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Genetic equation for the cutting force in ball-end milling

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Abstract: The paper presents the development of the genetic equation for the cutting force for ball-end milling process. The development of the equation combines different methods and technologies like evolutionary methods, manufacturing technology, measuring and control technology and intelligent process technology with the adequate hardware and software support. Ball-end milling is a very common machining process in modern manufacturing processes. The cutting forces play the important role for the selection of the optimal cutting parameters in ball-end milling. In many cases the cutting forces in ball-end milling are calculated by equation from the analytical cutting force model. In the paper the genetic equation for the cutting forces in ball-end milling is developed with the use of the measured cutting forces and genetic programming. The experiments were made with the system for the cutting force monitoring in ball-end milling process. The obtained results show that the developed genetic equation fits very well with the experimental data.
The developed genetic equation can be used for the cutting force estimation and optimization of cutting parameters. The integration of the proposed method will lead to the reduction in production costs and production time, flexibility in machining parameter selection, and improvement of product quality.

Keywords: Cutting forces, Cutting parameters, Ball-end mill, Genetic programming

1. INTRODUCTION

The paper presents the development of the genetic equation of machining process, which is shown in detail on the process of machining of steels with ball-end milling. The milling process has become a very important and useful procedure for the manufacture of 3D surfaces of different shapes. Due to the widespread use of highly automated machine tools in the industry, manufacturing requires reliable monitoring and optimization models and methods.

The cutting forces that are developed during the milling process, can directly or indirectly estimate process parameters such as tool wear, tool life, surface finish, etc. The capability of modeling cutting forces therefore provides an analytical basis for machining process planning, machine tool design, cutter geometry optimization, and on-line monitoring/control. A large amount of work has been carried out on force modeling.

Researchers, 1 have been trying to develop mathematical models that would predict the cutting forces based on the geometry and physical characteristics of the process. However, due to its complexity, the milling process still represents a challenge to the modeling and simulation research effort.

The main objective of this work is to develop an intelligent model for cutting forces in ball-end milling process. By exploring the advantages of the artificial intelligence methods, the genetic equation is developed. The genetic equation is developed for use as a direct modelling method, to predict cutting forces for the ball-end milling operations. Prediction of cutting forces in ball-end milling is often needed in order to establish automation or optimization of the machining processes. The developed genetic equation will be applied into the manufacturing process for the determination of optimal cutting parameters with a few numbers of experiments and maximum cutting power on tool machine.

2. BALL-END MILLING

Ball-end milling is a very common machining process especially in the automobile, aerospace, die and mold industries 3. It is used for machining the freely shaped surfaces such as dies, moulds, turbines, propellers, and for the aircraft structural elements. Due to various reasons, such as structural, optimization or esthetic points of view, nowadays, most of the industrial part geometries are becoming more and more complicated. The recent advance in CAD/CAM systems and CNC machining centers allows us to supply this demand of machining very complex sculpture surfaces by ball-end milling.

The importance of predicting the cutting forces in ball-end milling is evident. In the process planning stage, knowledge on the cutting forces helps the process engineers to select “appropriate values” for the process parameters. The prediction of cutting forces gives support in planning of the process, in selecting of suitable cutting parameters for reduction of excessive wear, deformation and breakage of the tool, helps to design better fixtures which increase the quality of parts. The analytical cutting force model for ball-end milling 4 can be also used for the prediction of the cutting forces in ball-end milling process.

3. GENETIC PROGRAMMING (GP)

The genetic algorithm (GA) is a model of machine learning which derives its behaviour from a metaphor of the processes of evolution in nature 5. This is done by the creation within a machine of a population of individuals represented by chromosomes, in essence a set of character strings that are analogous to the base-4 chromosomes that we see in our own DNA. The individuals in the population then go through a process of evolution.

Genetic programming is the extension of the genetic model of learning into the space of programs. That is, the objects that constitute the population are not fixed-length character strings that encode possible solutions to the problem at hand, they are programs that, when executed, "are" the candidate solutions to the problem. These programs are expressed in genetic programming as parse trees, rather than as lines of code.

The programs in the population are composed of elements from the "Function set" and the "Terminal set", which are typically fixed sets of symbols selected to be appropriate to the solution of problems in the domain of interest. In GP the crossover operation is implemented by taking randomly selected subtrees in the individuals (selected according to fitness) and exchanging them.

4. EXPERIMENTAL SETUP

The experiments were made with the system for the cutting force monitoring (F_x, F_y in F_z) in ball-end milling process. The system for monitoring consists of: (Figure 4)

- tool machine (CNC milling machine **MORI SEIKI FRONTIER - M**),
- tool (solid ball-end milling cutter type **R216.44-10030-040-AL10G**, tool material **GC 1010**),
- clamping device,
- workpiece (material: **Ck45**, **Ck45 (XM)**, **16MnCr5** in **16MnCr5 (XM)**),
- piezoelectric dynamometer (**KISTLER 9259A)**,
- amplifier (**KISTLER 5001)**,
- A/D interface board (**PC-MIO-16E-4**.),
- computer (PII 350MHz with Windows 2000 software) and
- programe package LabVIEW.

4. GENETIC EQUATION FOR CUTTING FORCE IN BALL-END MILLING

For the determination of the genetic equation in ball-end milling with the milling cutter type **R216.44-10030-040-AL10G** and workpiece material **Ck45** was selected 45 experimental data. The maximal cutting forces were monitored with different cutting conditions (radial depth R_D = 0,2 - 0,6 mm, axial depth A_D = 0,2 - 0,6 mm, feeding f_z = 0,08 - 0,12 mm/tooth and cutting speed V_c = 125 - 250 m/min). On the base of input and experimental data and with the selection of adequate arithmetic operations the genetic equation for the cutting force in ball-end milling was developed:

$$F_{\max} = f\left(R_D\ A_D\ f_z\ V_c\right) \tag{1}$$

For the determination of the genetic equation the independent variables must be set - Terminal set: $\mathscr{T} = \{x, y, z, w, \mathscr{R}\}$, where is x - radial depth R_D, y - axial depth A_D, z - feeding f_z, w - cutting speed V_c and $\mathscr{R}$ - random floating-point numbers between -10 and 10, arithmetic operations - Functional set: $\mathscr{F} = \{+, -, *, /\}$, where is "+" - addition, "-" - subtraction, "*" - multiplication and "/" – division and number of arguments: $\mathscr{P} = \{2, 2, 3, 2\}$. The evolutionary parameters for the determination of the genetic equation were: population size (number of organisms) M=1000 and number of generations G=100 The genetic operations reproduction, crossover and mutation were used. Probability of reproduction was p_r = 0,1, crossover p_c = 0,6 and mutation p_c = 0,1.

Figure 2 shows the average percentage deviation of the best genetic equation from initial generation to generation 100 where the best genetic equation of evolution was reached.

The first successful genetic equation for cutting forces prediction F_{max} was obtained in generation 29, with average percentage deviation 10,38 %. The best genetic equation for cutting forces prediction F_{max} was reached in generation 98, with average percentage deviation 3,83 %.

The comparison of the experimental data with the genetic equation data for cutting forces in ball-end milling is presented in Figure 3.

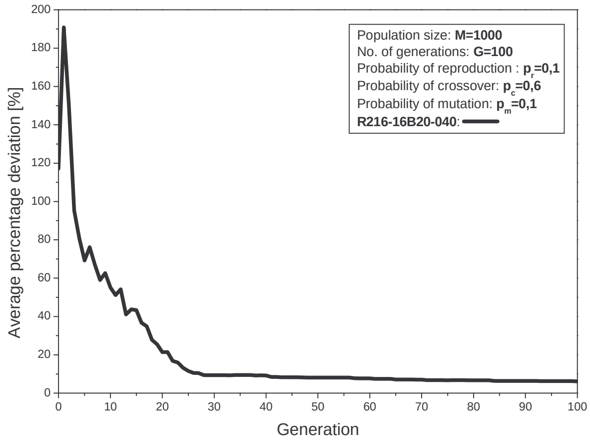

Figure 1. Average percentage deviation

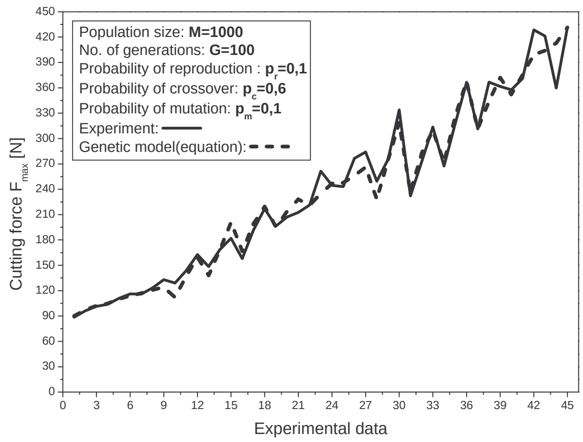

Figure 2. Experimental and genetic data

The best genetic equation for cutting forces prediction F_{max} is:

$$F_{\max} = 11{,}0486 + R_D - A_D + V_c \cdot R_D \cdot A_D - 58{,}5012 \cdot \left(-8{,}2466 + A_D\right) \cdot A_D + \frac{58{,}5012 \cdot \left(-8{,}2524 + A_D\right) \cdot \left(0{,}0058 + A_D\right) + V_c \cdot \left(-0{,}7975 - 0{,}2868 \cdot f_z\right)}{V_c \cdot \left(2{,}802 + R_D\right) \cdot \left(2{,}7956 - A_D\right) \cdot f_z^2} + \frac{V_c \cdot R_D \cdot \left(2{,}802 + R_D\right)}{0{,}1012 \cdot V_c - 2 \cdot R_D - A_D + f_z - 0{,}5736 \cdot V_c \cdot f_z} \quad (2)$$

5. CONCLUSION

The paper presents the development of the genetic equation in ball-end milling. The results obtained from the proposed genetic programming approach prove its effectiveness. The implication of the encouraging results obtained from the present approach is that such approach can be integrated on-line, with an intelligent manufacturing system for automated process planning. Integration of the proposed approach with an intelligent manufacturing system will lead to reduction in production cost and production time, flexibility in machining parameter selection, and improvement of product quality. This research definitely indicates some directions for future work.

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