OPTIMIZATION OF CUTTING FORCE BY MILLING OPERATION USING ARTIFICIAL TECHNIQUE

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ABSTRACT

Our research work will be focused on optimization of cutting force, by end milling process with four teeth's. As another problem, which will be treated is the cutting power that also plays an important role during machining process. The results of analyses are obtained for cutting power and cutting force, in theoretical and experimental aspects of achievement. To achieve the best value of cutting power and also cutting force is utilization of the multi objective genetic algorithm, as optimized method. Also, in our work, paper will be optimized by the main machining parameters for cutting power P_c , cutting force F_c and material removal rate MMR by end milling operation.

KEYWORDS: Cutting Force, End Milling, Cutting Power, Optimization & Artificial Technique

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1. INTRODUCTION

Nowadays, artificial technique in manufacturing processes has wide utilizations due to possibilities of minimization and optimization of errors. Therefore, their application by metal cutting has the biggest influence such us: to optimize cutting parameters, optimize two or more equations, and in the same time, to minimize the errors in theoretical way. In our research, by end milling process for cutting force, cutting power and material removal rate are investigated. Also, it applies the artificial techniques such as Genetic Algorithm to find the best solution of optimal machining parameters and other problems in the end milling process.

The device for measurement of cutting force used is, the 3 component dynamometer type 9257 Kistler, with force range for F_x (-5 ... 5kN), F_y (-5 ... 5kN) and F_z (-5 ... 5kN), and top plate with dimensions 100x170 mm. Also, for dynamometer 9257 Kistler, it is required to connect the multichannel charge amplifier 5070, for multicomponent force measurement during machining process setup. Expected measurement of cutting force is possible at the moment of measurement.

YAO Yunping et al. (2010) proposed the online optimal machining parameters for OPTIMILL control machine tools. The proposed system could shorten the working time as well as to protect milling tools, in the same time, reduces the cost of production and raise production. H. Ganesan et al. (2011) discussed about the optimization of machining parameters for continuous profile machining, with respect to reducing the time, cutting force, and cutting power by turning operation. Also, the authors due to the complexity of machining, have made the comparison of results obtained in environments of Genetic Algorithm as well as Particle Swarm Optimization. M. Janardhan and A. Gopala Krishna (2012) present the multi objective optimization of cutting parameters for

response surface roughness and metal removal rate by grinding operation.

In our work, the cutting force, cutting power and material removal rate by end milling operation for workpiece material **42CrMo4** are investigated. Also, the selection of tool, with four teeth's and diameter of tool ($d = 8$ mm) are used to achieved the optimal results for cutting force, cutting power and material removal rate in our experimental setup. Three objective functions i.e. cutting force (F_c), cutting power (P_c) and material removal rate (MRR) are simultaneously optimized using the Artificial Techniques.

2. THEORETICAL MODEL AND EXPERIMENTAL RESULTS FOR CUTTING FORCE BY END MILLING PROCESS

Many authors are oriented for optimal surface roughness, tool wear, cutting force machining parameters, tool geometry etc. In our paper, we analyse the expected cutting force (F_c), cutting power (P_c) and material removal rate (MRR) due to the importance of machining process investigated with the main machining parameters (v , f and a). The machining parameters play an important role for optimization and determination of the cutting power, cutting force as well as material removal rate by end milling operation.

Environmental influences on measuring data of cutting force such as mounting of dynamometer–work piece, vibration from aspect of machine tool, base strain from aspect of moving of machine table, coolant also have impact and temperature. Therefore, in order to optimize cutting power P_c and material removal rate MRR by end milling process, respectively, work piece material and tool geometry are taken in this case as constants. The main machining parameters such as depth of cutting, feed rate and cutting speed will be optimized by employing Genetic Algorithm.

Some problems that will be analysed are given with expression as follows. These are included for Cutting force F_c , material removal rate (MRR) and cutting power.

The cutting power P_c is given with expression as follows:

$$P_c = \left(F_c \cdot v \cdot Z \cdot \frac{\phi}{360^\circ} \right) \quad (1)$$

Where, Z – number of teeth ($Z=4$), ϕ - helix angle ($\phi = 30^\circ$)

The cutting force F_c is given with expression as follows:

$$F_c = b \cdot v^{\beta_1} \cdot f^{\beta_2} \cdot a^{\beta_3} \quad (2)$$

Exponent of cutting force β_1 , β_2 , β_3 and b are constants in our investigation of cutting power P_c and cutting force F_c . The material removal rate (MRR) can be expressed in analytical form, in function of the cutting speed (v), depth of cut (a) and feed rate (f) as follows:

$$MRR = 1000 \cdot v \cdot f \cdot a \quad (3)$$

There are several factor constrains of cutting parameters like feed rate, cutting speed, depth of cut, workpiece material, tool geometry, coolant system etc. In our work, we take only the main parameters as constrains.

The procedures of optimal limitations are presented as follows:

$$\begin{aligned} v_{\min} < v < v_{\max} \\ f_{\min} < f < f_{\max} \\ a_{\min} < a < a_{\max} \end{aligned} \quad (4)$$

The limitations in these cases, that are given in expression (4) are needed to analyse the cutting force F_c , cutting power P_c as well as material removal rate MRR. During the cutting process, the cutter removes a layer of material, due to the relative depth of cut and feed rate. The cutting force for three components (F_x , F_y and $F_z = F_c$) is measured on the plate with dimensions $b \times h$ [mm]. From the general expression of cutting speed v_c , we could find the spindle rotation. Also, cutting speed (v_c) can be expressed to spindle rotation (n) as follows:

$$n = \frac{v_c}{\pi \cdot d} \quad (5)$$

The feed f in milling operation is usually given as feed per cutter tooth. Each tooth represents the size of the chip, formed by each cutting edge in the milling process. The figure 1 shows the end mill operation, that will be the case of our research work of cutter into the work piece.

Figure 1: Side View of End Milling Tool Before Entry to the Workpiece

The feed rate f_r include the spindle speed and number of teeth for end ball milling tool, as follows:

$$f_r = n \cdot z_t \cdot f \quad (6)$$

where f_r – feed rate [mm/min], z_t – number of teeth for milling tool, n – spindle speed [rev/min] and f – feed rate for chip load [mm/tooth].

Therefore, taking into consideration the errors that are verified during the experiments, the multiple regression model is given as follows, with the expression:

$$Y = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \beta_3 \cdot X_3 + \varepsilon_i \quad (7)$$

Or

$$Y = \beta_0 + \beta_1 \cdot speed + \beta_2 \cdot feedrate + \beta_3 \cdot depth + \varepsilon_i \quad (8)$$

where ε_i , is called the error for the i^{th} measurement. In the expression above, the $Y = F$ is called the dependent variable, representing the cutting force, X_1 , X_2 and X_3 is called the independent variable in our case (cutting speed,

feed rate and depth of cut), β_0 , β_1 , β_2 and β_3 , are the regression coefficients. In any multiple regression model, the coefficients are required to be analysed by least squares equation.

The diapazon of value for measurement of cutting forces are taken from $t = 0 - 10$ [sec], presented with experiment number EXP1, EXP2, EXP3, ..., EXP12. The measurement values of main cutting force are presented without optimization in table 1, depending on the main machining parameters v , f and a .

Table 1: The Results of Main Cutting Force F_c without Optimization

No. Of Experiment	Main cutting Parameters			Cutting Force F_c	
	v [m/min]	f [mm/rev]	a [mm]	Measurement Value	Theoretical Value
1	10	0.24	0.2	4.01	4.231
2	15	0.24	0.2	3.29	3.432
3	10	0.65	0.2	4.78	4.932
4	15	0.65	0.2	4.24	4.445
5	10	0.24	0.8	3.73	4.183
6	15	0.24	0.8	3.39	3.613
7	10	0.65	0.8	3.31	3.552
8	15	0.65	0.8	2.83	4.099
9	12	0.4	0.5	3.98	3.482
10	12	0.4	0.5	3.3	3.482
11	12	0.4	0.5	3.79	3.482
12	12	0.4	0.5	3.04	3.482

For the cutting force F_c , the theoretical and practical procedure for feed rate (f) for four experiment number EXP7, EXP8, EXP11 and EXP12 are presented in relationship of feed rate f , as shown in figure 2.

Figure 2: Various Value of Main Cutting force (F_c) in Relationship of Feed Rate (f)

The cutting power (P_c) as well as depth of cut (a) could determine the value of volume for material removal rate (MRR). In table 2, the cutting power P_c based on the obtained results of cutting force (F_c) regarding the cutting speed (v) and helix angle (ϕ) are calculated with mathematical expression of cutting power for P_{cmax} , P_{cmean} and P_{cmin} .

Table 2: Obtained Results for Cutting Power P_c

Cutting Speed v	Number of	Helix Angle	Measurement	Cutting Power P_c [kW]
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[m/min]	Teeth Z	ϕ [°]	of Cutting Force Fc [N]	Pc Max	Pc Mean	Pc Min
12	4	30	3.31	16.55	13.24	11.033
15	4	30	2.83	14.15	11.32	9.433
10	4	30	3.79	18.95	15.16	11.607
12	4	30	3.04	15.20	12.16	10.133

In figure 3, cutting power Pc respect to the cutting force and cutting speed are presented. With minimal value of cutting, maximal of feed rate and depth of cut, it is possible to reach the maximum of cutting power, as in figure 3. With increase of the cutting speed, the cutting power will be decreased.

Figure 3: Cutting Power Pc in Function of Cutting Speed v and Cutting Force Fc

3. OPTIMIZATION METHOD USING GENETIC ALGORITHM

Being a population based approach; Genetic Algorithms are well suitable to solve multi – objective optimization problem. To find the optimal solution for treated problem, the multi-objective optimization problem using Genetic Algorithms are employed. This is a very popular problem in practice, and can be written in the following form:

$$\min f(x) = \begin{cases} f_1(x) \\ f_2(x) \\ \vdots \\ f_{n_{obj}}(x) \end{cases}; \quad n_{obj} \geq 2; \quad (9)$$

$$x = \{x_1 \quad x_2 \quad \dots \quad x_n\}^T \leq 0$$

The number of function required to be minimal two $n_{obj} > 2$, never than less, subjected to the constraints:

$$g(x) = \{g_1(x) \quad g_2(x) \quad \dots \quad g_{n_c}(x)\}^T \leq 0. \quad (10)$$

Where, scalar functions $f(x)$ and $g(x)$ are termed the multi – objective and constraint function, respectively. The vector x denotes variables. The symbol (n) denotes the number of variables, and (n_c) is the number of constrains. In many case of real problems, multi – objective optimization problem involve multiple and conflicting objectives. Hence, optimizing of the machining variables with respect to a single objective function often results in unacceptable results with respect to the other objectives functions. Therefore, a perfect multi – objective solution that simultaneously optimizes each objective function is almost impossible by Konak Abdullah et al. (2006). A reasonable solution to a multi – objective problem is to investigate a set of solutions, each of which satisfied with the objectives at an acceptable level without being dominated by any other solution. The definition of optimal cutting parameters plays an important role in metal cutting process. In this work, a multi-objective optimization technique is presented, based on genetic algorithms, for optimizing the cutting parameters by milling process. The cutting force is included in cutting power. So, in our case, there are two

objectives function i.e. cutting power P_c and material removal rate MMR are suggested to optimise in our research work.

Figure 4: Diagram of Genetic Algorithm process

The first multi – objective GAs, called vector evaluated GAs, was proposed by Schaffer (1995). Afterwards, several multi-objective evolutionary algorithms were developed, including Multi-objective Genetic Algorithms (MOGAs). Clearly, the above optimization process is a nonlinear programming problem. Optimization procedure in GAs, starts by reading the boundary of variables and initialize machining parameters: f , a , v . Furthermore, the main machining parameters are passed into the milling operation, to find near more and near optimal solutions of cutting power P_c and material removal rate MRR. These values are substituted into GAs process to calculate fitness function - objective function.

The optimization results for the two objective functions as cutting power and material removal rate are shown in figure 5. Also, the optimal machining parameters cutting speed (v), feed rate (f) and depth of cut (a) are obtained from the Pareto front graph. After optimization of the objective function, the optimal machining parameters are reached.

Figure 5: Pareto Front Solutions for Cutting Power P_c and Material Removal Rate MRR

CONCLUSIONS

As conclusion of this work, we conclude that optimization of cutting forces is achieved by the end milling

process. The obtained results of cutting force in experimental way are presented by the expression of cutting power P_c . Material removal rate MRR, cutting power P_c and main machining parameters are optimized in the environment of Matlab such as Genetic algorithm. The regression model for cutting force is described in our case during the analysis of the optimization procedure.

The most variables that have big influence in cutting force such as: tool geometry, workpiece material for our case 42CrMo4, feed rate, depth of cutting, cutting speed or number revolution, coolant and tool material are investigated in optimization. The measurement of cutting force is obtained in practical work through the device of Kistler dynamometer 9257B.

Theoretically and practically, the problem of optimization for the force by end milling was studied and the results were obtained and compared. The optimization results are plotted as Pareto optimal front. This paper also remarks the advantages of multi-objective optimization approach over the single-objective one.

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