

# Mathematic Model of the Spinning Process of a Wool Yarn

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*Wool as important raw material in textile processing is the oldest fibre used by people to make fabrics. In order to make products corresponding to market requirements, use of the increasingly fine wool fibres has expanded. This type of fibre is mainly imported. In order to establish optimal conditions for the experiment was chosen a central compose rotatable program, second order, with two independent variables: partial draft and spindles speed at spinning machine. Using data obtained with the program have established the optimum parameters of the spinning process. The paper examines the optimization of the spinning process of a yarn made by 100% wool, sort 70's Nm 52.*

*Keywords: breaking strength, mathematical model, second order, spinning, yarn, wool*

In wool combed spinning mill, fibre processing technologies for obtaining fine yarns presents the following steps: recombining and obtaining combed sliver, worsted drawing and spinning. With the equipments available in combed spinning mill are obtained quality yarns, which are situated at world level between 5 and 25%, because of ring frame rebuilt [1-5]. The irregularity at breaking strength assessed by the coefficient of variation of breaking strength influence the behaviours of the yarns during processing causing the machine's efficiency and the quality of product by the number of knots [6-9].

The importance of this parameter, in a practical point of view emerges from that found in quality standards or STAS from maximum acceptable value and the cotton wool and type combed wool fibres are divided into quality classes. Also, in the world, the company Zellweger Uster makes *Uster statistics* for cotton and type cotton, combed wool and type wool yarns, depending on the used dynamometer type [6]. Optimizing is the research operation of a problem after that we obtain a result [22-33]. This result, in comparison with other possible results is the best, the most suitable, and on the basis of which a decision with technical-economic character with may be taken. The optimisation of any technological process is based on a mathematical model, that in the main element in CAD CAM.

The optimisation includes: independent variables, controlled and uncontrolled and dependent variables. To resolve the optimisation problem must go through a series of stages [34-39]:

- gathering information about the analysed process;
- elaboration of mathematical model that include: model formulation, the purpose of the model determining, the delimitation of the process, setting the variables add determination of model type;
- establishing performance criteria that may be economic or noneconomic;
- establish the mathematical model equations with statistical- mathematical methods;
- model verification;
- determine optimal solution: setting some values for independent variables sot obtain optimum value of the scope function.

In this paper was studied the optimisation of the spinning process for a yarn made by 100% wool, Nm 52 [10, 16, 40-42].

## Experimental part

The experimental part was conducted under a correlation program with two independent variables, central compose rotatable second order program [40, 43-

**Table 1**  
THE LIMITS OF VARIABLES

Independent variables	Real value				
	Code value	- 1.414	- 1	0	1
x <sub>1</sub> partial draft	1.05	1.09	1.24	1.39	1.48
x <sub>2</sub> spindles speed	6500	6800	7500	8200	8500

**Table 2**  
THE EXPERIMENTAL PLAN

Experiment's number	x	y
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	-1.414	0
6	1.414	0
7	0	-1.414
8	0	1.414
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0

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**Table 3**  
THE EXPERIMENTAL MATRIX

x1	x2	y measured	y calculated
-1	-1	16.1	16.12314
1	-1	17	17.08699
-1	1	16.9	17.03699
1	1	17.3	17.50084
-1.414	0	16.3	16.28208
1.414	0	17.4	17.29147
0	-1.414	16.6	16.61749
0	1.414	17.7	17.55618
0	0	16.4	16.32411
0	0	16.4	16.32411
0	0	16.2	16.32411
0	0	16.3	16.32411
0	0	16.3	16.32411

46]. The limits of variation and the experimental plan are presented in table 1 and 2 [6].

The experimental program has 13 experiments. To determine the experiments' accuracy, 5 of them are made parallel at the central value of the independent variables. The encoding of the independent variables was made in such a way as to cover the whole variation area for the independent variables [47-49]. The experimental matrix used in mathematical simulation of the process containing the code values of the independent variables and the results of the measurement are presented in table no 3 [2, 50-54].

### Results and discussions

Based on the experimental values was determined the regression equation:

$$y(x_1, x_2) = 16.3241 + 0.3569 x_1 + 0.3319 x_2 + 0.2314 x_1^2 + 0.381478 x_2^2 - 0.125 x_1 x_2 \quad (1)$$

The two chosen independent variables are:

$x_1$  - partial draft and  $x_2$  - spindles speed. As goal - function it was chosen the irregularity at breaking strength (named  $y = f(x_1, x_2)$ ).

The significance of the regression equation coefficients were tested using Student test, with the critical value for the test  $t_{\alpha, v} = t_{0.05; 6} = 2.132$  [40, 43, 49-60]. The values of the test and the coefficients significance degree are presented in table 4.

After verifying the regression equation coefficients we know that all the coefficients are significant and the equation is the same (1). The model adequacy was verified with Fisher test and percentage deviations. The calculated value  $F_c = 25.36$  is greater than the critical value,  $F_{v_1, v_2, \alpha} = F_{12; 12; 0.05} = 2.69$  that shows the veracity of the model that is the ability of the model to represent mathematic the variation of y value [8, -11]. The percentage deviations A are smaller than 10%. The measured answer and the predict answer are shown in table 5.

The degree of concordance of the mathematical model was verified using  $F'_c$  statistics. The calculated value 3.58 is smaller than the critical value  $F'_c = F_{v_1, v_2, \alpha} = F_{5; 5; 0.01} = 6.59$  that shows a good concordance of the model. To verify deviation of the survey data from the mean value the Fisher-Snedecor test was used. The calculated value  $F_c = 116.31$  is greater than the critical value  $F_c = F_{\alpha, n_1, n_2} = F_{0.05; 12, 4} = 5.91$  which indicates that the deviations appear due to independent variables and not to experimental errors. The approximation quality of the mathematical model expressed by the standard error shows the

**Table 4**  
THE SIGNIFICANCE OF THE REGRESSION EQUATION COEFFICIENTS

Student test encoding	The calculated values of Student test	Regression equation coefficients
tc0	11660,08	b0 significant
tc1	407,9143	b1 significant
tc2	379,3429	b2 significant
tc11	229,8863	b11 significant
tc22	3789,769	b22 significant
tc12	-71,4286	b12 significant

**Table 5**  
THE ADEQUACY OF THE MODEL

y measured	y calculated	A (%)
16.1	16.12314	-0.144
17	17.08699	-0.512
16.9	17.03699	-0.811
17.3	17.50084	-1.161
16.3	16.28208	0.110
17.4	17.29147	0.624
16.6	16.61749	-0.105
17.7	17.55618	0.813
16.4	16.32411	0.463
16.4	16.32411	0.463
16.2	16.32411	-0.766
16.3	16.32411	-0.148
16.3	16.32411	-0.148

scattering of the experimental values around the regression equation 13.54 %.

The simple correlation coefficients has the following values  $r_{x_1 x_2} = 0$ ,  $r_{x_1 y} = 0.55$  and  $r_{x_2 y} = 0.52$ . The significance of the simple correlation coefficients is checked using the Student test. The calculated values are  $tc_{x_1 y} = 2.23$ ,  $tc_{x_2 y} = 2.22$ ,  $tc_{x_1 x_2} = 0$ . The calculated values are lower than the critical table value  $t_{\alpha, v} = t_{0.05; 11} = 2.201$  for  $t_{x_1 y}$  and  $t_{x_2 y}$  which indicates that there is a relationship between dependent variables and the independent variable. The value 0 for  $t_{x_1 x_2}$  shows that  $x_1$  and  $x_2$  are independent variables and there isn't any relation between them. The "+" sign for correlation coefficient shows that between the independent variables and the dependent one there is a direct relation, with the increasing of  $x_1$  and  $x_2$  there is an increase of y.

The square of the correlation coefficient  $R^2 = R_{x_1 y}$  is called coefficient of determination and expresses that part of the variation of variable y which can be attributed to variable  $x_1$ . The calculated values are:  $R_{x_1 y} = 0.31$  and  $R_{x_2 y} = 0.27$  which expresses how much of the variation of y is due to the variable concerned. The multiple correlation coefficient has the value  $F = 0.98$ . The value of the multiple correlation coefficients was verified with F test. The critical value  $F_{\alpha, f_1, f_2} = F_{0.05; 2; 10} = 4.1$  is smaller than the calculated one, 181.24 that shows that the independent values has a significant influence about the dependent variables.

The coefficient of multiple determination 0.9605 shows that the influence of the two independent variables on the dependent variable is 96.05 % the rest being caused by other factors. The canonical analysis transforms the regression equation in a more simple form and interprets

$$+ 0.381478 x_2^2 - 0.125 x_1 x_2 \quad (3)$$

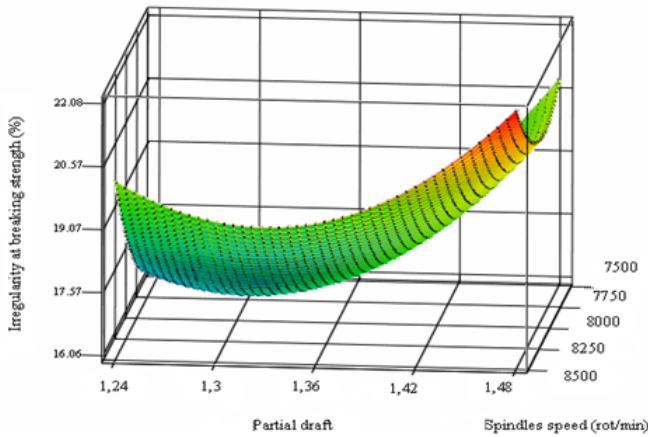


Fig. 1. The response surface for mean irregularity at breaking strength as function of partial draft and spindles speed

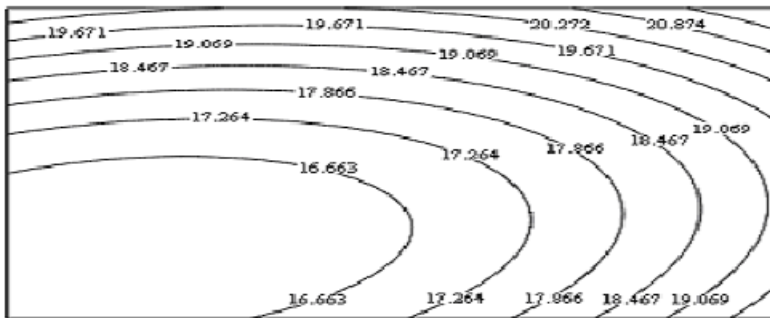


Fig. 2. Contour curves for various values of y (the irregularity at breaking strength)

the resulting expression using geometric concepts. It was passed to the canonical form of the regression equation, the new axis centre has the coordinates:  $x_1 = 1.028$ ,  $x_2 = 6.66$ . Value of the dependent variable in the centre of the response surface is  $y_c = 35.2104$ . The coefficients of the canonical form were calculated and the equation which resulted is:

$$y = 35.2104 + 0.3539 z_1^2 + 0.2094 z_2^2 \quad (2)$$

The response surface [12-15] of the regression equation presented in figure 1 is an elliptic paraboloid, the canonical equation coefficients having the same signs, positive sign. The constant level curves obtained by cutting the response surface with constant level planes [12-15] presented in figure 2 allows the evaluation of the dependent variable z, according to the conditions imposed by the independent variables  $x_1$  and  $x_2$ . The curves are ellipses because both  $B_{11}$  and  $B_{22}$  are positive and the minimum point is in the experimental area.

#### Interpretation of the technology of the obtained mathematical model

By analyzing the expression of the obtained goal-function:

$$y(x_1, x_2) = 16.3241 + 0.3569 x_1 + 0.3319 x_2 + 0.2314 x_1^2 +$$

Studying the numerical coefficients of the response equation can be relieve the following conclusions:

- the influence of the two independent parameters,  $x_1$  (partial draft) and  $x_2$  (spindles speed) on the dependent variable y (irregularity at breaking strength) manifests in the same way because their sign are the same; the growth of  $x_1$  variable (partial draft) and  $x_2$  variable (spindles speed) leads to dependent variable growth;
- the influence of variable  $x_1$  variable (partial draft) on y (irregularity at breaking strength) is 35.69%;
- the influence of variable  $x_2$  (spindles speed) on y (irregularity at breaking strength) is 33.19%;
- it is found that the influence of the parameters selected for conducted experiments is relatively low; this aspect

leads to the conclusion that the irregularity at breaking strength is influenced by other factors;

- the existence of quadratic form for both parameters indicates that the response surface defined by the obtained mathematical model, is well-formed, reinforcing the hypothesis regarding the influence of both parameters on the dependent variable;
- the ratio between the coefficients of the quadratic and free terms quantifies the speed of y (irregularity at breaking strength) the dependent variable change variation to the variation of the two parameters, the variable  $x_1$  variable (partial draft) influences the outcome with 1.4% and the  $x_2$  (spindles speed) influences the dependent variable with 2.33%;
- the influence of the interaction of the two parameters on the dependent variable is 0.7%; the concerted increase of the two independent variables leads to a decrease of the dependent variable because the coefficient  $b_{12}$  is negative.

The analyses of variance of the exhaustion impose the graphic representation of the equations presents in table 6.

Table 7 and 8 show the variation of the dependent variable - the irregularity at breaking strength - at constant values of  $x_1$  and  $x_2$ .

$x_1$	Regression equation	Equation no.
-1.414	$y = 16.2821036 + 0.50865 x_2 + 0.381478 x_2^2$	(4)
-1	$y = 16.1986 + 0.4569 x_2 + 0.381478 x_2^2$	(5)
0	$y = 16.3241 + 0.3319 x_2 + 0.381478 x_2^2$	(6)
1	$y = 16.9124 + 0.2069 x_2 + 0.381478 x_2^2$	(7)
1.414	$y = 17.2914168 + 0.15515 x_2 + 0.381478 x_2^2$	(8)
-1.414	$y = 16.617519 + 0.53365 x_1 + 0.2314 x_1^2$	(9)
-1	$y = 16.373678 + 0.4819 x_1 + 0.2314 x_1^2$	(10)
0	$y = 16.3241 + 0.3569 x_1 + 0.2314 x_1^2$	(11)
1	$y = 17.037478 + 0.2319 x_1 + 0.2314 x_1^2$	(12)
1.414	$y = 17.5561322 + 0.18015 x_1 + 0.2314 x_1^2$	(13)

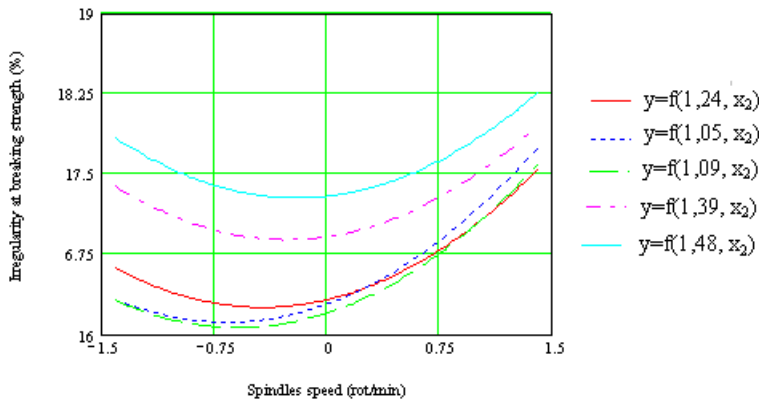
**Table 6**  
MATHEMATICAL MODELS FOR MEAN IRREGULARITY AT BREAKING STRENGTH AS FUNCTION OF PARTIAL DRAFT AND SPINDLES SPEED

$x_1$	-1.414	-1	0	1	1.414	$X_2$
y	16.75227	17.93342	16.6175	17.3826	17.83476	-1.414
y	14.23765	17.42493	14.2965	17.087	23.378314	-1
y	14.5024	16.58008	14.537	16.9124	25.130481	0
y	15.18268	17.91198	15.2203	17.5008	26.292457	1
y	15.6163	19.22553	15.6536	17.9677	27.152646	1.414

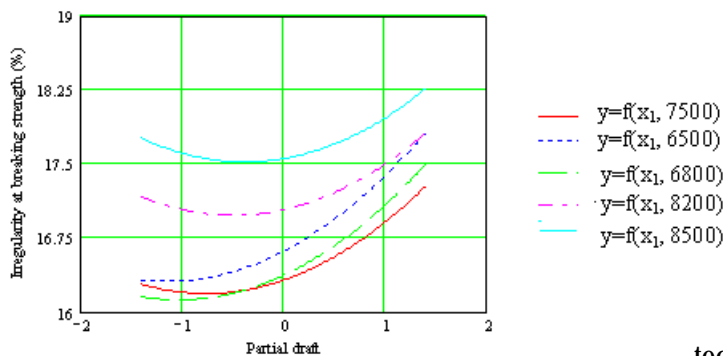
**Table 7**  
THE VARIATION OF THE DEPENDENT VARIABLE  
AT  $X_1$  CONSTANT

$x_2$	-1.414	-1	0	1	1.414	$x_1$
y	16.3256	16.15493	15.8194	17.1722	17.76406	-1.414
y	16.31527	16.12318	15.9672	17.037	17.607382	-1
y	16.61752	16.37368	16.3241	17.0375	17.556132	0
y	17.38257	17.08698	16.681	17.5008	17.967682	1
y	17.83476	17.51774	16.8288	17.828	18.273525	1.414

**Table 8**  
THE VARIATION OF THE DEPENDENT VARIABLE  
AT  $X_2$  CONSTANT



**Fig. 3.** The dependence of the goal- function (irregularity at breaking strength) on all significant values of  $x_2$  parameters (spindles speed) for five value of  $x_1$  (partial draft) = constant:  $x_1 = 1.48$ ,  $x_1 = 1.39$ ,  $x_1 = 1.24$ ,  $x_1 = 1.09$ ,  $x_1 = 1.05$



**Fig. 4.** The dependence of the goal-function (irregularity at breaking strength) on all significant values of  $x_1$  parameters (partial draft) for  $x_2$  parameter (spindles speed) = constant  $x_2 = 8500$ rot/min,  $x_2 = 8200$ rot/min,  $x_2 = 7500$ rot/min,  $x_2 = 6800$ rot/min,  $x_2 = 6500$ rot/min

The curves for irregularity at breaking strength of a wool yarn Nm 52 were obtained at constant value of the partial draft and changing the spindle speed. It is noted that at  $x_2$  - spindle speed - growth, regardless the chosen value of partial draft, the dependent variable is increasing.

Figure 4 shows the dependence of the goal-function - irregularity at breaking strength - on partial draft when the spindle speed is constant. It is noted that at  $x_1$  - partial draft - growth, regardless the chosen value of spindle speed, the dependent variable is increasing.

### Conclusions

The smallest values of the irregularity at breaking strength are obtained when the process is carried on code values of the partial draft between -1 and 0 that correspond to partial draft between 1.09 and 1.24. At partial draft over 1.24 the irregularity at breaking strength in bigger. The irregularity at breaking strength values are at upper limit when we work with high values of speed spindle, no matter the adjustment of the spinning machine.

At constant value of partial draft, the irregularity at breaking strength is bid at big value of spindle speed. The smallest value of the irregularity at breaking strength is set down at spindle speed 6600rot/min. We set the

technological parameters:  $x_1 = 1.15$ ,  $x_2 = 6500$  rot/min and was spin a yarn in the laboratory. We obtain 15.9% for the irregularity at breaking strength so it was a decrease with 2.5% that shoes that the optimisation process was a success, the yarn is come under 5% Uster world level.

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