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# Multi – Criterion Assessment of Pneumatically Spliced Cotton Combed Ring – Spun Yarns

**Abstract**
*The results of examinations of the strength and geometric dimensions of pneumatically spliced cotton combed ring spun yarns are presented. Unknotted spliced joints were linked using a Jointair 4941 splicing device produced by Mesdan installed on an automatic winder made by the company Savio. The investigations were performed during the winding of the cotton combed yarns (linear density: 16 tex and 36 tex, i.e. fine and relatively coarse yarns, respectively) most often manufactured in the textile industry. For the multi – criterion estimation of pneumatically spliced joints, the Integral Index of Quality – $Q_Z$ was introduced, based on the considerations of Żyliński, which is connected with the General Index of Quality. The total plan of the experiment was carried out, comprising the simultaneous influence of two settings of the splicing device: $t_E$ – time of preparing the yarn ends and $t_A$ – time of splicing the yarn ends. In the examinations, the most beneficial settings of the splicing device were established subsequently for the particular features tested. Therefore, sets of recommended settings for the splicing device were obtained. Only one of the useful sets of settings in the technology permits the creation of unknotted pneumatically spliced yarn joints with features fulfilling many criteria.*

**Keywords:** *yarn, unknotted spliced yarn ends, Integral Index of Quality.*

## Introduction

In the modern textile industry, similar to other branches of industry, there appears to be a systematic rise in the quality of products. The quality of final goods begins to be shaped at the moment when the raw material is purchased. Moreover, it is dependent on the degree of modernity of the factory, the technology applied and, to a greater extent, on the industrial engineering. Yarn is a semi-finished article for producing textile products and it should be characterized by an optimal evenness of linear density and strength as well as by a minimal number of errors. Probabilistic occurring errors determine the fundamental source of yarn breakages during the production of textile products.

In the process of preparing spun yarns for further processing, 50% of breaking elongation is lost, and they reach the limit of breaking durability in the effect faster, so they are subject to destruction faster. The quality assessment of the yarn cannot be limited for determining only the average values of each parameter. Sources of threat are weak places occurring in yarns. Moreover, spun yarns produced as a result of the small dimensions of cheeses, compared with packages produced on the rotor spinning machines, have a significantly larger number of errors. This reduction of weak places and increase in the yarn packages is very significant. The application of yarn joints narrowly departing in appearance and strength properties from the original yarn is also very important. Initially, liquidation of the yarn breaks was led by linking the ends with knots.

Nowadays, in connection with the growing requirements for yarns, making knotted joints is not very useful. Because of the large capacity, such knotted joints make other yarns breaks and create errors of the product in overcoming frictional barriers.

There are barriers to knots: guides, tension devices, heald shafts and needles of knitting machines among others. For the purpose of the elimination of this problem, a number of unknotted joining techniques were elaborated by entangling with the foreign fibre, gluing, alloying, mechanical splicing, electrostatic splicing and pneumatic splicing.

The application found a place for these technologies in practice. In the leading producers of the devices most often used for spliced yarn ends, it is possible to count such companies as Süssen, Mesdan, Savio, Enka AG, Murata and Shlafchorst. The technology of pneumatic splicing found the largest pneumatic application in the world industry with regard to low costs of ownership, small dimensions of the actual device and its high efficiency. Splicing devices produced by the Mesdan company are most often applied in Poland.

## Properties of spliced yarn ends

The place of spliced yarn ends should have the character of the yarn and sufficient durability in order to satisfy the requirements and the expense of the splicing process should be small. The properties of the spliced joints are determined by their length, the linear density and mechanical parameters. Many factors impact on the quality of spliced yarn ends. During pneumatic splicing, both the shape and the structure of the yarn change at the place of the join.

During the assessment of quality of the obtained spliced joints, it is necessary to focus special attention on two basic parameters: the strength of the joint and its similarity to the yarn subjected to the splicing operation. These properties depend strictly on themselves and they have a large impact on other features of the yarn subjected to the joining. Despite the simplicity of the principle of working of splicing devices, it is necessary to change a number of technological parameters in order to ensure optimal joining. A change in the assortment of raw materials involves a change of modules in some models and sub-assemblies [1, 2].

Both a wide range of applications of the pneumatic splicing technology and a large choice of devices causes significant constructional differences of each model to occur. The principles of working of these devices also differ. The air pressure that is led to the splicing chamber in the process of pneumatic splicing has a very significant importance. The pressure and the time of the preparation of spliced yarn ends directly impacts on the degree of untwisting of the joined yarn ends.

The geometry of the shape and putting handles in tubular or chute preparators also influence the length of the untwisted segments of the yarn, thanks to having achieved suitable strength of the fibre assembly at the moment of air swirling in the splicing chamber [3]. The shape of the prism [6], the length and the number of streams of compressed air and the dimensions of the splicing chamber decide the length of the spliced joint and the impact on the ratio between the swirling part and the part of the fibres that twirl around the yarn in the place of the join [4, 5]. In the process of unknotted yarn joining, we aim to achieve such a joint that the outer appearance and physical properties are the most similar to the appearance and properties of the remaining parts of the yarn. As a result of the same splicing process, obtaining "perfect" joining is now possible.

Companies producing splicing chambers together with other devices recommend standard settings of the splicing device most suitable to the given assortment of wound yarns. It isn't possible to determine an unambiguous way to adjust the splicing device because of special properties of the yarns. At present, companies that produce splicing devices do not elaborate any criteria connected with the assessment of spliced yarns. In the textile mills, the physical properties of spliced yarn ends are determined using an organoleptic method. Special attention is paid to the appearance of connections. The fluctuation of physical properties of yarns with the same linear density, in the opinion of companies producing splicing devices [6, 8, 9], can also impact on the selection of proper settings for this device. The final selection of settings of the splicing device is always left to the technologists' management to fulfil the function of experts in this field. According to the producers [6, 8, 9], perfect preparation of the ends of the yarn should result in its diameter being slightly bigger than the diameter of the yarn and the fibres not protruding from the yarn body. The joined places of yarn should have identical lengths. Splicing of the yarn has to be closed well (lack of clearance, the included structure uniform); however, no damage should occur in the zone of the joining.

Joining the yarn by pneumatic splicing has been the subject of many experimental studies. As the criteria for the assessment of the quality of spliced yarn, Lünenschloss [3-5], Gebald [10-12] and Szosland, Nikolaev and M.Snycerski [30] assumed basic strength properties. The authors stated that the quality of spliced yarn ends is mainly dependent on the kind of splicing chamber, the number and location of holes in the splicing chamber and the method of preparing the yarn ends before the joining process.

Kaushik, Sharma and Hari [14-15] studied the process of joining yarn ends produced from blended yarns (a blend of polyester and viscose fibres). In their investigations, the authors used splicing chambers produced by the Schlafhorst company. These authors [14-18] compared the physical properties of spliced yarn ends. They evaluated static strength, elongation at the break and work to break both yarns containing splices and yarns without splices. The authors stated that the strength of spliced yarn ends is dependent on the method of preparation of the ends of the yarn for splicing. They were judging the degree of blending in the place of splicing and the twisting of fibres.

Frontczak-Wasiak and Snycerski [19, 20] undertook an attempt to widen the knowledge about the structure and physical properties of the spliced yarn joints.

They analysed spliced yarn joints performed from blended carpet yarns (ARGONA 60%/POLAN 40%) with a linear density of 100 tex used for the production of pile carpets. Spliced joints were executed on the splicing device Jointair 130 of the Mesdan firm. The authors also evaluated the usefulness of two structurally different splicing devices: MAS-2G of the Mayer firm and Jointair 130 of the Mesdan firm [20]. They stated that both the air pressure and the time of airflow to the chamber impact on the general quality of spliced yarn joints.

Cheng and Lam [21-23] undertook an attempt to determine the relationship between the parameters of the splicing device 114 of the Mesdan firm and the influence of the settings on the properties of cotton yarns and cotton/polyester 65/35 blended yarns. The authors managed only to determine that the length of the yarn tails and yarn linear density are the dominant parameters that affect the quality of the spliced yarns.

Machnio and Drobina [24-25] evaluated the physical properties of spliced yarn ends. Joints were executed on the splicing device Jointair 4941 of the Mesdan firm. The subjects of their examinations were joints performed from worsted wool yarns. The authors stated that the splicing device Jointair 4941 worked correctly at the settings recommended by the manufacturer, but the quality of splicing yarn ends is dependent on the linear density of yarn. The visual estimation of those spliced joints was also examined [24].

They first proposed patterns of joints, making possible expert visual assessment of spliced yarn-end joints. According to a literature analysis, they stated that joints of yarn ends made by the splicing operation are able to be shaped by such factors as the time of preparing yarn ends for splicing, the length of yarn ends not spliced to the joint, the air volume during the splicing cycle and the time of the splicing cycle. The examination of the relationship between the input and output quantities only makes sense when the number of input variables as well as the number of levels of these variables are taken appropriately. The examination of the relationship in the function of one variable was unable to carry out an interactive evaluation of the influence of the working parameters of the splicing device on the subjected features. However, it is difficult to interpret an examination of simultaneous interaction of the larger number of input factors.

An example of an experiment planned this way is examinations carried out by Cheng andH.L.I. Lam [21-23]. Taking into account the presented state of existing examinations, the analysis of the influence of settings of the working parameters of the splicing device on the quality of the spliced yarn joints was carried out using both a digital image and determining the strength properties. According to literature information, it is possible to state that, at present, the quality assessment of the spliced joints of yarn ends is made on the basis of their strength properties, basic geometric dimensions and the organoleptic estimation of appearance, but without comparing joints with patterns.

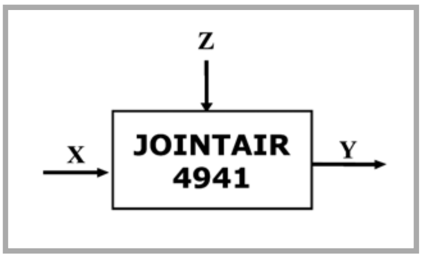


*Figure 1. Schema of technological identification of the Jointair 4941 splicing device made by the Mesdan firm with a suitably modified splicing chamber devoted to splicing cotton yarns and cotton blend yarns. X – input variables, Y – properties of spliced yarns, Z – non-measurable disturbances.*

## Experimental

The realization of these tasks is possible by carrying out examinations in accordance with the schema presented in ***Figure 1.***

Executing spliced joints of yarn ends in the function of four settings of the splicing device is possible but it's very expensive for various linear densityes of yarn and it may already have unsatisfactory effects when taking place. Therefore, it was arbitrarily preliminarily assumed that each linear density of yarn would be assessed separatelylinear density. Two levels of linear densityes were assumed, typical of the cotton mill linear densityin the range of thin and thick weaving yarns – $T_{tp} = [16\ 36]^T$ tex. Planning the experiment, an analysis of the state of knowledge was carried out for the subject of the influence of individual settings of the splicing device on the properties of the spliced yarn ends – $X = [V_C, l_B, t_A, t_E]^T$.

In accordance with the recommendation of the manufacturer, the adjustment of the $V_C$ "air volume during splicing cycle" takes place exclusively for yarns characterized by a very high number of twists. The impact of the number of twists in the yarn wasn't subject to examination since this is normalized and rarely subjected to changes for the determined linear yarn masses. So, it was assumed that this setting would be a constant dimension in accordance with the manufacturer's recommendation – $V_C$ = 0.6 litre per splice. The settings are left as: $X = [l_B, t_A, t_E]^T$.

Performing examinations in the function of three settings is possible but it considerably raises the expense of the realization of the experiment. Being based on experience and identification examinations, it was decided to check the impact of the $l_B$ control "length of yarn ends not spliced to the joint" on the properties of spliced yarns and to execute joints at the variable control: $l_B = [0\ 2\ 4\ 6\ 8]^T$ and of the constant remaining settings of the splicing device recommended by the manufacturer: "air volume during the splicing cycle" – $V_C$ = 0.6 litre per splice, "time of preparing yarn ends for splicing" – $t_E = 1$ and "time of splicing cycle" – $t_A = 1$.

In order to check whether the $l_B$ control has a statistically significant influence on the length of tails not spliced to the joint and the geometric dimensions and static strength for the yarns of linear densityes – $T_{tp} = [16\ 36]^T$ tex, preliminary examinations were performed. The realization of this fragment of examinations permitted us to reduce a number of settings of the splicing device.

Examinations of the impact of the settings – $X_2$ on the properties of spliced yarns were realized according to the plan illustrated in ***Figure 2.***

The planned experiment on the joining of yarn ends with linear densities $T_{tp} = [16\ 36]^T$ tex should enable us to check whether changes of settings of the splicing device have a statistically significant influence on the static strength properties of joints and their geometric dimensions; moreover, it should allow a multi-criterion assessment of spliced yarn-end joints with the use of the Integral Index of Quality – $Q_Z$.

## Materials and methodology

The joints of yarn ends by the splicing operation were carried out in laboratory conditions on the experimental splicing device Jointair 4941 of the Mesdan firm, which has a partial modification of the splicing chamber designed for worsted woollen for yarns from cotton fibres and their blends. Each time, the segments of yarns containing the spliced joint ends were taken after the execution of the joint. The length of these joints was approximately 100 cm. The physical properties of the yarns used for the examination of joint ends are tabulated in ***Table 1.***

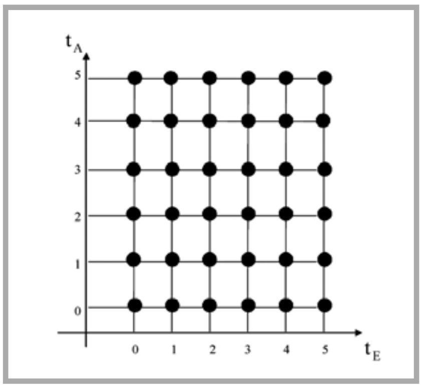


*Figure 2. Plan of the experiment on the impact of the settings time of preparing yarn ends – $t_E = [0\ 1\ 2\ 3\ 4\ 5]^T$ and time of splicing – $t_A = [0\ 1\ 2\ 3\ 4\ 5]^T$ on the properties of spliced yarn-end joints manufactured from yarns Ttp = $[16\ 36]^T$ tex.*

## Measurements of static strength

The static strength of spliced yarn-end joints, as well as that of yarns without spliced joints, was determined in accordance with the recommendation of standard PN-EN ISO 2062:1997 'Textiles. Threads in packages'. Measurements of the static strength of yarns were carried out using a tensile testing machine INSTRON model 5544.

Samples of yarns containing spliced joints were placed in the clamps of the tensile testing machine in such a way that the place of splicing was located in the middle of the clamps. This distance was 500 mm. Only those measurements were remarked in which breaking occurred in the place of the joint. In every variation, 50 measurements were executed [27].

## Measurement of geometric dimensions of spliced yarn-end joints by digital analysis of the images using the MicroScan 1.5 system [27]

Our own new procedure for the assessment of the outer parameters of spliced yarn-end joints was applied in the presented examinations. The optoelectronic method based on digital image analysis

*Table 1. Physical properties of combed cotton yarns used during examinations.*

| Analysed parameter of yarn | Unit | Linear density of yarns | |
|---|---|---|---|
| | | 16 tex | 36 tex |
| Breaking force $R_{mn}$ | cN | 82.9 | 194.62 |
| Breaking tenacity $W_t$ | cN/tex | 5.18 | 5.41 |
| Coefficient of variation of breaking force $V(R_{mn})$ | % | 10.64 | 7.26 |
| Breaking elongation $E_m$ | % | 8.81 | 10.06 |

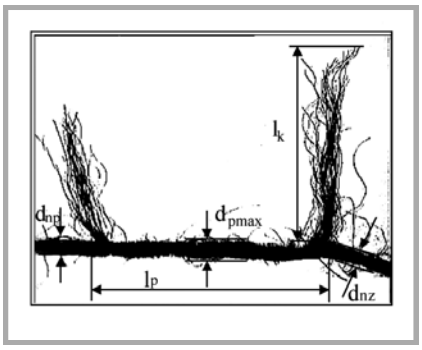


*Figure 3. An example of assigning geometric dimensions of the joint [27].*

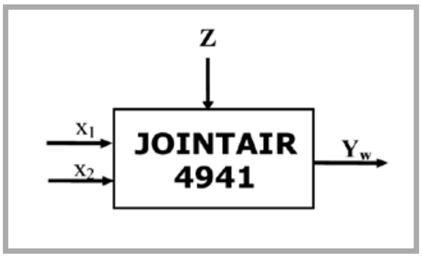


*Figure 4. Examined object; $x_i$ – input variables, $Y_w$ – output variables, Z – non-measurable disturbances.*

in a 2D system was used for the measurements of the geometric dimensions of spliced yarn-end joints. A digital camera CCD NIKON-800 was used, as well as a stereoscopic microscope equipped with a trinocular in order to connect the colour camera STEDDY-T type from the CETI firm and a multimedia card digitizing the image of the video and the computer set with MICROSCAN-1.5 software in the measurement set-up.

A preliminary digital image analysis of the spliced yarn-end joints by automated measuring activities in the 'MicroScan of the Viewer video' system didn't achieve positive results. The basic obstacle in the automation of the activities was the determination of proper measuring points in the structure of the spliced yarn-end joints. The automatic measurement comes down to executing the binary image and to automatic counting up of pixels.

Precision, by sharpening the edge of the image through manual mounting of the cursor and the same measurement, permits us to obtain greater objectivity and accuracy in making the measurement of geometric dimensions by the proper determination of points lying on the edges of the measured object.

Therefore, we also decided to make a manual segmentation of the image and perform the measurements of the geometric dimensions. The measurements of the identified objects were determined on the basis of the measurements of the distance in pixels (***Figure 3***):

- Length of the spliced yarn-end joints – $l_{pi}$ [px], which is the length of the joined structure of both ends of the yarn,
- crosswise dimensions at the yarn jointing – $d_{ni}$, determined as the average value:

$$d_{ni} = \frac{d_{npi} + d_{nzi}}{2} \text{ [px]}, \qquad (1)$$

where: $d_{npi}$ – crosswise dimension of the yarn at the front of the join,
$d_{nzi}$ – crosswise dimension of the yarn behind the join,

- maximum crosswise dimension of the yarn joint – [px],
- coefficient of the increase in the crosswise dimension in the yarn joint:

$$\lambda_{Di} = \left( \frac{d_{p\max i} - d_{ni}}{d_{ni}} \right) \text{ [px]}, \qquad (2)$$

- length of the longer yarn tail, not spliced into the joint – $l_{ki}$ [px].

In earlier examinations, averaged lengths of yarn tails not spliced to the joint were taken into account. The average lengths of protruding yarn tails do not cause errors in more technological processes but errors are created only by the longest protruding tails. They are a threat in more distant processes and only these are able to cause errors. So, we decided to measure the longer protruding tails from joints.

## Methods applied in the analysis of measurements' effects

The analysis of measurements was carried out using their statistical parameters, tests of significance, regression analysis and indicators of multi-criterion assessment of quality. The usage of the presented statistical set permitted us to make a choice of settings of the splicing device ensuring the creation of technologically useful spliced yarn-end joints.

## Tests of significance

In order to check:

- whether setting $l_B$ of the splicing device Jointair 4941 has a statistically significant influence on the geometric dimensions and strength properties of spliced yarn-end joints, the test of the variance analysis according to the single classification was used,
- whether simultaneous changes of settings $t_E$ and $t_A$ in the splicing device Jointair 4941 have a statistically significant impact on the geometric dimensions, the form of splicing fibres in the joint, strength properties and also the integral index of quality of yarns containing spliced yarn-end joints, the test of the variance analysis according to the double classification was used.

Suitable calculations of statistics were executed with the help of the Statistica 7.0 software.

## Regression analysis

As a result of the experiment carried out with the purpose of identification of the splicing process of yarn ends, substitute characteristics were determined approximating the real characteristics of examination of the object. The form of the substitute characteristics was also called the mathematical mode or the regression function, and was determined separately for every output variable $y_W \in Y_W$ (***Figure 4***).

In the examinations carried out, the number of input variables was limited to two (settings of the splicing device Jointair 4941), researching yarns with two nominal linear densityes in such a way that, in every series of examinations, *Ttex = const.*

In the assessment of the relationship between the setting of the splicing device time of preparing yarn ends for splicing – $t_E$ and time of splicing cycle – $t_A$ and their geometric dimensions of joints, static strength with joints and the integrated index of the quality of yarns with joints, the best regression equation was matched, applying the method of rejection. During the analyses, the following were taken into consideration:

- increases in squares of ratios of the multidimensional correlation – $R_w^2$,
- values of Fisher and Snedecor statistics – $F$ ($K$; $N - K - 1$),
- values of statistics of the partial term of equation of the regression – $F_{kr}$ (1; $N - K - 1$).

The presented procedure is most similar to creating the stepping method of the mathematical model describing the subjected process. We not took into consideration the 'pure' stepping method because the Statistica 7.0 system realizes its task according to calculation methods without analyzing the problem. It is necessary to leave the equation of regression as less statistically significant in reliable technological situations, since the technologist has to know even seemingly insignificant impacts on the course of the process, in order to be able to make decisions on the settings.

During the analysis of the assigned and contour diagrams, a check was made of whether the tested function has the line of the inflection, or alternatively the local extreme.

For this purpose, the necessary and the sufficient conditions of existence of the local extreme were examined.

## Multi-criterion assessment of measurable properties of spliced yarn-end joints

A result from earlier reflections was that the quality of spliced yarn-end joints is dependent on various features of these joints. So, it is difficult to find an objective estimation of the quality of spliced yarn-end joints and the assessment of its technological usefulness. A final estimation of the quality of spliced yarn-end joints can be made analytically or synthetically. It is a relatively simple matter to determine the usefulness of the examined product under consideration of a particular feature. In this case, it is sufficient to judge the given feature through its measurements. The situation becomes very complicated when the need to perform a multi-criterion assessment occurs. For the major shortcomings of the analytical methods, we can include the need of consideration each feature irrespective from all other features.

A multi-criterion assessment of the measurable properties of spliced yarn-end joints was performed thanks to the application of the Integral Index of Quality – $Q_Z$, in which were taken into consideration:

- indexes of static strength – $\eta_s$,
- indexes of the increase in crosswise dimensions in the joint of yarn – $\lambda_D$,
- lengths of the spliced joints of the yarn ends – $l_p$,
- lengths of longer yarn ends not spliced to the joint of the yarn – $l_k$.

Weights were allocated to the enumerated features arbitrarily in the three-stage scale – 1, 2, 3:

- the highest mark of importance $t_{\eta_s} = 3$ was allocated to the index of static strength of spliced yarn-end joints, since this parameter plays the most significant part in more distant stages of the technological process, especially from the point of view of undesirable breakage,
- the mark of importance $t_{\lambda_D} = 2$ was allocated to the index of the increase in the crosswise dimension in the joint of the yarn, since an excessive increase in the crosswise dimension has a negative influence not only on the appearance of the spliced joint but on the appearance of the final goods. It may also increase the probability of the occurrence of disturbances when overcoming frictional barriers through the yarns, in the form of heald shafts, guides and needles of knitting machines.
- the mark of importance $t_{l_p} = 1$ was allocated to the length of spliced yarn-end joints, since the used splicing devices forms joints of a length that does not make good visible errors in the final goods,
- the mark of importance $t_{l_k} = 1$ was also allocated to the length of a longer tail of the yarn not spliced to the joint since the error is easily removable from the final goods.

The Integral Index of Quality – $Q_Z$ was determined using the reflections of Żyliński [35], referring to the General Index of Quality.

Among the performed examinations, building the form of the Integral Index of Quality – $Q_Z$, the average values of measurable physical properties of the spliced joints of yarn ends were taken into consideration, the minimal and maximum value of these properties, random errors of the properties and also relative indicators of the subjected features.

Finally, the Integral Index of Quality – $Q_Z$ was expressed with the following formula:

$$Q_{Z_i} = \frac{\sqrt{t_{\eta_s}^2 + t_{\lambda_D}^2 + t_{l_p}^2 + t_{l_k}^2}}{\sqrt{(\frac{t_{\eta_s}}{W_{i\eta'_s}})^2 + (\frac{t_{\lambda_D}}{W_{i\lambda'_D}})^2 + (\frac{t_{l_p}}{W_{il'_p}})^2 + \frac{t_{l_k}}{W_{il'_k}})^2}}, \quad (3)$$

where:

$t_{\eta_s}$ – the ratio of static strength of spliced yarn-end joints,

$t_{\lambda_D}$ – the ratio of the increase in the crosswise dimension in the joint of the yarn,

$t_{l_p}$ – the lengths of spliced yarn-end joints,

$t_{l_k}$ – the lengths of longer protruding tails, not spliced into the joint of the yarn.

The Integral Index of Quality – $Q_Z \geq 0.5$ was regarded as acceptable. To find the settings permitting the creation of joints fulfilling the above-mentioned condition, the analysis of the regression function was carried out:

$$Q_Z = B_0 + B_1 \cdot t_A + B_2 \cdot t_E + B_{11} * t_A^2 + \\ + B_{22} * t_E^2 + B_{12} * t_A * t_E \geq 0.5. \quad (4)$$

## Results and discussion

### Impact of setting the length of protruding tails on the properties of spliced joints

In accordance with the research programme, the methodology of examinations and the methodology of the analysis of the experimental data were carried out to determine the impact of setting the length of protruding tails – $l_B$ on the strength properties and geometric dimensions of spliced yarn-end joints.

As a result of the examinations carried out, it was stated that the analysed setting length of tails protruding behind from joint – $l_B$ does not have a statistically significant influence on the following properties of spliced joints of yarns – $T_{tp} = [16\ 36]^T tex$: static strength, the index of static strength, the length of spliced yarn-end joints, the maximum crosswise dimension of the joint of the yarn and the index of the increase in the crosswise dimension in the joint of the yarn.

A statistically significant influence was only found in the case of the length of protruding yarn tails not spliced to the joint of the yarn. This error is easily removable.

### Impact of the remaining settings on the properties of spliced yarn-end joints

Taking into account the achieved results, the length of protruding tails was assigned a constant value $l_B = 4$ in more distant examinations. In accordance with the presented research programme, the methodology of the examinations and the methodology of the analysis of the effects of measurements were carried out

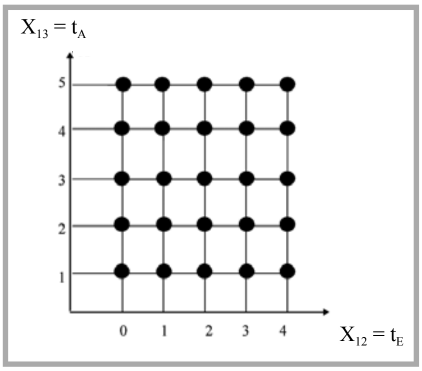


***Figure 5.*** *Corrected plan of the experiment: $Y = f(X_{12}, X_{13}; X_{21})$: Y – analysed properties of yarns $T_{tp} = [16\ 36]^T$ tex with spliced joints, $X_{12} = t_E$ – time of preparing yarn ends for splicing, $X_{13} = t_A$ – time of splicing cycle, $X_{21} = T_{tp}\ [16\ 36]^T$ tex.*

to determine the impact of the settings time of preparing yarn ends for splicing – $t_E$ and time of splicing cycle – $t_A$ on the properties of spliced yarn-end joints – Y, static strength and geometric dimensions joints of yarn ends.

During the realization of the research programme, it was stated that, at the boundary settings of the splicing device Jointair 4941 of the Mesdan firm $t_E = 5$, and $t_A = 0$, it wasn't possible to obtain spliced joints of the tested yarns. Because of this, the plan of the experiment was corrected to the form shown in ***Figure 5***.

## Strength parameters

In the case of yarns with linear densities , joining the yarn ends by splicing always causes a decrease in their static strength in the function of the applied settings. The index of static strength is changed in the range of:

- 66.89% ÷ 90.61% – for yarns with a linear density of 16 tex,
- 73.82% ÷ 96.06% – for yarns with a linear density of 36 tex.

It is worth noticing that the upper value of this index is increasing together with the increase in the linear yarn mass. The impact of settings for the static strength of yarns isn't uniform. The results of statistical inference are taken down in ***Table 2***.

The interaction of the tested settings for the static strength of yarns is diversified. In the case of thin yarns of 16 tex, both settings play a significant part; however, when joining ends of yarns of 36 tex (about the largest linear density), the time of the splicing cycle is significant in turn.

It is possible to explain this phenomenon as follows: when joining thin yarns, a longer time is necessary to obtain the untwisting of the prepared ends of yarn, regarding their twist. A longer time of air blast causes the intensive relaxation of the yarn ends in the splicing chamber. In the case of thick yarns, their twist is significantly lower but the number of fibres in the cross section is significantly larger. Splicing the large number of fibres requires a longer time of the splicing cycle.

### Geometric dimensions of spliced yarn-end joints

Before starting the examinations of spliced yarn-end joints – $T_{tp} = [16\ 36]^T$ *tex*, the structure and the kind of mask of the object were determined separately for every yarn and scaling of the system and the resolving power of the image was established.

### Length of spliced yarn-end joints

In the case of yarns with linear densityes – $T_{tp} = [16\ 36]^T$ *tex*, joining their ends by splicing at variable settings of the time to prepare yarn ends and the time of splicing results in joints of various lengths.

The interaction of the tested settings for the length of spliced yarn-end joints is diversified. The setting time for preparing yarn ends – $t_E$ influences significantly the length of the spliced yarn-end joints for all of the tested yarns. The setting time of splicing – $t_A$ does not influence statistically significantly the length of joints of yarn ends of all the analysed yarns.

### Maximum crosswise dimension of joints

Summing up this fragment of the examinations, it is possible to state that both the analysed controls time of preparing yarn ends – $t_E$ and time of splicing – $t_A$ do not have a statistically significant influence on the maximum crosswise dimension of joints.

However, it is worth looking at the changes in the indexes of the increase in the crosswise dimension in yarn joints – $\lambda_D$. The index of the increase in the crosswise dimension was introduced for the assessment of changes in the increase in the crosswise dimensions of yarns. Analysing the changes in the indexes of the increase in the crosswise dimension in yarn joints, it is possible to notice their random character. The average increase in the crosswise dimension of yarns of 16 tex is relatively small, i.e. 30%; however, the average increase in the crosswise dimension of yarns of 36 tex exceeds 50%.

### Length of the longer yarn tail not spliced to the joint

In the case of yarns with linear densityes $T_{tp} = [16\ 36]^T$ *tex*, joining their ends by splicing with variable settings of the time of preparing the yarn ends – $t_E$ and the time of splicing – $t_A$ results in joints with various length of tails not spliced into the joint.

The interaction of the tested settings for the length of the longer yarn tail not spliced to the joint is diversified. The setting time of preparing the yarn ends – $t_E$ has a statistically significant influence on the lengths of longer tails not spliced into the yarn joint of all the tested yarns. The setting time of splicing – $t_A$ does not have a statistically significant influence on the lengths of longer tails not spliced into the yarn joint.

### Multi-criterion assessment of the measurable properties of yarns with spliced joints of ends

In the examinations, settings were sought that ensured the most profitable

***Table 2.*** *Results of statistical inference referring to the static strength of yarns.*

| Linear density of yarn [tex] | Significance of influence of settings | |
|---|---|---|
| | Time of preparing yarn ends – $t_E$ | Time of splicing – $t_A$ |
| 16 | yes | yes |
| 36 | no | yes |

***Table 3.*** *Coefficients of the regression function, the coefficient of the multidimensional correlation and computing – $F_{comp}$ and critical – $F_{comp}$ statistics of Fisher – Snedecor for the integrated quality index – $Q_Z$.*

| Analysed function | Coefficients of the regression function | | | | | | Values of statistics | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $B_0$ | $B_1$ | $B_2$ | $B_{11}$ | $B_{22}$ | $B_{12}$ | $R^2$ | R | $F_{comp}$ | $F_{cr,\alpha=0.05}$ |
| $Q'_Z = f(t_E; t_A)$ | 0.058 | 0.195 | 0.064 | -0.136 | 0.001 | -0.021 | 0.43 | 0.66 | 2.97 | 2.71 |

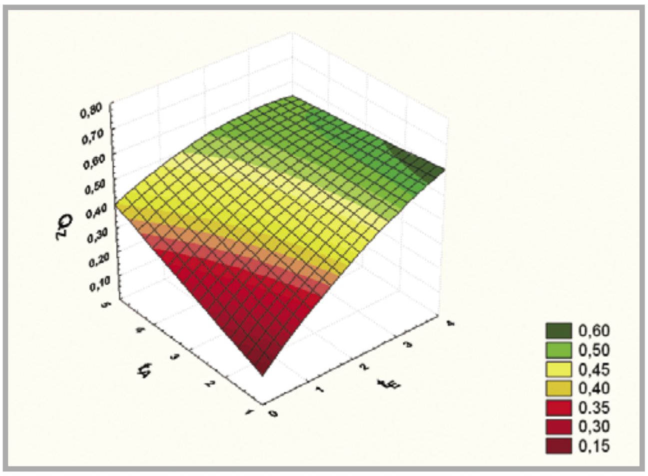


*Figure 6. Plot of the regression function of the integrated quality index $\dot{Q}_Z = f(t_E; t_A)$ of yarns of 16 tex.*

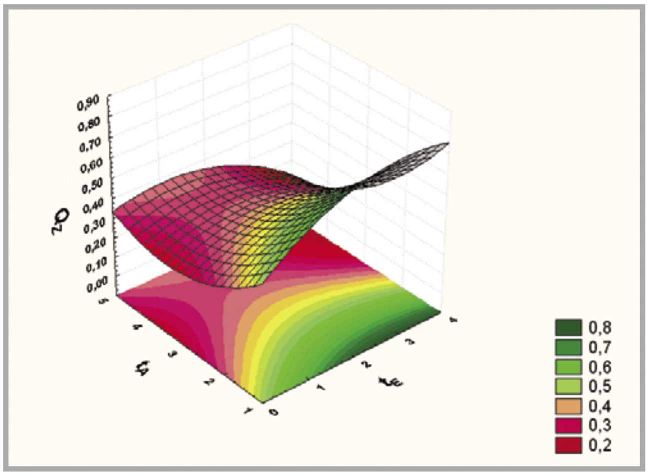


*Figure 8. Plot of the regression function of the integrated quality index $\dot{Q}_Z = f(t_E; t_A)$ of yarns of 36 tex.*

features of spliced joints, for each of the subjected features in turn. So, sets of recommended settings were received. Only one set of settings is useful in the technology, permitting the creation of joints with features fulfilling many criteria.

To check whether simultaneous changes in the settings of the splicing device $t_E$ and $t_A$ have a statistically significant influence on the Integral Index of Quality – $Q_Z$, statistical inferences were taken using the test of the variance analysis according to the double classification.

### Yarns with a linear density of 16 tex

Following the determined statistics $F_{tE} = 9.54 > 3.01 = F_{TE,\alpha=0.05}$, it is possible to state that the time of preparing yarn ends for splicing – $t_E$ has a statistically significant influence on the averages of the integral indexes of quality of 16 tex yarns with joints.

With the determined statistics

$$F_{tA} = 0.96 > 3.01 = F_{TA,\alpha=0.05},$$

it is possible to state that the time of the splicing cycle – $t_A$ does not have a statistically significant influence on the average values of the integrated quality indexes of 16 tex yarns with joints. To illustrate the changes in the integrated quality index $\bar{Q}_Z$ in the function of the settings time of preparing yarn ends – $t_E$ and time of splicing – $t_A$, the form of replacement characteristics $\dot{Q}_Z = f(t_E; t_A)$ was determined. The coefficients of the regression function, the coefficient of the multidimensional correlation and computing – $F_{comp}$ and critical – $F_{comp}$ statistics of Fisher–Snedecor are presented in ***Table 3***.

A graphical image of the interaction of the time of preparing yarn ends – $t_E$ and of the time of splicing – $t_A$ for forming the integrated quality index $Q_Z$ is illustrated in ***Figure 6***.

The settings of the splicing device to ensure joints of 16 tex are obtained with the Integrated Index of Quality $Q_Z = R^+ \cup \{0.5\}$ are presented in ***Figure 7***. These settings were found as a result of the analysis of the regression function:

$$Q_Z = 0.058 + 0.195 * t_A + 0.064 * t_E - 0.0136 * t_A^2 + 0.001 * t_E^2 - 0.021 * t_A * t_E \geq 0.5$$

### Yarns with a linear density of 36 tex

With the determined statistics

$$F_{tE} = 1.41 < 3.01 = F_{TE,\alpha=0.05},$$

it is possible to state that the time of preparing yarn ends for splicing – $t_E$ does not have a statistically significant influence on the average values of integrated quality indexes of yarns of 36 tex with joints. With the determined statistics

$$F_{tA} = 11.12 < 3.01 = F_{TA,\alpha=0.05},$$

it is possible to state that the time of splicing – $t_A$ has a statistically significant influence on the average values of integrated quality indexes of yarns of 36 tex with joints.

To illustrate the changes in the integrated quality index $\bar{Q}_Z$ in the function of the settings time of preparing yarn ends for splicing – $t_E$ and time of splicing – $t_A$, the form of replacement characteristics $\dot{Q}_Z = f(t_E; t_A)$ was determined. The coefficients of the regression function, the coefficient of the multidimensional correlation and computing – $F_{comp}$ and critical – $F_{comp}$ statistics of Fisher–Snedecor are presented in ***Table 4***.

A graphical image of the interaction of the time of preparing yarn ends for splicing – $t_E$ and of the time of splicing cycle – $t_A$ for forming the integrated quality index $Q_Z$ is illustrated in ***Figure 8***.

The settings of the splicing device assuring joints of 36 tex are obtained with the Inte-

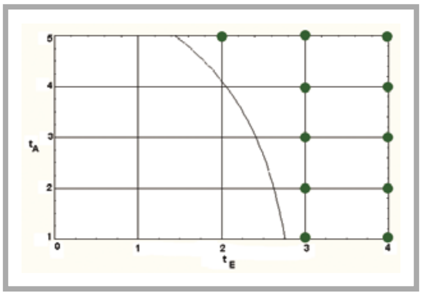

*Figure 7. Settings of the splicing device Jointair 4941 of the Mesdan firm to ensure joints of 16 tex are obtained with the Integrated Index of Quality – $Q_Z = R^+ \cup \{0.5\}$.*

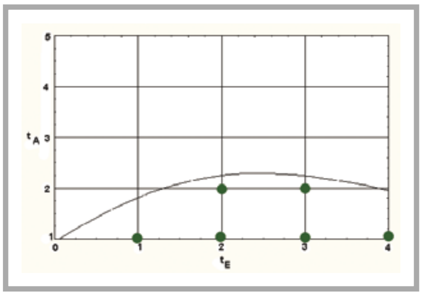

*Figure 9. Settings of the splicing device Jointair 4941 of the Mesdan firm assuring of joints of 36 tex are obtained with the Integrated Index of Quality – $Q_Z = R^+ \cup \{0.5\}$.*

***Table 4.*** *Coefficients of the regression function, the coefficient of the multidimensional correlation and computing – $F_{comp}$ and critical – $F_{comp}$ statistics of Fisher–Snedecor for the integrated quality index – $Q_Z$.*

| Analysed function | Coefficients of the regression function | | | | | | Values of statistics | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $B_0$ | $B_1$ | $B_2$ | $B_{11}$ | $B_{22}$ | $B_{12}$ | $R^2$ | R | $F_{comp}$ | $F_{cr,\alpha=0.05}$ |
| $\dot{Q}_Z = f(t_E; t_A)$ | 0.707 | 0.219 | -0.254 | -0.030 | 0.035 | -0.029 | 0.80 | 0.89 | 15.60 | 2.71 |

grated Index of Quality $Q_Z = R^+ \cup \{0.5\}$ are presented in ***Figure 9***. These settings were found as a result of the analysis of the regression function:

$$Q_Z = 0.707 + 0.219 * t_E - 0.254 * t_A - + 0.030 * t_A^2 + 0.035 * t_E^2 - 0.029 * t_E * t_A .$$

## Conclusions

The realization of the examinations allowed us to draw the following final conclusions (on the significance level of $\alpha$ = 0.05) referring to the settings of the Jointair 4941 splicing device:

1. Setting the length of protruding tails has a statistically significant influence only on the length of the longer tails not spliced into the joint.

2. The interaction of the settings time of preparing yarn ends and time of splicing on the strength of spliced yarn-end joints is diversified. In the case of thin yarns of 16 tex, both of the settings have significant importance, whereas for joints of yarns of 36 tex, only the time of splicing is significant.

3. The setting time of preparing yarn ends significantly influences the length of spliced end-joints for all of the yarns subjected – $T_{tp} = [16\ 36]^T$ *tex*; however, the setting time of splicing does not have a statistically significant influence on the length of spliced yarn-end joints for all of the analysed yarns.

4. The interaction of the settings time of preparing yarn ends and time of splicing on the length of the longer tails not spliced into the joint is diversified. The setting time of preparing yarn ends influences significantly the length of the longer tails not spliced into the joint of all the subjected yarns; however, the setting time of splicing does not have a statistically significant influence on the length of the longer tails not spliced into the joint.

5. The interaction of the settings time of preparing yarn ends and time of splicing on the integrated quality index of spliced end joints is diversified. In the case of thin yarns of 16 tex, the impact of the time of splicing is more intensive, whereas in the case of thicker yarns of 36 tex, the influence of the time of preparing yarn ends is more intensive.


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