The parameters impact on cutting forces and determination of regression function

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Abstract: The aim of this paper is to present results of certain experiments related to material workability characteristics, taking into consideration its high quality features and large usability for special manufacturing. It is highly used in various industrial processes, such as aeronautics, petrochemical industry, chemical industry, etc. It was examined the influence of milling parameters upon the three dimensional cutting force and after it was determinate regression function.

1. Introduction

Many problems regarding the pieces manufacturing posed challenges for many researchers which contributed and are still contributing to determine the most efficient approach in describing the complex process of turning. The entire spectrum of the actual researches regarding the workability represents the multiple directions of this complex knowledge. After a slight examination, an expert is tempted to define the turning workability related to its field of activity [1, 2,7]. Although many researches were focused on the material workability, at the time of speaking there is no clear definition and no appropriate index widely accepted. In terms of methods regarding the material machining, is well known that there are many manufacturing processes, but with no strict constraints according to the material. Machining restrictions depending on the material were defined by many facts [1, 3, 4, 5]; they are strictly related to the effective time of machining, which has to be as short as possible, decreased costs and possibilities of standardisation [1]. In this paper approaches the 41MoCr11 workability using an experimental method (using defined milling conditions), following the material workability markers as the cutting efforts which appear in the machining process, and after we determinate the regression function with specific program.

2. Paper contents

The aim of the experiment is to determine machinability of 41MoCr11 material in terms of forces that appear during cutting, knowing the processing system parameters, used at the plane milling operation and determine the influence of each parameter of cutting regime on these efforts. Because "the basis of machinability is any relationship of dependence between the quantities involved in processing" [3,11], so that the resulting relationship 1,

\[ Y = \Gamma (x_1, x_2, \ldots, x_k) \]

(1)

Y is the dependent variable and Xn are independent variables.
In this case the relations (2,3,4) used are:

\[
F_x = \Gamma(v, f_z, a_e, a_p)N \\
F_y = \Gamma(v, f_z, a_e, a_p)N \\
F_z = \Gamma(v, f_z, a_e, a_p)N
\]

Where:

- \(F_x, F_y, F_z\) — cutting force on X, Y and Z [N]
- \(a_p\) — depth of cut [mm]
- \(a_e\) — radial depth [mm]
- \(f_z\) — feed per tooth [mm/tooth]
- \(n\) — cutting speed [m/min]

3. Experimental Details

All the experiments of this paper were made with machine-tool MCV 300. This is CNC milling machine with 5 axes. For the tests was used a milling cutting tool, with coated carbide, with \(z = 3\) and 18 mm diameter, made by Taegu Tec Company [7,11,12]. Flat milling was chosen. The machining method is dry type cutting. It consists of two activities:

- the mechanical activity, including the machine tool, cutting tools – milling cutters, work piece made of 41MoCr11
- the data acquisition, including the KISTLER measuring table (dynamometer), an electronic amplifier and the computer having a data acquisition system (figure 2).

| Table 1 Initial characteristic of piece. |
|----------------------------------------|
| Material | Piece | Hardness HRC |
|-----------|-------|---------------|
|           |       | Interval     | Value  |
| MP4       | Steel 41MoCr11 | 31.78 - 33.00 | 32.4 |

| Table 2. Chemical composition. |
|-------------------------------|
| Element | C[%] | Mn[%] | P[%] | Si[%] | S[%] | Cr[%] | Ni[%] | Mo[%] | Fe[%] |
|---------|------|-------|------|-------|------|-------|-------|-------|-------|
| Conform STAS 8185 | 0.38-0.45 | Max. 0.035 | Max. 0.035 | 0.17-0.37 | 0.9-1.30 | Max. 0.3 | 0.15-0.30 | Rest |
After this analysis, with special spectrometer it can conclusion that material is 41MoCr11 steel (see value compared with STAS 8185); and in figure1 we can see a uniformity dispersion of elements, a sorbite structure with fine grain in ASTME112 standard.

![Figure 1: Metallographic structure of 41MoCr11 material.](image)

**Table 3 The experimental program.**

| Independent variables                      | Code |
|--------------------------------------------|------|
| depth of cut, \( a_p \): 1 to 2.5 mm       | \( X_1 \) | \( X_2 \) | \( X_3 \) |
| radial depth \( a_c \): 0.5 to 2.5 mm      | 1 | 1.58 | 2.5 |
| feed rate \( f_z \) mm/ tooth : 0.01 to 0.1 mm/ tooth | 0.01 | 0.032 | 0.1 |
| cutting speed: 200 to 300 m/min            | 200 | 245 | 300 |

The registration data were done by the DynoWare program. In figure 3 (a, b, c,) graph forces...
torque (Fx, Fy, Fz, Mz) for only first processing are presented.

(a) Fx(ap,ae,fz,v)=167.57 N
(b) Fy(ap,ae,fz,v)=185.49 N
(c) Fz(ap,ae,fz,v)=101.90 N

Figure 3 The graph of cutting forces Fx, Fy, Fz for first experience

Cutting regime parameters in this case are: ap= 1mm; ae = 0.5 mm; fz= 0.01mm/tooth; v= 200 m/min.
The experiments revealed the next values of cutting forces on the three directions: Fx Є [167.57;886.14]N,
Fy Є [185.49; 992.07]N, Fz Є [101.9, 627.2]N. To determine the total cutting force we used the formula 5.

\[ F = \sqrt{F_x^2 + F_y^2 + F_z^2}, N \] (5)

The values obtained for total cutting force are in the interval, F Є [269.94, 1470.65] N. The variation of cutting force depending on the parameter is shown in Figure 3, 4, 5 and 6.

Influence of depth of cut on the cutting force; study of the obtained diagrams reveals that, with the increase of the depth of cut (see figure 3), the cutting force increase on the first interval [13,7,9] and decrease on the second interval [11,10, 8]. Influence of radial depth on the cutting force in figure 4 the obtained diagrams reveals that cutting force increase with the increase of radial depth. This increase of cutting force is approximately constant. Influence of feed rate on the cutting efforts; study of the obtained diagram reveals that cutting force F have same trend with the increase of the feed rate (see figure 5). In this case we see that the influence of feed rate is very high. Influence of cutting speed on the cutting efforts; study of the diagram (see figure 6) reveals that force F have same trend with the easy increases of the spindle speed. After study all obtained diagrams that cutting force increase when the feed rate increases. This influence is very high.
The cutting speed hasn’t important influence of the cutting force. Regression functions for cutting force $F_x$, $F_y$ and $F_z$. The regression function for cutting force $F_x$, $F_y$ and $F_z$ were determinate as multivariate regression functions for each material processed form:

$$Y = A_0X_1^{A_2}X_2^{A_3}X_3^{A_4}X_4^{A_5} \Leftrightarrow y = a_0 + \sum a_jz_j, y = \ln Y, z_j = X_j, j = (1,4)$$

Practically, the experimental data obtained and with DataFit 9.0 program were calculated equation (7,8,9) the coefficients $A_0, A_j, j = (1,4)$.

$$F_x = e^{5.11075056160716} \times x_1^{0.14490730699812} \times x_2^{0.09175551117487432} \times x_3^{0.064671095677042} \times x_4^{0.512564541459054}$$

$$F_y = e^{6.18615740615673} \times x_1^{0.042917790689648} \times x_2^{0.49241226870457} \times x_3^{0.4708630529917147} \times x_4^{0.022304060382545}$$

$$F_z = e^{2.0406151604464} \times x_1^{1.80247014865895} \times x_2^{0.26177401182276} \times x_3^{0.582470057076012} \times x_4^{0.5174525243271664}$$
4. Conclusions

This work allows the following conclusions:

- the variation depth of cut have nonlinear influence for cutting force and require a higher degree of attention and is necessary more study for another intervals.
- the cutting force variation is direct proportional with radial depth variation.
- the increase of feed rate have the greatest influence on cutting force.
- the increase of cutting speed haven’t influence or have easy influence for the variation of cutting force.
- to optimize cutting processing on the 41MoCr11 is necessary to use all the cutting parameters.

Research Directions - develop research methods cutting machinability of this material in order to standardize some of them, determination of machinability data for this material using different tools geometry, coating, composition and processing methods, and the development of data banks workability, machinability, continuous updating of data in accordance with the new tool materials with improved characteristics precision, stiffness and power of machine tools.

5. References

[1] C Picoş et al, 1981 Turning workability of ferrous alloys, Ed. Tehnică, Bucharest
[2] T Grămescu et al, 2000 Material workability, Ed. Tehnica-Info, Chişinău,
[3] M Gheorghe, 1984 Research on the machinability of malleable cast iron removing, PhD Thesis, Bucharest
[4] N Andrei, 2010 Simulation of integrated CAD-CAM-CAE for parts of the composition of turbo engines. Experimentation IQMD integrated, Bucharest
[5] M Sime, 2011. Contributions regarding workability and working rate optimisation on drilling of high alloy steel, Doctoral thesis, Bucharest,
[6] Metal Working Cutting Tools, Taegu Tec, Member IMC Group, 2011.
[7] D L Martin, A N Tabenkin, F G Parsons, 1995 Precision Spindle and Bearing Error Analysis, International Journal of Machine Tools & Manufacture, 187-193 vol. 35 No 2
[8] N Lynagh, H Rahnejat, M Ebrahimi, R Aini, 2000 Bearing induced vibrations in precision high speed routing spindles, International Journal of Machine Tools & Manufacture, 561-577 vol. 40
[9] D M. Marin, D Marin, R.C Varban, Dynamical behaviour analysis of three-axis milling centres, Scientific Bulletin, series D: Mechanical Engineering, vol. 71.
[10] S Aspiwak and T Nickel, Vibration based preload estimation in machine tool spindles, International Journal of Machine Tools & Manufacture, 567-588 vol. 41
[11] Iliescu M Vladareanu L Spanu 2010 Modelling and Controlling of Machining Forces when Milling Polymeric Composites, Materiale Plastice , 231-235, WOS:000281051300022, SN 0025-5289
[12] F.T Jay 1996 Strain field analysis and sensor design for monitoring machine tool spindle bearing force, International Journal of Machine Tools & Manufacture, 203- 216 vol. 36 No 2
[13] Sandru O I, Vladareanu L, Sandru A, 2008 A new method of approaching the problems of optimal control, Proceedings of the 10th WSEAS International Conference on Mathematical and Computational Methods in Science and Engineering, 390- 393, WOS: 000262436800083.