilni Kombinat Zagreb and Kelteks Karlovac textile companies within the scope of the HITRA project. We thank all the companies for providing assistance in realising the HITRA project.

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Received 03.12.2004 Reviewed 04.10.2005

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