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# Prediction of Properties of Unknotted Spliced Ends of Yarns Using Multiple Regression and Artificial Neural Networks. Part II: Verification of Regression Models

**Abstract**
*A verification of regressive models based on artificial neural networks and multiple regression analysis was carried out. The analysis of the results obtained showed that artificial neural networks realizing regressive operations are useful for identifying the character of changes of additive quantities, in particular geometric dimensions and strength parameters. However, they are not suitable for identifying non-additive features, represented by tangling as well as teaseling. In this case, better predictive possibilities are provided by models based on multiple regression.*

**Key words:** *layer diagrams, surface diagrams, learning quality, validation quality, testing quality, learning error, validation error, testing error, correlation.*

## Introduction

The first part of the article [1] presented the construction of the package of artificial neural networks realizing regressive tasks, designed for the technological identification of the pneumatic splicing process of ends of yarns and the prediction of the physical properties of unknotted joints of yarn ends represented by additive and non-additive quantities. For this purpose, models were designed based on artificial neural networks (ANN), particularly a multilayer perceptron network (MLP) and a general neural regression network (GRNN), and alternatively models based on multiple regression. The mathematical analysis, creating the model and structures of ANN structures, were designed using the software environment STATISTICA for NEURAL NETWORKS.

### A. Verification of the quality of the models based on multiple regressions

The verification of the models based on multiple regression was carried out in accordance with the research procedure characterized in the first part of the article.

***The realization of the plan and carrying out the research experiment – step 1***

During the realization of the research, in the sampling from the Jointair 4941 splicing device, it was stated that there was no chance of obtaining spliced joints of yarn ends at the settings of both $t_A = 0$ and $t_E = 5$. During the preliminary attempts at technological research, when taking samples with the combination of settings of the splicing device Jointair 4941 $t_A = 1$ and $t_E = 0$, only 15 joints were executed. Taking into consideration the necessary number of measurements stated, to take 70 samples for splicing with the combination of settings $t_A = 1$ and $t_E = 0$ around 470 joints would need to be executed, which would considerably shorten the operation lifetime of the splicing device and has no economic justification, because it would considerably extend the elapsed time of production.

With reference to the above-mentioned experiment of the type 5 × 5, two plans of the types 5 × 4 and 4 × 5 were corrected – ***Figure 1***.

***Creation of the database – step 2***

The database given in the form of the results of measurements of additive quantities and non-additive features, as well as of images of unknotted spliced joints of yarn ends, was created in accordance with the assumed methodology characterized in the first part of the article.

***Assessment of the interaction settings of the Jointair 4941 splicing device on the properties of joints by means of the test of variance analysis according to the double classification – step 3***

Proceeding in accordance with the assumed research procedure, the test of the variance analysis according to the double classification was carried out in the first order. The results of the test are shown together in ***Table 1***.

The analysis of the data set together proves that:

- simultaneous changes of settings $t_A$ and $t_E$ of the splicing device Jointair 4941 exert an impact on the maximal increase of the crosswise dimension of the joint – max $\lambda'_D$, the coefficient of the retained spliced breaking elongation – $\eta_E$ and the coefficient of the retained spliced strength – $\eta_W$ (only in the plan of research 5 × 4) of the joint,
- simultaneous changes of the settings $t_A$ and $t_E$ of the splicing device Jointair 4941 do not exert an impact on non-additive features, represented through tangling – $S_p$ and teaseling – $M_p$,
- only changes of setting $t_A$ influence the length of the joint – $l_p$, without regard to the analysed plan of research,
- the interaction of settings $t_A$ and $t_E$ for the length of the ends protruding from the joint $l_k$ is made dependent on the plan accepted in the analysis of the experiment. In the case of analysing the data according to the 5 × 4 plan, an insignificant impact of the setting $t_A$ and a lack of the interaction variable $t_E$ are apparent. A completely different situation takes place in the case of analysing the data according to the 4 × 5 plan, where the control $t_A$ has no influence; however, the very large interaction of the setting $t_E$ is marked.

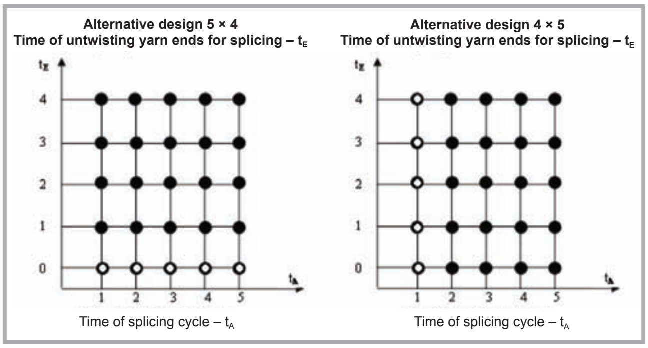


***Figure 1.*** *Corrected plan of research of the physical properties, geometric dimensions and non-measurable features of spliced joints of yarn ends from the worsted woollen single yarn – 15 tex.* ***Note:*** *variations rejected from the statistical data analysis are marked with* **O**.

***Assessment of the significance of the regression function and analysis of the surface and layer diagrams – step 4***

In the more distant order, functions of regression were assigned together with their graphical interpretation in the form of surface and layer diagrams. The results of the estimation of the summarized statistics are shown together in ***Table 2***.

The analysis of the data set together proves that:

- of the two examined settings of the splicing device Jointair 4941, the larger interactions exert changes in the time of untwisting yarn ends for splicing – $t_E$,
- without regard to the analysed plan of the experiment 5 × 4 or 4 × 5, replacement characteristics were not found for the length of joint – $l_p$ and tangling of the joint – $S_p$,
- replacement characteristics were found for the coefficient of retained spliced strength – $\eta_W$, only in the case of the plan of the experiment 5 × 4,
- replacement characteristics were found for the length of yarn ends protruding from the joint – $l_k$, only in the case of the plan of the experiment 4 × 5,
- replacement characteristics were found for the teaseling of the joint – $M_p$, after elimination *a posteriori* of the $B_1 \cdot t_A$ modulus function,
- replacement characteristics were found for the maximal increase of the crosswise dimension of the joint – max $\lambda'_D$ and the coefficient of the retained spliced breaking elongation – $\eta_E$, applying both the plans of the experiment 5 × 4 and 4 × 5.

The forms of statistically significant regression functions which obtained, are presented as the set of equations (1).

In order to characterize the quality of the interaction settings $t_A$ and $t_E$ of the splicing device Jointair 4941 for the physical properties of unknotted joints, surface and layer diagrams were made for the statistically significant functions of the regression for the largest value – $R^2$, R and $F_{calc}$ (***Figures 2-5***).

An analysis of the diagrams shown in ***Figure 2*** proves that, for the length of yarn ends protruding from the joint – $l_k$, changes in the time of untwisting yarn ends for splicing – $t_E$ have a considerably larger influence, but changes in the time of the splicing cycle – $t_A$ have a significantly smaller influence. Together with the increase of the $t_E$, in the whole analysed range of the $t_A$ time, length $l_k$ decreases to the quantity determined by the equation: $t_E = 2.69 – 0.01\ t_A$, but after its exceeding it grows slightly.

Analysing the diagrams shown in ***Figures 3*** and ***5***, it is possible to notice that they have very similar proceedings. Along with the simultaneous increase in $t_A$ and $t_E$ times, the maximal increase of the crosswise dimension of the joint – max $\lambda'_D$ and the coefficient of the retained spliced breaking elongation – $\eta_E$ decrease. The greater influence on the quantity of the analysed properties of the joint exert changes in the time of untwisting yarn ends for splicing – $t_E$. Changes of the coefficient of the retained spliced strength – $\eta_W$ of the joint have a completely different and quite complex character (see ***Figure 4***). The analysed function of the regression doesn't possess the local extreme, but only the line of the inflection described by means of the equation: $t_A = 1.73 + 0.23\ t_E$. The most profitable values of the coefficient of retained spliced strength – $\eta_W$ of the joint are included in the interval of times: $t_A = 1 \div 3$ and $t_E = 1 \div 2$.

The layer and the surface diagrams of the regression function, executed for

***Table 1.*** *Results of the test of variance analysis according to the double classification;* ***Note:*** *Statistically significant values of the test are bolded.*

| Analysed parameter of spliced joint | Experiment 5 × 4 | | | | Experiment 4 × 5 | | | |
|---|---|---|---|---|---|---|---|---|
| | setting $t_A$ | | setting $t_E$ | | setting $t_A$ | | setting $t_E$ | |
| | $F_{A,\alpha}$ | $F_{cric.}$ | $F_{E,\alpha}$ | $F_{cric}$ | $F_{A,\alpha}$ | $F_{cric}$ | $F_{E,\alpha}$ | $F_{cric}$ |
| Length of joint – $l_p$ (mm) | **3.38** | 3.26 | 0.94 | 3.49 | **4.20** | 3.49 | 1.49 | 3.26 |
| Length of yarn ends protruding from joint – $l_k$ (mm) | **3.91** | 3.26 | 0.62 | 3.49 | 2.76 | 3.49 | **57.18** | 3.26 |
| Maximal increase of crosswise dimension of joint – max $\lambda'_D$ | **4.63** | 3.26 | **20.30** | 3.49 | **5.87** | 3.49 | **26.69** | 3.26 |
| Coefficient of retained spliced strength – $\eta_W$ (%) | **5.96** | 3.26 | **3.56** | 3.49 | 1.44 | 3.49 | 0.59 | 3.26 |
| Coefficient of retained spliced breaking elongation – $\eta_E$ (%) | **7.16** | 3.26 | **6.99** | 3.49 | **5.41** | 3.49 | **6.55** | 3.26 |
| Tangling – $S_p$ | 0.56 | 3.26 | 0.45 | 3.49 | 0.61 | 3.49 | 2.22 | 3.26 |
| Teaseling – $M_p$ | 1.69 | 3.26 | 0.48 | 3.49 | 2.08 | 3.49 | 1.70 | 3.26 |

***Table 2.*** *Results of the estimation of significance of the assigned regression function *)* ***Note:*** *statistically significant functions of the regression are written in* ***bold****, whereas statistically significant functions of the regression, which surface and layer diagrams were made, are written in italic.*

| In. | Analysed parameter of spliced joint | Experiment 5 × 4 | | | | Experiment 4 × 5 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R^2$ | R | $F_{calc}$ | $F^5_{14}$ | $R^2$ | R | $F_{calc}$ | $F^5_{14}$ |
| 1 | Length of joint – $l_p$ | 0.293 | 0.544 | 1.16 | 2.96 | 0.198 | 0.444 | 0.69 | 2.96 |
| 2 | Length of yarn ends protruding from joint – $l_k$ | 0.246 | 0.496 | 0.91 | 2.96 | *0.782* | *0.884* | *10.07* | *2.96* |
| 3 | Maximal increase of crosswise dimension of joint – max $\lambda'_D$ | **0.739** | **0.860** | **7.94** | **2.96** | *0.867* | *0.931* | *18.35* | *2.96* |
| 4 | Coefficient of retained spliced strength – $\eta_W$ | *0.538* | *0.734* | *3.27* | *2.96* | 0.408 | 0.638 | 1.93 | 2.96 |
| 5 | Coefficient of retained spliced breaking elongation – $\eta_E$ | **0.671** | **0.819** | **5.71** | **2.96** | *0.782* | *0.884* | *10.08* | *2.96* |
| 6 | Tangling – $S_p$ | 0.119 | 0.345 | 0.38 | 2.96 | 0.424 | 0.651 | 2.06 | 2.96 |
| 7 | Teaseling – $M_p$ | 0.325 | 0.571 | 1.35 | 2.96 | 0.503 | 0.709 | 2.83 | 2.96 |
| 8 | Teaseling – $M_p$ | | | | | $R^2$ | R | $F_{calc}$ | $F^5_{14}$ |
| | | | | | | *0.502* | *0.708* | *3.776* | *3.06* |

$$\hat{l}_k = 9{,}339 + 0{,}673 \cdot t_A - 7{,}152 \cdot t_E - 0{,}168 \cdot t_A^2 + 1{,}331 \cdot t_E^2 + 0{,}020 \cdot t_A \cdot t_E \quad ^{*)}$$

$$\max \hat{\lambda}'_D = 2{,}339 - 0{,}079 \cdot t_A - 0{,}179 \cdot t_E + 0{,}006 \cdot t_A^2 + 0{,}025 \cdot t_E^2 - 0{,}007 \cdot t_A \cdot t_E \quad ^{*)}$$

$$\hat{\eta}_W = 87{,}921 + 6{,}410 \cdot t_A - 9{,}086 \cdot t_E - 1{,}755 \cdot t_A^2 + 0{,}699 \cdot t_E^2 + 0{,}847 \cdot t_A \cdot t_E \quad ^{*)}$$

$$\hat{\eta}_E = 96{,}331 - 5{,}690 \cdot t_A - 2{,}974 \cdot t_E + 0{,}442 \cdot t_A^2 + 0{,}365 \cdot t_E^2 - 0{,}746 \cdot t_A \cdot t_E \quad ^{*)}$$

$$\hat{M}_p = 2{,}096 - 0{,}095 \cdot t_E - 0{,}004 \cdot t_A^2 + 0{,}028 \cdot t_E^2 - 0{,}017 \cdot t_A \cdot t_E \quad ^{*)} \qquad (1)$$

***Equation 1.***

teaseling of the joint – $M_p$, are shown in ***Figure 6***. Of both the analysed settings of the splicing device, changes of the $t_E$ control have a significantly greater influence on teaseling. The analysed function of the regression doesn't possess the local extreme, but only the line of the inflection. Along with the increase in the time of untwisting yarn ends for splicing – $t_E$, in the whole analysed range of $t_A$ times, the teaseling of the connection decreases to the value $t_E = 1.70 + 0.30\ t_A$, but after its exceeding it increases slightly.

***Assessment of the Pearson's correlation matrix between geometric dimensions, strength properties and non-measurable features for unknotted spliced joints of yarn ends – step 5***

The estimation of the correlation between geometric dimensions, strength properties and non-additive features is shown together in ***Tables 3*** and ***4.***

Describing verbal labels characterizing the intensity of the correlation was derived from the publication by A. Stanisz [2] . The data analysis shows that the correlation is made dependent on the plan accepted for the analysis of the experiment to a very large degree.

***The choice of optimal value levels of settings of the splicing device – step 6***

The analysis of the research carried out shows that there are no single optimal settings of the splicing device Jointair 4941 dominating the remaining settings, of which the best qualitative indices are obtained for the unknotted joints of yarn ends.

Moreover, the results of the research confirmed that a "good"-looking joint is not able to fulfil the strength criteria and also yarns distinguishing themselves with suitable durability of the executed joint retain a low evaluation under visual consideration. Because it is stated that, along with the increase of the maximal increase of the crosswise dimension of the joint – max $\overline{\lambda}_D$, i.e. the parameter making the appearance worse, the coefficient of the retained spliced strength – $\overline{\eta}_D$ as well as the coefficient of the retained spliced breaking elongation – $\overline{\eta}_E$ are increasing. However, from the point of view of the more distant processing of the yarn in the operations of warping and weaving, it is above all necessary to be guided by the strength consideration and to avoid at all costs breakages in the process of weaving.

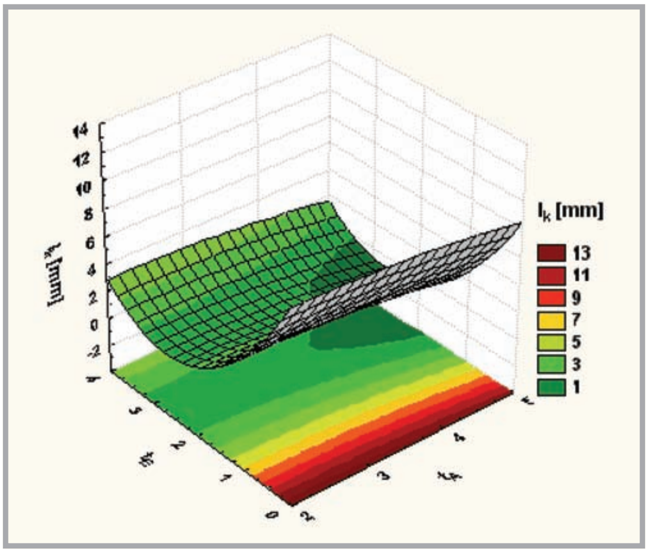


***Figure 2.*** *The diagrams $\hat{l}_k = f\ (t_A\ ;\ t_E)$; the plan of the experiment 4 × 5.*

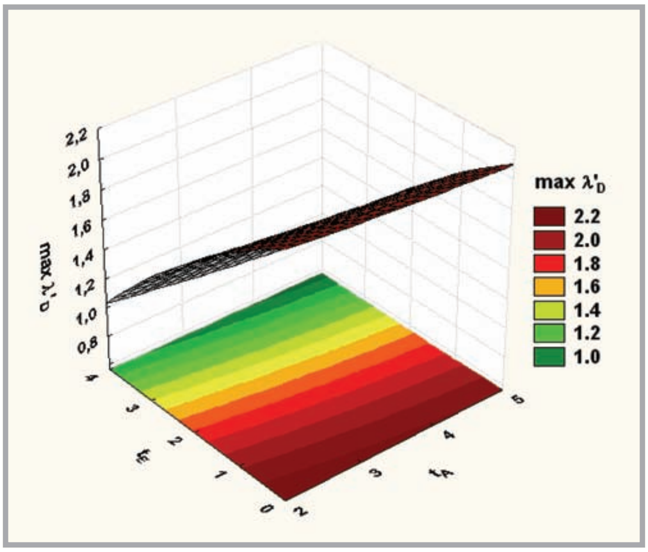


***Figure 3.*** *The diagrams $\hat{\lambda}'_D = f\ (t_A\ ;\ t_E)$; the plan of the experiment 4 × 5.*

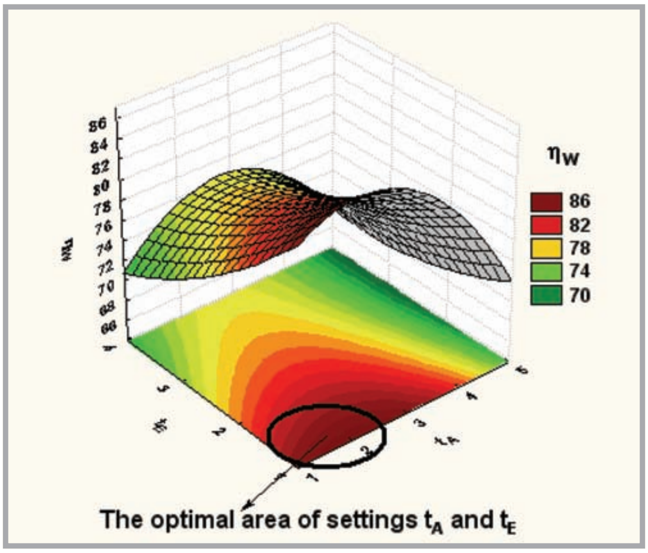


***Figure 4.*** *The diagrams $\hat{\eta}_W = f\ (t_A\ ;\ t_E)$; the plan of the experiment 5 × 4.*

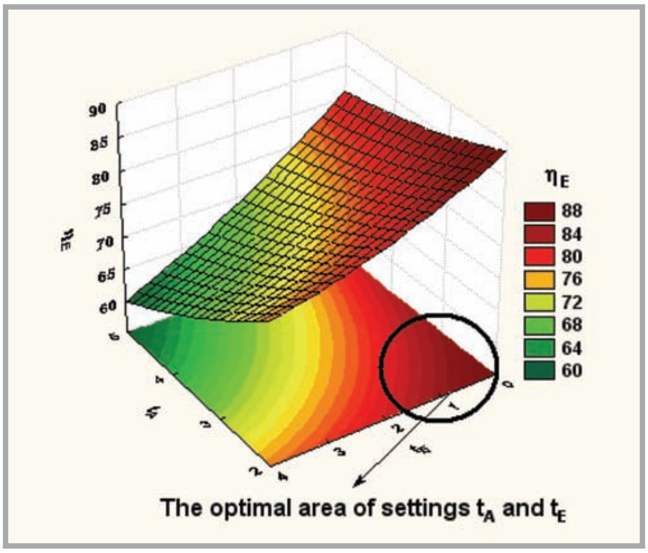


***Figure 5.*** *The diagrams $\hat{\eta}_W = f\ (t_A\ ;\ t_E)$; the plan of the experiment 4 × 5.*

Therefore, wanting to obtain joints marked by high values from coefficients $\bar{\eta}_W$ and $\bar{\eta}_E$, above 80%, it is necessary to apply the time of untwisting the yarn ends for splicing $t_E = 1$, with the chance of the selection time of the splicing cycle $t_A$ in the area of settings $t_A = 1 \div 3$ (see ***Figures 4*** and ***5***).

## Verification of the quality of neural models

### *The realization of the plan and carrying out the research experiment – step 1*

As it has already been remembered, during the realization of the research and taking samples from the Jointair 4941 splicing device, it was stated that there had been no chance to obtain joints of yarn ends at settings $t_A = 0$ and $t_E = 5$. During the preliminary attempts at technological research, when taking samples with the combination of settings of the splicing device Jointair 4941 equal to $t_A = 1$ and $t_E = 0$, only 15 joints were executed.

Therefore, 24 variations of the research were taken into consideration in the analysis, each repeated 50 times, and the 1 variation of research repeated 15 times. In this connection, 1215 experiments were carried out, all things considered.

### *Creation of the database – step 2*

The database, in the form of the results of the research of additive and non-additive quantities, as well as of images of unknotted joints of yarn ends, was created in accordance with the assumed methodology of measurements, characterized in the first part of the article.

### *Modelling geometric dimensions, strength properties and non-additive features when using artificial neural networks – step 3*

In accordance with the assumed research programme, artificial neural networks of the multilayer perceptron (MLP) type with a diversified number of neurons and a diversified number of concealed layers were applied for modelling the properties of unknotted spliced joints of yarn ends. They were used both from the option of the designer of the user of the network and of the automatic designer of the network. The artificial neural network realizing the generalized regression (GRNN) was also applied.

### *Assessment of the quality of learned artificial neural networks – step 4*

***Table 3.*** *Assessment of Pearson's correlation matrix between geometric dimensions, strength properties and non-additive features – experiment 5 × 4.*

| Properties of joints | $\bar{l}_p$ | $\bar{l}_k$ | max $\bar{\lambda}'_D$ | $\bar{\eta}_W$ | $\bar{\eta}_E$ | $\bar{S}_p$ | $\bar{M}_p$ |
|---|---|---|---|---|---|---|---|
| Length of joint – $\bar{l}_p$ | | (–) very high | (–) average | (–) high | (–) high | (–) high | (–) high |
| Length of ends protruding from joint – $\bar{l}_k$ | (–) very high | | (+) average | (+) high | (+) average | (+) high | (+) high |
| Maximal increase of crosswise dimension of joint – max $\bar{\lambda}'_D$ | (–) average | (+) average | | (+) very high | (+) very high | (+) high | (+) high |
| Coefficient of retained spliced strength – $\bar{\eta}_W$ | (–) high | (+) high | (+) very high | | (+) almost full | (+) average | (+) high |
| Coefficient of retained spliced breaking elongation – $\bar{\eta}_E$ | (–) high | (+) average | (+) very high | (+) almost full | | (+) average | (+) high |
| Tangling – $\bar{S}_p$ | (–) high | (+) high | (+) high | (+) average | (+) average | | (+) very high |
| Teaseling – $\bar{M}_p$ | (–) high | (+) high | (+) high | (+) high | (+) high | (+) very high | |

***Table 4.*** *Assessment of Pearson's correlation matrix between geometric dimensions, strength properties and non-additive features – experiment 4 × 5. Legend: (+) dependence directly proportional, (–) dependence inversely proportional.*

| Properties of joints | $\bar{l}_p$ | $\bar{l}_k$ | max $\bar{\lambda}'_D$ | $\bar{\eta}_W$ | $\bar{\eta}_E$ | $\bar{S}_p$ | $\bar{M}_p$ |
|---|---|---|---|---|---|---|---|
| Length of joint – $\bar{l}_p$ | | (–) faint | (–) faint | (–) average | (–) average | (–) average | (–) average |
| Length of ends protruding from joint – $\bar{l}_k$ | (–) faint | | (–) very high | (–) faint | (–) high | (–) high | (–) high |
| Maximal increase of crosswise dimension of joint – max $\bar{\lambda}'_D$ | (–) faint | (+) very high | | (+) average | (+) very high | (+) very high | (+) very high |
| Coefficient of retained spliced strength – $\bar{\eta}_W$ | (–) average | (+) faint | (+) average | | (+) very high | (+) average | (+) average |
| Coefficient of retained spliced breaking elongation – $\bar{\eta}_E$ | (–) average | (+) high | (+) very high | (+) very high | | (+) high | (+) very high |
| Tangling – $\bar{S}_p$ | (–) average | (+) high | (+) very high | (+) average | (+) high | | (+) almost full |
| Teaseling – $\bar{M}_p$ | (–) average | (+) high | (+) very high | (+) average | (+) very high | (+) almost full | |

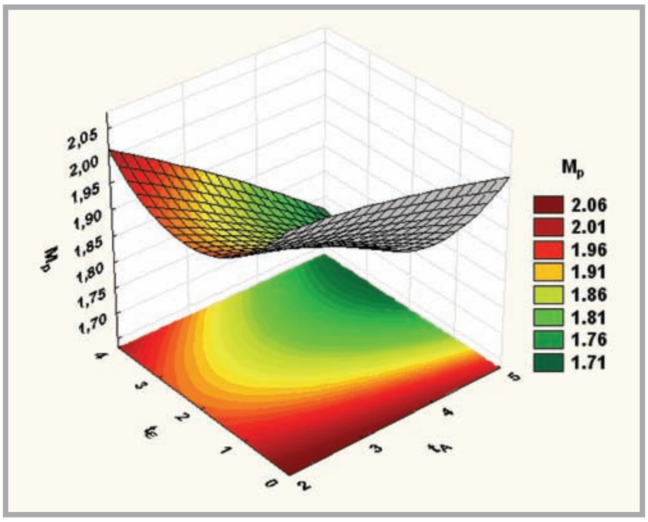


***Figure 6.*** *The diagrams $\bar{M}_p = f\ (t_A;\ t_E)$; the plan of the experiment 4 × 5.*

In accordance with the plan of technological identification of the process of unknotted joining of yarn ends restated in the first part of the article, for every analysed parameter describing additive quantities and non-additive features was assigned the learning quality and the learning errors of ANN. Values of the network were determined for teaching, validation and testing subsets. Moreover,

*__Table 5.__ Assessment of the quality parameters shown together in statistics summing up the quality. Legend: Assessment of network quality: Poor, Average, High.*

| In. | Analysed quality parameter of the network | Assessment of quality | | |
|---|---|---|---|---|
| 1 | Learning – LQ, validation – VQ and testing quality – TQ | Q > 0.90 | 0.75 ≤ Q ≤ 0.90 | Q < 0.75 |
| | | Small | Middle | High |
| 2 | Learning – LE, validation – VE and testing error – TE | Er > 0.20 | 0.12 ≤ Er ≤ 0.20 | Er < 0.12 |
| | | Big | Middle | Small |
| 3 | Quotient of deviations – $Q_{STD}$ | Qt > 0.95 | 0.95 ≥ Qt ≥ 0.85 | Qt < 0.85 |
| | | Big | Middle | Small |
| 4 | Pearson's correlation | $r_{xy}$ < 0.3 | 0.3 ≤ $r_{xy}$ < 0.5 | $r_{xy}$ ≥ 0.5 |
| | | Weak | Average | High |

*__Table 6.__ Descriptive statistics assigned to additive and non-additive features of unknotted joints of yarn ends using artificial neural networks of the type multilayer perceptron (MLP) from the option of the designer of the user of the network. Legend: Assessment of network quality: Poor, Average, High.*

| In. | Analysed parameter of the neural network | Properties of unknotted spliced joints of yarn ends | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Additive quantities | | | | | Non-additive features | |
| | | $l_p$ | $l_k$ | max $\lambda'_D$ | $\eta_W$ | $\eta_E$ | $S_p$ | $M_p$ |
| | | MLP 2–3–1 log. | MLP 2–3–3–1 log. | MLP 2–3–3–1 log. | MLP 2–3–3–1 lin. | MLP 2–3–3–1 lin. | MLP 2–2–3–1 lin. | MLP 2–3–3–1 lin. |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | Learning quality – LQ | 0.858 | 0.661 | 0.833 | 0.948 | 0.875 | 0.964 | 0.949 |
| 2 | Validation quality – VQ | 0.872 | 0.658 | 0.886 | 0.938 | 0.890 | 0.977 | 0.988 |
| 3 | Testing quality – TQ | 0.944 | 0.724 | 0.874 | 0.980 | 0.924 | 0.959 | 0.984 |
| 4 | Learning error – LE | 0.130 | 0.106 | 0.104 | 0.148 | 0.165 | 0.273 | 0.246 |
| 5 | Validation error – VE | 0.127 | 0.097 | 0.112 | 0.152 | 0.175 | 0.271 | 0.244 |
| 6 | Testing error – TE | 0.131 | 0.118 | 0.112 | 0.160 | 0.173 | 0.291 | 0.249 |
| 7 | Quotient of deviations – $Q_{STD}$ | 0.879 | 0.677 | 0.862 | 0.954 | 0.891 | 0.966 | 0.967 |
| 8 | Pearson's correlation – $C_P$ | 0.476 | 0.736 | 0.507 | 0.301 | 0.454 | 0.259 | 0.256 |

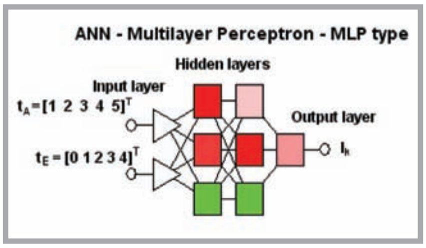


*__Figure 7.__ Architecture of the ANN of the type MLP 2–3–3–1, designed from the option of the designer of the user of the network for the length of yarn ends protruding from the joint $l_k$.*

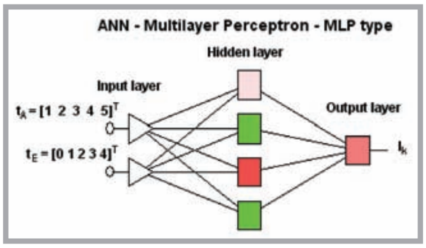


*__Figure 8.__ Architecture of the ANN of the type MLP 2–4–1, designed from the option of the automatic designer of the network for the coefficient of retained spliced strength $\eta_W$.*

the accuracy of the regression using the quotient of deviations of standard errors of the prediction and the deviations of standard measuring data and of the coefficient of R Pearson correlation were characterized. For every parameter of the spliced joint, the architecture of 15 artificial networks was analysed. The values of the parameters of the network are accessible in the periodical "Fibers and Textiles in Eastern Europe". Using literature news, as well as taking into consideration experience from the field of the textile industry and of mapping objects, the graphical method of describing the quality and accuracy of learning ANN was presented but the ranges of values characterizing quality and accuracy were accepted arbitrarily – ***Table 5***.

The intensity of the interaction of the value of ranges accepted arbitrarily is presented graphically, describing the quality and accuracy of the SSN teaching – ***Table 5***. It is limited to the combination of the most beneficial of possible cases in the presented article, for which the network obtained the choice of quality of learning, the smallest learning errors and was proved to have the greatest accuracy.

Describing values of adding up statistics characterizes the quality and accuracy of the learning network obtained from the option of the designer of the user of the network shown together in ***Table 6***. The analysis of data shown together in the tables points out that, by means of neural models, it is possible to obtain high accuracy of the regression in regard to the prediction of geometric dimensions of unknotted joints represented by the length of yarn ends protruding from the joint – $l_k$ and a maximal increase of the crosswise dimension of the joint – $\lambda'_D$.

The best quality of learning, the smallest learning error and the greatest learning accuracy were obtained for the additive quantity – $l_k$ by means of the MLP 2–3–3–1:1 architecture network (one neuron in the input layer, two hidden layers included three neurons in each of them and one neuron in the output layer) and using the logistic function of the activation. The graphical structure of this network is shown in ***Figure 7***.

In turn, a not-very-profitable learning quality was observed for the architecture of MLP 2–2–3–1 networks with the linear function of the activation in regard to non-additive features represented by tangling – $S_p$ and teaseling – $M_p$ (see ***Table 6***). The above-mentioned state doesn't have the content-related justification but it is caused "with implicit obedience" of the learning network procedures on the basis of measuring the data fed to the set-up.

The values of adding up statistics characterizing the quality and accuracy of the learning network, obtained from the option of the automatic designer of the network, are shown together in ***Table 7***.

While carrying out the learned procedures, connected with creating the architecture's multilayer perceptron (MLP) networks, when using the automatic designer of the network, a similar quality of learning of the network to that of the option from the designer of the user of the network was obtained. The best quality of learning, the smallest learning error, as well as the greatest accuracy of learning were also obtained for the additive quantity – $l_k$, by means of network MLP 2–4–1 with the linear function of the activation – see ***Figure 8***. However, it is necessary to take note that better quality and accuracy of the learning network were obtained when using the option of the designer of the user network.

Analysing together the effects of the statistics adding up in ***Table 8***, it is possible to find that, when using artificial neural networks realizing the generalized regression (GRNN) for all additive quantities and non-additive features of unknotted spliced joints of yarn ends, poor quality and a low accuracy of learning were obtained.

Special note, however, should be made that very small errors of learning the network in regard to additive quantities are represented by the strength parameters of joints, i.e. the coefficient of retained spliced strength – $\eta_W$ and the coefficient of retained spliced breaking elongation – $\eta_E$. The example view of this network is shown in ***Figure 9***.

### *Assessment of layer and surface response diagrams – step 5*

In order to characterize the quality interaction settings $t_A$ and $t_E$ of the splicing device Jointair 4941 for the physical properties of the joints, diagrams of the layer response and the surface response were made, in accordance with the assumed procedure – ***Figures 10-13***.

The analysis restated in ***Figures 10*** and ***11*** proves that they have a very similar course to analogous graphs obtained with the use of multiple regression. Somewhat the other character of changes was noted for the coefficient of retained spliced strength – $\eta_W$ (***Figure 12***) and the coefficient of retained spliced breaking elongation – $\eta_E$ (***Figure 13***).

### *Designation of the optimal setting of the splicing device – step 6*

In accordance with expectations, a single, optimal setting of the splicing device dominating the remaining settings wasn't found, but merely a Pareto front, i.e. the area of settings. Not a dominating, although an optimal, area of settings, of which the joint was characterized by the largest values of coefficients $\eta_W$ and $\eta_E$, was included in the intervals (see ***Figures 11*** and ***12***):

- $t_A \in$ <2 ; 3>, $t_E \in$ <0 ; 1>, for the coefficient of retained spliced strength – $\eta_W$,
- $t_A \in$ <1 ; 3>, $t_E \in$ <0 ; 1>, for the coefficient of retained spliced breaking elongation – $\eta_E$.

***Table 7.*** *Descriptive statistics assigned to additive and non-additive features of unknotted joints of yarn ends using artificial neural networks of the type multilayer perceptron (MLP) from the option of the automatic designer of the network. Legend: Assessment of network quality: Poor, Average, High.*

| In. | Analysed parameter of the neural network | Properties of unknotted spliced joints of yarn ends | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Additive quantities | | | | | Non-additive features | |
| | | $I_p$ | $I_k$ | max $\lambda'_D$ | $\eta_W$ | $\eta_E$ | $S_p$ | $M_p$ |
| | | MLP 2–3–1 lin. | MLP 2–4–1 lin. | MLP 2–5–1 lin. | MLP 2–4–1 log. | MLP 2–6–1 lin. | MLP 2–3–1 log. | MLP 2–6–1 lin. |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | Learning quality – LQ | 0.918 | 0.663 | 0.870 | 0.948 | 0.897 | 0.978 | 0.979 |
| 2 | Validation quality – VQ | 0.919 | 0.678 | 0.882 | 0.950 | 0.917 | 0.976 | 0.986 |
| 3 | Testing quality – TQ | 0.945 | 0.813 | 0.876 | 0.967 | 0.921 | 0.989 | 0.986 |
| 4 | Learning error – LE | 0.171 | 0.122 | 0.125 | 0.121 | 0.173 | 0.150 | 0.252 |
| 5 | Validation error – VE | 0.170 | 0.430 | 0.145 | 0.124 | 0.172 | 0.153 | 0.246 |
| 6 | Testing error – TE | 0.177 | 0.124 | 0.138 | 0.120 | 0.162 | 0.148 | 0.252 |
| 7 | Quotient of deviations – $Q_{STD}$ | 0.925 | 0.697 | 0.876 | 0.953 | 0.908 | 0.980 | 0.982 |
| 8 | Pearson's correlation – $C_P$ | 0.381 | 0.719 | 0.483 | 0.303 | 0.419 | 0.199 | 0.187 |

***Table 8.*** *Descriptive statistics assigned to additive and non-additive features of unknotted joints of yarn ends using artificial neural networks of the generalized neural network GRNN 2–609–2–1 type from the option of the designer of the user of the network. Legend: Assessment of network quality: Poor, Average, High.*

| In. | Analysed parameter of the neural network | Properties of unknotted spliced joints of yarn ends | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Additive quantities | | | | | Non-additive features | |
| | | $I_p$ | $I_k$ | max $\lambda'_D$ | $\eta_W$ | $\eta_E$ | $S_p$ | $M_p$ |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | Learning quality – LQ | 0.908 | 0.775 | 0.856 | 0.965 | 0.910 | 0.971 | 0.965 |
| 2 | Validation quality – VQ | 0.919 | 0.816 | 0.888 | 0.974 | 0.930 | 0.992 | 0.989 |
| 3 | Testing quality – TQ | 0.934 | 0.782 | 0.884 | 0.968 | 0.912 | 0.972 | 0.988 |
| 4 | Learning error – LE | 0.138 | 0.158 | 0.620 | 0.044 | 0.027 | 1.703 | 1.877 |
| 5 | Validation error – VE | 0.142 | 0.191 | 0.795 | 0.042 | 0.026 | 1.722 | 1.884 |
| 6 | Testing error – TE | 0.134 | 0.181 | 0.652 | 0.044 | 0.027 | 1.772 | 1.911 |
| 7 | Quotient of deviations – $Q_{STD}$ | 0.917 | 0.789 | 0.871 | 0.948 | 0.915 | 0.976 | 0.977 |
| 8 | Pearson's correlation – $C_P$ | 0.439 | 0.670 | 0.498 | 0.321 | 0.413 | 0.223 | 0.219 |

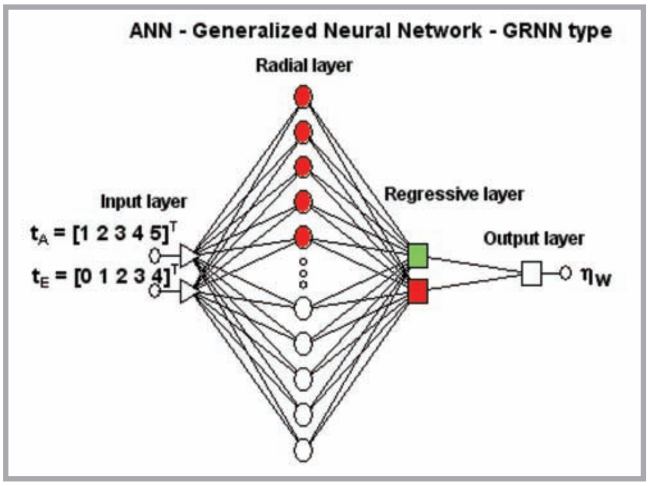


***Figure 9.*** *The network GRNN 2–609–2–1 applied for the prediction of the coefficient of retained spliced strength $\eta_W$.*

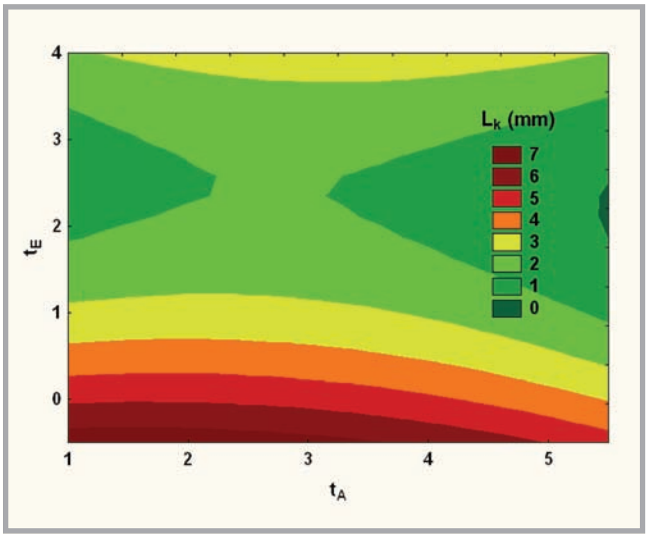


*Figure 10. The diagrams executed for $l_k$, obtained by means of network MLP 2–3–3–1, with logistic function of activation (see Table 6).*

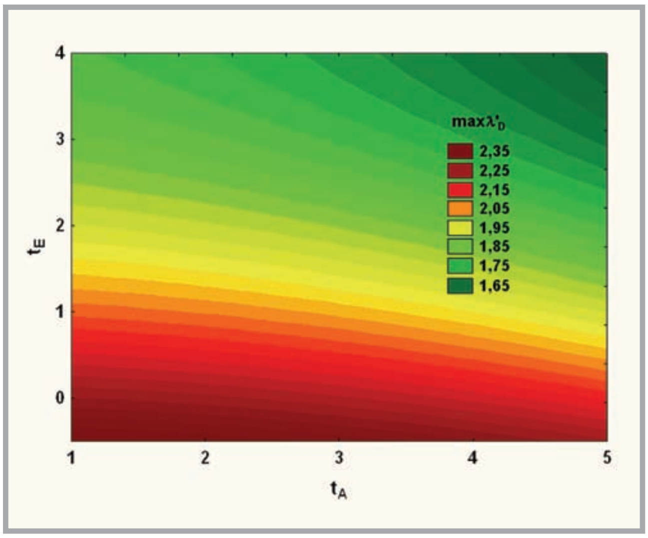


*Figure 11. The diagrams executed for max $\lambda'_D$, obtained by means of network MLP 2–3–3–1, with logistic function of activation (see Table 6).*

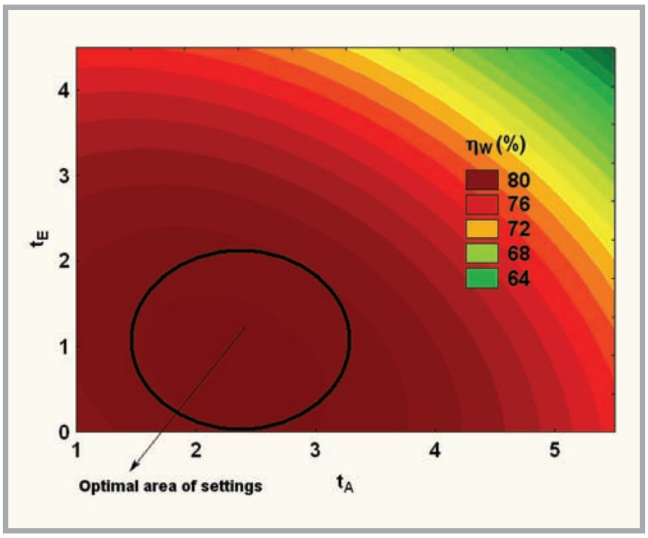


*Figure 12. The diagrams executed for $\eta_W$, obtained by means of network GRNN 2–609–2–1 (see Table 8).*

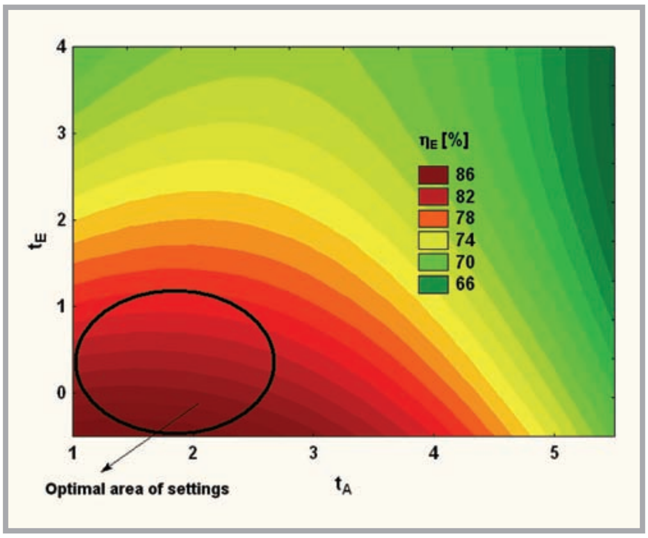


*Figure 13. The diagrams executed for $\eta_E$, obtained by means of network GRNN 2–609–2–1 (see Table 8).*

## Comparison of the multiple regression with the neural one

In the case of multiple regressions, on the quality of matching the accepted model to the investigated object in the form of linear-square polynomials, its statistical parameters are decided (see the first part of the article). Besides, the lack of possibilities to carry out the complete plan of the experiment precludes the tracing of the character of changes taking place. with regard to imposing "stiff rules" of inferring. This situation has quite often taken place during research realized in industry conditions. In the case of the neural regression, the learning quality – LQ, validation quality – VQ and testing quality – TQ as well as the learning error – LE, validation error – VE and testing error – TE and also the quotient of deviations and Pearson's correlation, the matching of the neural model mapping the researched object is decided. Artificial neural networks (ANN) realizing tasks of regression make it possible to find the area optimal setting of the splicing device – Jointair 4941. The application of the model based on multiple regressions requires the full combination of input variables (explaining variables) of the plan of the experiment to be carried out, in the form of settings $t_A$ and $t_E$.

In the case of applying multiple regressions, the graphical image of the mathematical description of dependence is diagrams of the regression function, most often surface graphs or layer ones. The analysis of the above-mentioned graphs allows the tracing of the character dropping in of changes and shows which setting is exerting the larger interaction on the investigated physical parameter of the unknotted spliced joint. It also permits the calculation of the local extreme, either of equations or the line of the inflection along with the designated optimal settings of the splicing device. This information is obtained after consideration of the necessary condition and the sufficient existence of this extreme.

In the case of applying the neural regression, the graphical image of investigated relationships is the surface response diagram to given signals (input vectors), as well as the course of the equipotential lines of graphs of the purpose function. These graphs make it possible to trace the of changes taking place and carry out the analysis of the interaction of each input variable $t_A$ and $t_E$ for the physical properties of unknotted spliced joints – $Y_i$. For the line of the inflection, the local extreme calculates itself directly from the diagrams without the need to consider the necessary and sufficient conditions of its existence.

In the case of multiple regression, assigning the regression function, along with estimating their significance and tracing the character dropping in changes, are performed on the basis of the insertion of average values into the application, in the considered case of two combinations according to the experiments 5 × 4 and 4 × 5, including 40 average values for each analysed parameter.

In the case of neural regression, learning sequences are created from the full base of joints, comprising all the experiments carried out (see Part I of the article). It is a very essential difference, in comparison with the classic multiple regressions, gathering special importance with reference to rarely appearing weak places in the yarn. In the least comfortable cases, these places overlap with the highest loads to which the yarn is subjected further away from the winding stages of the manufacturing process, often causing a breakage.

Artificial neural networks (ANN) realizing the regressive tasks are useful for identifying and tracing the character of changes of additive quantities, making it possible to execute empirical operations by letting the model itself add the numeric values (e.g. geometric dimensions and strength parameters); however, they aren't suitable for identifying non-additive features of joints (see ***Tables 6-8***). The better abilities of prediction in this case are proved to be mathematical models of objects of research based on multiple regressions.

## Conclusions

On the basis of the analysis of the examinations carried out, it is possible to state that:

- Joints, being marked by a profitable appearance, do not always distinguish themselves with good strength properties and vice versa. It is necessary, however, from the point of view of the processing of the yarn in more distant operations of the manufacturing process, to optimize the settings of the splicing device primarily in such a way to obtain the greatest strength of joints and their largest breaking elongations, sometimes even at the cost of their appearance.
- In the case of neural regression, the learning quality – LQ, validation quality – VQ and testing quality – TQ as well as the learning error – LE, validation error – VE and testing error – TE and also the quotient of deviations – $Q_{STD}$ and Pearson's correlation are decided about the matching of the neural model mapping the researched object.
- Artificial neural networks realizing tasks of regression, such as the multilayer perceptron (MLP), and realizing the generalized regression (GRNN) enable the prediction of additive quantities of unknotted joints of yarn ends, but in particular of geometric dimensions and strength properties. However, the mentioned networks aren't suitable for identifying non-additive features of joints represented by tangling and teaseling. Better abilities of prediction in this case are proved to be mathematical models of objects of research based on multiple regressions.
- When using artificial neural networks to realize the generalized regression (GRNN) for all additive quantities and non-additive features of unknotted spliced joints of yarn ends, poor quality and low accuracy of learning were obtained.
- The layer and surface response diagrams executed for the length of yarn ends protruding from the joint – $l_k$ and for the maximal increase of the crosswise dimension of the joint – max $\lambda'_D$, obtained with the use of neural regression, have a very similar course to analogous graphs achieved via the multiple regression.
- In order to obtain joints marked by maximum values from the coefficients of retained spliced strength – $\eta_W$ and of the retained spliced breaking elongation – $\eta_E$, it is necessary to apply the time of untwisting yarn ends for splicing – $t_E$ = 1, with the chance of the selection of the time of splicing cycle – $t_A = 1 \div 3$.
- In the case of multiple regression, assigning of the regression function, along with the estimation of their significance and tracing of the character dropping in changes are performed with the discreet method; however, in the case of neural regression, learning sequences are created from the full base of joints. Thus, it is a very essential difference in comparison with the classic multiple regressions, gathering special importance with reference to rarely appearing weak places in the yarn.
- Planning experimental studies with the use of multiple regression can lead to reducing the grid of points penetrating the space of events (with regard to the requirement of orthogonality and diagonality), significantly narrowing the combination of the splicing device and in not very profitable events to cause the loss of optimal solutions (settings). This problem does not exist in the case of neural regression, since the orthogonality and diagonality requirements of the plan don't have to be fulfilled.
- Artificial neural networks are able to be applied everywhere where tasks occur relying on predicting, classification and control. They are particularly useful to search for such dependence between the input and output of the object, which is very complex and therefore difficult to express by the means usually used for such statistical situations of concepts of the type "correlation" or "differences between groups". The obtained results by means of artificial neural networks are used independently and they are also able to pose the valuable completion of the obtained results by means of other calculation techniques, e.g. statistical methods.
- Applying models based on neural networks, especially non-linear models, significantly increased the possibilities of modelling but there is no certainty of whether the error fulfilled during the process of learning the network achieved its minimal level. It is necessary to carry out the verification of the identified model, relying on the estimation of the chance of using neural models for predicting features of similar objects in the defined area of the model.

## Acknowledgement

*The article was financially supported by the Ministry of Science and Higher Education within the realization of the Research Project No. 1064/T08/2005/28.*

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***Received 23.05.2007 Reviewed 29.03.2008***