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System for cutting force monitoring and simulation in milling

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With the use of highly automated machine tools in the industry, manufacturing requires reliable models and methods for the prediction of output performance of machining processes. The present work deals with the study and development of a simulation system of the cutting process on the model of the ball-end milling process with GA. The system for simulation of the cutting process contains the experimental model and the simulation model based on genetic algorithms. The experimental model presents the data acquisition system, LabVIEW software, and the results measured cutting forces, which are a starting point for simulation of the cutting forces. A genetic algorithm (GA) based simulation procedure has been developed for the prediction of the cutting forces in ball-end milling. The GA procedure is illustrated with an example and results, to confirm the simulation system with different cutting modes and parameters.

1. INTRODUCTION

The purpose of this paper is to presents the acquisition and simulation system for the measuring and simulation of cutting forces during ball-end milling. Cutting force is an important factor to predict machining performances of any machining operation [1]. The predictive modelling of machining operations requires detailed prediction of the boundary conditions for stable machining [2]. The number of cutting force prediction models available in literature is very limited [3, 4].

With the use of artificial intelligence, such as: neural network and fuzzy theory etc., the optimization and the simulation of machining parameters and cutting forces become easier [5, 6]. Genetic algorithms (GA), based on the principles of natural biological evolution, have received considerable and increasing interest over the past decade. Compared to traditional simulation and optimization methods, a GA is robust, global and may be applied generally without recourse to domain-specific heuristics.

2. MONITORING SYSTEM

The monitoring system presents the data acquisition equipment, LabVIEW software, and the results measured cutting forces. The data acquisition equipment used in this acquisition system consists of dynamometer, fixture module, hardware and software module. The dynamometer system is composed of a dynamometer (Kistler Model 9255), a multi-channel charge amplifier (Kistler Model 5001) and their connecting cable. When the tool is cutting the workpiece, the force will be applied to the dynamometer through the tool. The piezoelectric quartz in the dynamometer will be strained and an electric charge will be generated. The electric charge is then transmitted to the multi-channel charge amplifier through the connecting cable.

The interface hardware module consists of a connecting plan block, analogue signal conditioning modules and a 16 channel A/D interface board (PC-MIO-16E-4). In the A/D board, the analogue signal will be transformed into a digital signal so that the LabVIEW software is able to read and receive the data. With this program, the force components can be obtained simultaneously, and can be displayed on the screen for analyzing force changes.

3. CUTTING FORCES

Products with 3D sculptured surfaces are widely used in the modern tool, die and turbine industries. These complex-shaped premium products are usually machined using the ball-end milling process.

The cutting edge of the milling cutter lies on the hemisphere surface and is determined with the constant helix angle. The cutting edges have the helix angle λ_b at the transition from the hemispherical part of the milling cutter into the cylindrical part. With respect to reduction of the milling cutter radius in *X-Y* plane towards the milling cutter tip in *Z* direction the helix angle - the local helix angle changes.

The equation for the tangential cutting force, radial cutting force and axial cutting force is:

$$dF_{T,R,A} = K_{T,R,A} \cdot h_b \cdot db = K_{T,R,A} \cdot f_{z_b} \cdot sin\,\mathrm{B} \cdot sin\,\eta \cdot db \tag{1}$$

K_T - tangential coefficient of material, K_R - radial coefficient of material, K_A - axial coefficient of material, db - differential length of cutting edge, h_b - chip thickness, f_{zb} - feeding per tooth, η - angular position in the direction of Z axis from the center of the hemispherical part to the point on the cutting edge, $B(i,j,k)$ - Angular position of the cutting edge during cutting, dz - differential length of axial differential elements

The generalized equation for the tangential, radial and axial cutting force is:

$$dF_{T,R,A}(i,j,k) = K_{T,R,A} \cdot f_{z_b} \cdot sin[\mathrm{B}(i,j,k)] \cdot dz \tag{2}$$

The forces expressed in the Cartesian coordinate system are obtained if the transformation matrix [T] is inserted [7]:

$$\{dF_{X,Y,Z}\} = [T]\{dF_{R,T,A}\} \tag{3}$$

$$[dF_{X,Y,Z}(i,j)] = \sum_{k=1}^{N_f} [T](i,j,k)[K_{R,T,A}] \cdot f_{z_b} \cdot sin[\mathrm{B}(i,j,k)] \cdot dz \tag{4}$$

The total force on the cutting edge in case of *j*-th position:

$$[dF_{X,Y,Z}(j)] = \sum_{i=1}^{N_z} \sum_{k=1}^{N_f} [T](i,j,k)[K_{R,T,A}] \cdot f_{z_b} \cdot sin[\mathrm{B}(i,j,k)] \cdot dz \tag{5}$$

The average cutting force is:

$$[\overline{F}_{X,Y,Z}] = \left\{ \sum_{i=1}^{N_z} \sum_{j=1}^{N_\theta} \sum_{k=1}^{N_f} [T](i,j,k)[K_{R,T,A}] \cdot f_{z_b} \cdot sin[\mathrm{B}(i,j,k)] \cdot dz \right\} \Big/ N_\theta \tag{6}$$

4. GENETIC ALGORITHMS

A genetic algorithm was applied to the simulation model to determine the process parameter values that would result the simulated cutting forces in ball-end milling. Most of the researchers have used traditional simulation techniques for solving machining problems [8].

Genetic algorithms are search algorithms for simulation and optimization, based on the mechanics of natural selection and genetics [8]. The power of these algorithms is derived from a very simple heuristic assumption that the best solution will be found in the regions of solution space containing high proposition of good solution, and that these regions can be identified by judicious and robust sampling of the solution space. The mechanics of genetic algorithms is simple, involving copying of binary strings and the swapping of the binary strings. The simplicity of operation and computational efficiency are the two main attractions of the genetic algorithm approach. The computations are carried out in three stages to get a result in one generation or iteration. The three stages are Reproduction, Crossover and Mutation.

5. MODEL VALIDATION

The present model has been validated by comparing the simulated and the measured cutting forces in 3D ball-end milling. An extensive number of experiments have been performed on a milling machine to confirm the simulation model with different cutting parameters.

A set of 80 experiments was conducted to evaluate the validity of the simulation model in various cutting modes and conditions. The instantaneous cutting force signals in three orthogonal directions were measured by a table mounted piezoelectric dynamometer (**Kister Model 9255**). These signals were amplified (**Kistler Model 5001**), digitized (**PC-MIO-16E-4**) and stored in computer. The measured data was processed with the computer program made by **LabWIEV**. The experiments were run on the NC milling machine (type HELLER BEA1) and performed on material **Ck 45** and **Ck 45 (XM)** with improved machining properties. The ball-end milling cutter with interchangeable cutting inserts of type **R216-16B20-040** with two cutting edges, of 16 mm diameter and 10° helix angle was used for machining of the material. The cutting inserts **R216-16 03 M-M** with 12° rake angle were selected. The cutting insert material is **P30-50** coated with TiC/TiN, designated **GC 4040** in **P10-P20** coated with TiC/TiN, designated **GC 1025**. The coolant RENUS FFM was used for cooling.

The present model provides excellent cutting force predictions. It accurately predicts fine details of the measured force signals. The present model has proven to provide reliable cutting force simulation for 3D ball-end milling.

Let the number of population be 200, number of generations 200, elitism 20, the reproduction probability 0,85, the mutation probability 0,001, selection probability 0,7, regeneration period 10 and regeneration percent 10. A group of the initial population is first produced randomly, then the reproduction, recombination and mutation operations are run repeatedly, based on the fitness of the individual until the GA converges.

The simulation and experimental results are presented in figure 1 for the comparison purposes. The dashed lines in diagrams represent the simulated cutting forces, whereas the continues lines represent the experimental cutting forces.

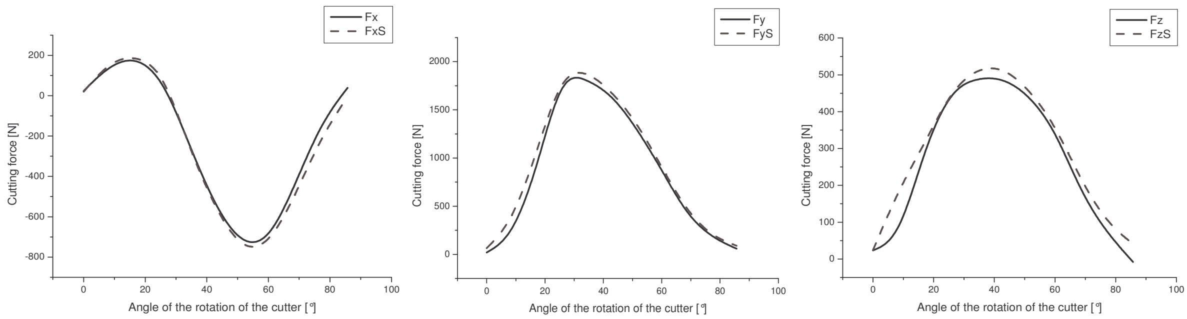

Figure 1. Measured and simulated cutting forces

6. CONCLUSION

The paper presents the development and use of the cutting force monitoring and simulation in in ball-end milling. The simulation system is based on genetic algorithm and on the analytical formulation of the components of cutting forces for the ball-end milling cutter. All influencing factors: tool geometry, workpiece material, and cutting parameters were considered.

It can be claimed that the comparison of the results obtained from the simulation and of the experimental results confirms the efficiency and accuracy of the system for acquisition and simulation of the milling process in predicting the cutting forces. The system for simulation of the cutting process presents an approach to predicting the cutting forces in the milling process and opens new possibilities for optimization of the cutting process, manufacture of new shapes of tools and greater utilization of the machine tools.

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