Innovative solution for increasing the performance of the cutting equipment for textile subassembly having variable geometry

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Abstract. Although the textile industry is in worldwide recession, the field of technical textile articles is in a continuous development, proving that the manufacturers of these products are concerned about finding solutions and creating high performance articles. Considering the need to increase productivity and product quality while reducing the consumption of materials, in the last decades, processing technologies specific to textile industry had a quick dynamic, that has led to the development of new, very efficient technological methods and processes, characterized by an advanced degree of automation. The proposed technological solution was developed based on the correlational analysis of the technological parameters of the variable geometry subassemblies, targeting the following technological aspects: monitoring of the functional parameters during the technological process development and real-time warning of the occurring dysfunctions; display of functional parameters and controls on a HMI touch panel display; adjusting the settings of the parameters of each inverter according to the dynamic parameters of the ordered devices (couple, speed, acceleration-deceleration, brake moment, etc.); PLC circuit logic programming via a software program dedicated to the application.

1. Introduction

The main result of the automation of the installation of textile subassemblies with variable geometry for technical articles consists in the production of a quasi-continuous production, associated with the increase of the number of subassemblies realized in a reduced time with the following performances: the speed of the cutting device 100-500 RPM; roller speed 150-500 rpm; feed rate of cutting device 1-100 mm/sec; positioning accuracy of the cutting device 0.025 mm; sharpening time of the cutting device 1-10 sec; the deburring time of the cutting device 1-5 sec; average number of cuts per minute 2-10 pcs/min. (depending on the type of material and its geometry).

At the same time, the automation of the installation ensures the reduction of non-periodic losses due to working bodies, control and control devices, scrap production, improper organization, etc. Thus, the considerable increase of the main indicator of the economic efficiency represented by the labor productivity is obtained [1].

Also, of particular importance is the improvement of exploitation indices by: early detection of the non-productive sequences of the cutting devices functionality; detection of accidental stops; quickly adoption of the imposed measures for a correct functioning regime restoring [2].
In addition, the automation will allow to obtain a higher quality of the textile subassemblies, generated by the technological results represented by: - precise control of the movement of the cutting devices; - the correction of the cutting parameters even during the operation of the installation; - easy visualization of possible errors and damages by using the programmable terminal; - reduction of material losses by about 35 - 40%; - increasing the cutting efficiency and the sectioning accuracy (<0.1 mm) with a positive impact on the quality of the subassembly and implicitly of the final application; - 80% reduction of material deformation, so as to ensure a very good dimensional reproduction, with high precision markings and cuts; - reduction of waste by about 40%; - intuitive, friendly and easy usage.

Thus, it should be noted that between competitiveness, quality and productivity there is a direct link, both quality and productivity being determinants of a company's competitiveness.

In this context, it is obvious that the research results had a very good contribution to the SME’s competitiveness development by increasing the: quality of the products through the automatic and efficient control of the factors that influence it (the technological process, the quality control, the personnel qualification); diversification of production through production renewal, modernization and improvement of existing products in accordance with consumer demand; the profitability of the production process; labor productivity; innovative character of the automation system; celerity of the innovation process implementation, design, production, delivery to the consumer; level of flexibility and adaptability as well as the ability to adapt to the markets’ changes and requirements; the professionalism of the personnel and the activity in the group; strategies adopted etc.

2. Material and methods

As it results from the operating algorithm of the variable-geometry sub-assembling textile cutting equipment, under conditions of increased productivity and efficiency, the main parameter influencing the performance of the device is represented by the cutting advance rate.

On the basis of an experimental program implemented in the industrial environment, a multilinear regression analysis, that allowed to predict the performances of the device, both technologically (e.g. speed, productivity, product quality) and implicitly – financially (i.e. costs) has been carried out [3].

Experimental data obtained as a result of running the testing program allowed to process through a software package dedicated to the application more than 50 results that have been processed using a specialized software package, based on the following working hypotheses:

- independent variables are represented by: \( X_1 \) – ballot weight, \( X_2 \) – length of the material, \( X_3 \) – speed of the ballot positioning shaft, \( X_4 \) – speed of the cutting device;
- dependent variable: \( Y \) - advanced cutting speed.

The sequential commands for database initialization are shown in figure 1.

![Figure 1. Secvential commands for database initialisation.](image-url)
where: $A_0$, $A_1$, $A_2$, $A_3$, $A_4$ – represent the coefficient of the regression equation and $Y$, $X_1$, $X_2$, $X_3$, $X_4$ are the dependent, respectively the independent variables defined above.

The initialization commands are presented in the figure 2 and the histogram of the standard notes of the model residues in figure 3.

![Figure 2. Specific commands for regression analyses initialisation.](image1)

![Figure 3. Histogram of standard residue notes (deviations from the model from reality).](image2)

The regression equation coefficients are presented in the table 1 and the correlation between these coefficients is summarized in table 2.

**Table 1. Coefficients of the model.**

| Independent variables                  | Non-standardised coefficients | Standardised coefficients | t    | Sig. |
|----------------------------------------|-------------------------------|---------------------------|------|------|
|                                        | B                             | Std.Error                 | Beta |      |
| Constant.                              | -79.069                       | 11.785                    | -6.709 | 0.000|
| Ballot weight.                         | 1.224                         | 0.462                     | 0.143 | 2.652| 0.011|
| Length of the material.                | 0.017                         | 0.042                     | 0.018 | 0.397| 0.694|
| Speed of the ballot positioning shaft. | 0.115                         | 0.062                     | 0.124 | 1.861| 0.069|
| Speed of the cutting device.           | 0.652                         | 0.061                     | 0.774 | 10.644| 0.000|

The main output of regression equation is highlighted in the figure 4, the dependence between the analyzed variables is presented in the figure 5.

**Table 2. Coefficients correlations.**

| Independent variables                  | Non-standardised coefficients | Standardised coefficients | t    | Sig. |
|----------------------------------------|-------------------------------|---------------------------|------|------|
|                                        | B                             | Std.Error                 | Beta |      |
| Constant.                              | -79.069                       | 11.785                    | -6.709 | 0.000|
| Ballot weight.                         | 1.224                         | 0.462                     | 0.143 | 2.652| 0.011|
| Length of the material.                | 0.017                         | 0.042                     | 0.018 | 0.397| 0.694|
| Speed of the ballot positioning shaft. | 0.115                         | 0.062                     | 0.124 | 1.861| 0.069|
| Speed of the cutting device.           | 0.652                         | 0.061                     | 0.774 | 10.644| 0.000|
In order to verify the regression model, three experiments were performed and the obtained values are centralized in Table 3.

Table 3. Experimentally recorded values versus those calculated according to the multivariate regression model.

| Variables | U.M | Experimentally recorded values | Dependent variable values calculated according to the model (regression equation) |
|-----------|-----|--------------------------------|----------------------------------------------------------------------------------|
|           |     | Exp. 1                          | Exp. 2                          | Exp. 3                          | Exp. 1 | Exp. 2 | Exp. 3 |
| $X_1$     | kg  | 15.50                           | 16.60                           | 16.70                           |        |        |        |
| $X_2$     | m   | 107                             | 122                             | 88                              |        |        |        |
| $X_3$     | rot/min | 250                           | 230                             | 224                             |        |        |        |
| $X_4$     | rot/min | 198                           | 195                             | 180                             |        |        |        |
| $Y$       | m/min| 100                             | 99                              | 85                              | 100.65 | 97.94  | 86.91  |

The differences between the model predicted value and those determined experimentally are: for experiment 1 with 0.65 m/min higher; for experiment 2 with 1.06 m/min smaller, and for experiment 3 with 1.91 m/min higher, but all values are within the standard deviation of the dependent variable, of 2.74 m/min.

The same algorithm can be used for the prediction of other important parameters of the device, respectively: time of rolls, the density of wrapping of the material cut, the speed of variation of the type-dimensions. This will contribute to the elimination of the stationary time for sizing and implicitly to the increase of the labor productivity.

3. Results and discussion
The standard scores histogram of the residues follows the normal curve, so the model accurately predicts the cutting advance speed, depending on the considered predictors.
The graph of the cumulative probabilities of the residues standard scores reveals a normal distribution because it follows the line of the cumulative percent described by the normal curve (the right line on the diagonal of the graph, from left to bottom to right - up), so the prediction model demonstrated to be accurate.

All the predictors used for the dependency variable – advanced cutting speed- helps very well in the prediction phase, because neither for low values of the dependent variable (on the lower part of the graph – left side) neither for high values (superior part of the graph – right side), the model does not have the tendency of underestimate or overestimate the reality.

The obtained regression equation is on the form:

\[ \text{advanced cutting speed} = -79.10 + 1.22 \times \text{ballot weight} + 0.02 \times \text{length of material} + 0.12 \times \text{speed of the ballot positioning shaft} + 0.65 \times \text{speed of the cutting device} \]  \hspace{1cm} (2)

The value of the square multiple correlation coefficient \( R^2 \) reveals that 92.4% of the variance of the dependent (predicted) variable represented by the advanced cutting speed is explained by the model, with the prediction security of 91.7%.

The standard error of the predicted dependent variable (cut-off speed) demonstrates that the standard deviation of the cutting advance speed is of 2.74 m/min when the value of the independent variables in the model is known, respectively: the mass of the ballot, the length of the material, the ballot and the knife shaft speed.

The value of 0.924 demonstrates that \( R^2 \) does not change when additional variables are considered to the model.

Analysis of the variance highlights, with a probability of error of 5%, that the model significantly explains the variance of the dependent variable. In addition, the F-values demonstrate that the variance explained by the model is significantly higher than the residual one, so the created model is effective in prediction.

4. Conclusion

The created mathematical model allowed the prediction of the advanced cutting speed, knowing the ballot weight, the length of the material, the speed of the ballot positioning shaft, and the knife axis speed.

Experimental tests of the regression equation revealed that the differences between the predicted values of the model and those determined experimentally fall within the standard deviation of the dependent variable.

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