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Investigation of the Cutting Force Based on the Full Factorial Experiment When Cutting Frozen Meat

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Abstract: *Cutting is a main process in the meat industry. In the food industry the meat is fresh or frozen. The relationship of cutting forces to cutting speeds and food temperatures when cutting frozen meat is in interest for science and practice. This work presents a full factorial experiment which was carried out to determine the influence of three variables: velocity speed V_n, m/s, temperature of the cutting frozen food t°C and frequency speed of the disc knife n, min^{-1} on the cutting force. The experiments were carried out with three speed velocities of the food sample and frequency speeds of the knife in a range from 110 $min^{-1}$to 414 min^{-1}. It was found a regression equation $F = f(t,V_n,n)$, describing the relation between the studied factors and the cutting force when cutting frozen pork meat.*

Keywords: *full factorial experiment, cutting force, velocity speed, frequency, temperature, pork meat.*

1. Introduction

The aim of the full factorial experiment is to create a mathematical model of the investigated process for determination of the quantitative connection between input variables and output variable. The input variable quantities exert influence on the way the object functions. They must be dirigibles and synonymous, compatibles, independents of each other and nocorrelatives.[1]

The cutting force *F,N*, which is the sum of the resistance forces on the knife cutting edge and the friction forces between the cutting surface of the food and the side surfaces of the disc knife, has been chosen as function.

The cutting force depends primarily on the temperature of the cutting food, the velocity speed, the frequency speed of the disc knife, the geometrical parameters of the disc knife: diameter, thickness, wedge angle and the surface quality of the instrument. [2]

In the food industry the meat is cut in fresh or in frozen state. To make frozen meat suitable for next treatment in grinders and cutters frozen meat blocks can be cut without previous thawing. The direct chopping of the frozen meat particles ensures no drip losses, discoloration, and bacterial growth which could happen during thawing. The machines cut frozen meat with temperature from -30°C to -5°C. In the production of sausages the temperature of the grinding meat is -20°C. [3]

Many researchers have formulated the relationship between the cutting force and the temperature of cutting meat. [4, 5, 6] However, the information about cutting frozen meat with disc knife is insufficient.

This research uses full factorial experiment to establish the effect of the three factors: temperature of the cutting food, velocity speed and frequency speed of the disc knife on the response variable - cutting force when cutting frozen meat. The established results could be used for improving the cutting devices and the technology in the meat industry.

2. Materials and Method

The experimental material was frozen pork meat from upper extremity. The material for the tests was cut in the form of parallelepiped with dimensions 100 mm/50 mm/10 mm. The influence of three factors was investigated:

1. Temperature of the cutting product $t°C - X_1$.

   For low level we determined (-18) °C and for upper level (-4) °C.

2. Velocity speed of the frozen sample Vп, m/s – X2.

   The low level of this factor is 0, 05 m/sand the upper level is 0, 125 m/s. These values were fixed on the base of the existing technologies [3]

3. Frequency speed of the disc knife n, min-1 – X3.

   The low level 110 min-1and the upper level 410 min-1 of this variable were determined on the base of the existing technologies and design limitations.

The natural values of the factors and their coding to turn into dimensionless quantities are shown in Table 1.

Table1. *Natural Values of the Factors and Their Coding to Turn into Dimensionless Quantities*

Level	X_1	X_2	X_3
	t – temperature of food product, *°C*	V_n– velocity speed, [*m/s*]	*n* – frequency speed, [min^{-1}]
Upper (+)	*- 4*	*0,125*	*410*
Low (-)	*- 18*	*0,05*	*110*
Standard (0)	*- 11*	*0,087*	*260*
Interval of variability	*7*	*0,038*	*150*
Code	$X_1 = \frac{t+11}{7}$	$X_2 = \frac{V_n - 0{,}087}{0{,}038}$	$X_3 = \frac{n - 260}{150}$

Table 2 contains the design matrix of the full factorial experiment and coded values of the factors. Here $Y_1 \div Y_3$ are measured values of the response variable for all of the repetition and $\overline{Y}$ is the mean of the three repeats.

Table2. *Design Matrix of Full Factorial Experiment*

№	X_1	X_2	X_3	Y_1	Y_2	Y_3	$\overline{Y}$
1	+	-	+	*119,1*	*116,3*	*117,0*	*117,46*
2	-	-	-	*387,5*	*390,2*	*391,3*	*389,67*
3	+	-	-	*194,2*	*195,1*	*192,4*	*193,89*
4	-	+	+	*319,7*	*320,8*	*326,0*	*322,15*
5	-	+	-	*456,5*	*458,4*	*452,1*	*455,67*
6	+	+	+	*207,3*	*209,1*	*206,6*	*207,68*
7	+	+	-	*224,9*	*226,8*	*227,7*	*226,48*
8	-	-	+	*184,6*	*182,2*	*181,1*	*182,62*

The full factorial experiment the type of 2^3 with three repeats in all points of the plan was provided to receiving an adequate regression equation, describing the process of cutting frozen meat and determining the influence and the connections between the factors. To avoid the influence of systematical and random errors the experiments were made in casual order.

The process reproducibility has been checked with the help of Kohren criterion:[7]

$$G = \frac{S^2_{max}}{\sum_{i=1}^{N} S_i^2} \le G_T \text{,} \tag{1}$$

where $S_i^2 = \frac{\sum_{n=1}^{m}\left(Y_{in} - \overline{Y}_i\right)^2}{m-1}$ is experiment dispersion of the results (the values are given in Table 3);

m- the number of replicate tests;

S^2_{max} *= 11, 32*- the maximum of dispersions;

G(0,05; k_1; k_2) = 0,516 is the table value of Kohren criteria at 5% significance level; [7]

$\kappa_1 = m - 1 = 3 - 1 = 2$ - the number of freedom degrees of each value;

$\kappa_2 = N = 8$ - the number of dispersion independent evaluations

The process is reproducible as $G<G_T$.

Table3. *Experimental Results*

№	$\left(Y_1 - \bar{Y}\right)^2$	$\left(Y_2 - \bar{Y}\right)^2$	$\left(Y_3 - \bar{Y}\right)^2$	$\sum_{i=1}^{m}\left(Y_i - \bar{Y}_i\right)^2$	S_i^2
1	2,68	1,34	0,21	4,23	2,12
2	4,70	0,28	2,04	7,02	3,51
3	0,09	1,46	2,22	3,77	1,88
4	6,00	1,82	14,82	22,64	11,32
5	0,68	7,45	12,74	20,87	10,43
6	0,14	2,02	1,17	3,33	1,66
7	2,50	0,10	1,49	4,09	2,04
8	3,92	0,17	2,31	6,4	3,2
$\sum_{i=1}^{N} S_i^2 = 36,2$					

The regression coefficient was calculate with Statgraphics Centurion software. The obtained equation is:

Y = 261,952 – 75,575.X1 + 41, 0425.X2 – 54,475.X3 – 10, 34.X1.X+

+30,66 +16,395.X2.X3(2)

$R^2 = 99,9662\ \%$

The significance of each of the coefficients was determined by the Pareto chart (Fig.1).

According to it, the regression equation takes the description

Y = 261,952 – 75,575.X1 + 41, 0425.X2 – 54,475.X3 +30, 6675.X1.X3 (3)

After the transformation to natural variables we receive

F = 58,299 – 18,388.t + 1094, 46.vn – 0, 0418.n + 0, 0292.t.n (4)

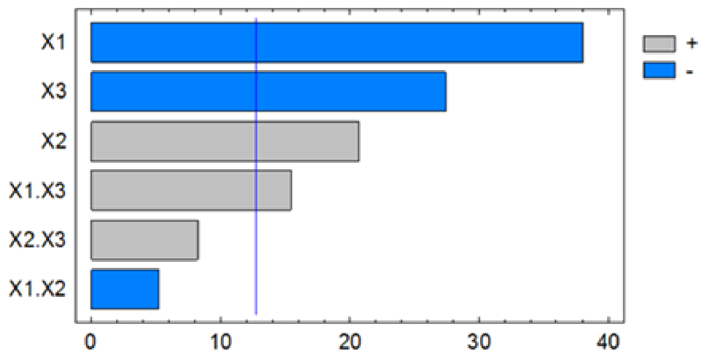

Figure1. *Pareto chart*

The validity of the received model has been checked by Fisher's ratio test. If the equation is true the validity of the received model is accepted:

$$F = \frac{S_{a\partial}^2}{S_y^2} = 0,001828, \quad (5)$$

where $$S_{a\partial}^2 = \frac{m\sum_{i=1}^{N}\left(\bar{Y}_i - \hat{Y}_i\right)^2}{N - l}; \quad (6)$$

$\hat{Y}$ is the calculated response value in the *i* experiment;

F_T *(0,05; k_1; k_2)* is Fisher's ratio test at 5% significance level, $k_1 = N\text{-}l = 8\text{-}3 = 5$is the number of freedom degrees of validity dispersion; $k_2 = N.(m - 1) = 8.2 = 16$ is the number of freedom degrees of error mean square; *FT = 2, 9.* [7]

$F<F_{T,}$

Hence, the received model is valid for the studied process.

Each coefficient value was checked separately by Fisher's ration test. All the calculated regression coefficients are true.

3. Results and Discussion

Fig.2 shows the contour plot and the response surface plot of the combined influence of the factors: temperature of the food product X_1 and velocity speed X_2 on the resulting cutting force. The cutting force decreases when the temperature increases and velocity speed decreases.

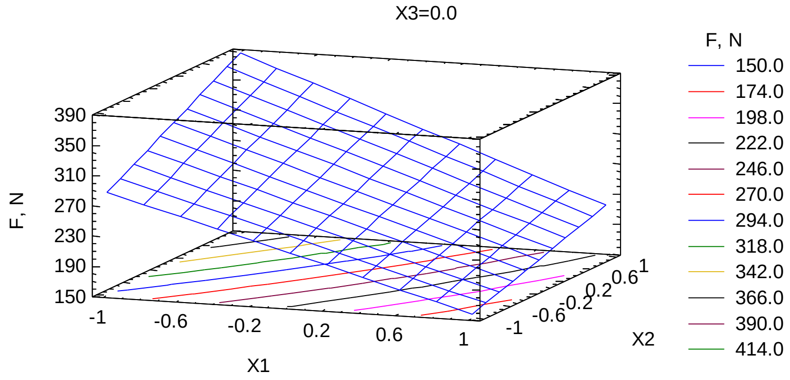

Figure2. *Contour and surface plots indicated the influence of the factors: temperature of the food product X_1 and velocity speed X_2 on the resulting cutting force.*

The combined influence of the factors: velocity speed X_2 and frequency speed X_3 on the cutting force is shown in Fig.3. The cutting force increases when the velocity speed increases and frequency speed decreases.

Fig.4 shows the contour plot and the response surface of the combined influence of the factors: temperature of the food product X_1 and frequency speed X_3 on the resulting cutting force. When both of the factors temperature of the food and frequency speed increase, the resulting cutting force decreases.

According to regression equation to decrease the cutting force it is necessary to increase the values of the factors X_1 (food temperature) and X_3 (frequency speed), and to reduce the value of the factor X_2 (velocity speed).

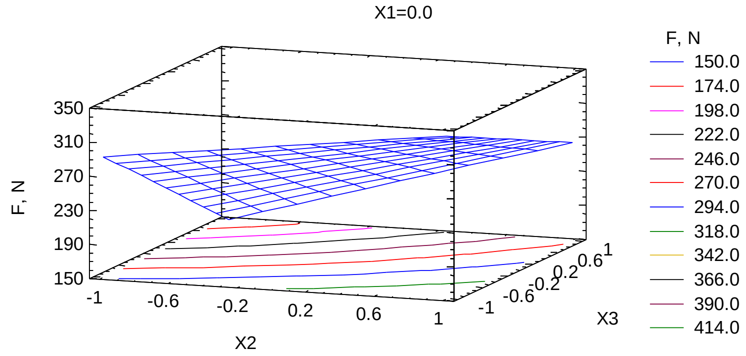

Figure3. *Contour and surface plots indicated the combined influence of the factors: velocity speed X_2 and frequency speed X_3 on the resulting cutting force.*

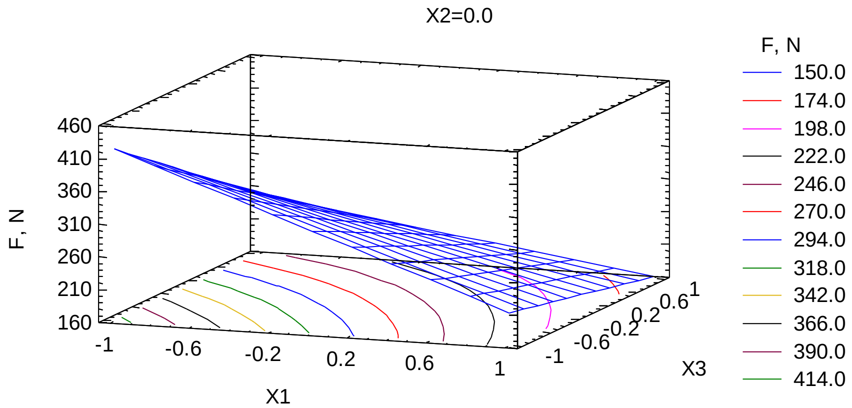

Figure4. *Contour and surface plots indicated the combined influence of the factors: temperature of the food product X_1 and frequency speed X_3on the resulting cutting force.*

4. Conclusion

The current study defines the regression equation describing the influence of the factors temperature of the food product X_1, velocity speed X_2 and frequency speed of the disc knife X_3.

The lowest value of the cutting force is determined when the temperature of the product is on the upper level (-4°C), velocity speed is on the low level (*0,05m/s*) and the frequency speed of the disc knife is on the upper level (*410* min^{-1}).

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