

MACHINING AND OPTIMIZATION OF 3D SCULPTURED SURFACES IN BALL-END MILLING BASED ON COMBINED ARTIFICIAL INTELLIGENCE METHODS

Franc Cus

Matjaz Milfelner

franc.cus@uni-mb.si

matjaz.milfelner@uni-mb.si

University of Maribor, Faculty of Mechanical Engineering,
Smetanova 17, SI-2000 Maribor, Slovenia

Janez Kopac

janez.kopac@fs.uni-lj.si

University of Ljubljana, Faculty of Mechanical Engineering,
Askerceva 6, SI-1000 Ljubljana, Slovenia

Abstract. *An intelligent machining system is applied in a high speed machining robot with on-line monitoring and optimization for ball-end milling process. Manufacturing of 3D sculptured surfaces on high speed machining robot involves a number of machining parameters and tool geometries. An intelligent machining system for on-line monitoring and optimization in ball-end milling is developed for the simulation and testing on the PC machine. It is based on a main PC computer, which is connected to the high speed machining robot main processor so that control and communication can be realized. The system collects the variables of the cutting process by means of sensors. The measured values are delivered to the computer program through the data acquisition system for data processing and analysis. The optimization technique is based on genetic algorithms for the determination of the cutting conditions in machining operations. In metal cutting processes, cutting conditions have an influence on reducing the production cost and time and deciding the quality of a final product. Simulated results show that the proposed intelligent machining system with the genetic algorithm-based procedure for optimization is effective and efficient, and can be integrated into a real-time intelligent manufacturing system for solving complex machining optimization problems.*

Keywords: *Machining, Artificial intelligence methods, Ball-end milling, Simulation, Optimization Estimation*

1. INTRODUCTION

This paper presents an intelligent machining system on high speed machining robot with system for on-line monitoring and optimization of cutting conditions in ball-end milling (Fig. 1). Finding optimum machining parameters in 3D sculptured surface machining is quite a widely researched problem. The cutting force generated during machining process is an important parameter, which reflects the machining conditions. The other important factors for the optimum machining are: cutting time, cutting tool cost, quality of surface achieved, and machining errors visualized as shape deviation from the ideal. The above mentioned issues should really be considered simultaneously, which would render the optimization problem quite intricate. With an on-line monitoring system, the machining process and above mentioned factors can be monitored easily. The determination of efficient cutting parameters has been a problem confronting manufacturing industries for nearly a century, and is still the subject of many studies. To ensure the quality of machining products, and to reduce the machining costs and increase the machining effectiveness, it is very important to select the optimal machining parameters. Optimal machining parameters are of great concern in manufacturing environments, where economy of machining operation plays a key role in the competitive market. For that reason the genetic algorithms (GA), based on the principles of natural biological evolution, will be used in our research for the optimization of the cutting conditions in ball-end milling. (Cus et al., 2000).

2. ON-LINE MONITORING SYSTEM

In this paper, an intelligent system is developed with the on-line monitoring equipment (hardware) and real-time data analysis and optimization software.

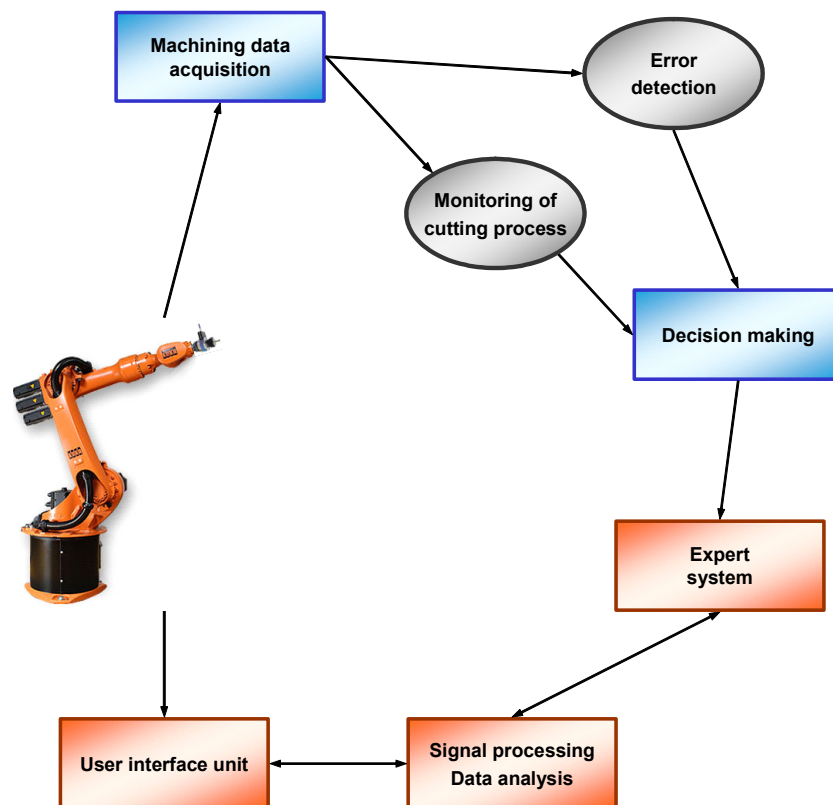


Figure 1- Intelligent machining system.

The monitoring system (Milfelner et al., 2005) frequently commences with experiments using a force dynamometer on HSC spindle, which quantifies the actual force exerted on the milling tool during the cutting process. The monitoring system is connected with the PC (data processing and analysis, optimization), which is connected to the HSM robot main processor, so that the communication with the HSM robot (optimal cutting conditions) can be realized (Fig. 2). The on-line monitoring module is based on a PC computer, and is a general-purpose programming system with an extensive library of functions and subroutines for any programming task (Zuperl et al., 2004). It also contains an application specific library for data acquisition, serial instrument control, data processing, analysis presentation and storage.

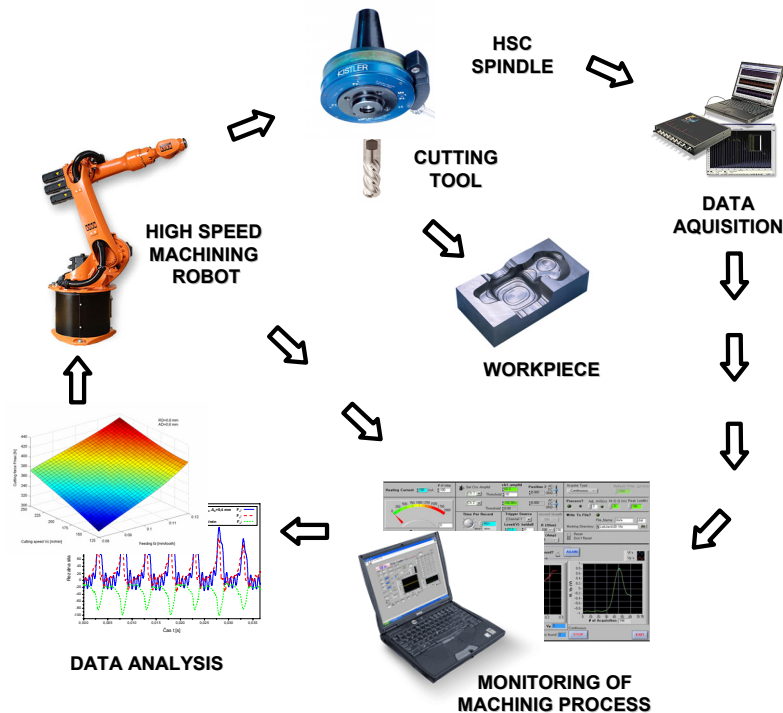


Figure 2- On-line monitoring system.

3. BALL-END MILLING

Ball-end milling has been widely used in the manufacture of free form surfaces such as those embodied in dies and moulds, turbine engine blades and aircraft structural components. Geometrical shapes of product become more and more complex and can be made only with ball-end milling on modern CNC machining centers. Prediction of cutting forces during milling with ball-end milling cutter is very important. In the cutting process planning stage the knowledge of cutting forces helps the technologist to determine the cutting parameters for machining. Prediction of cutting forces supports the process planning, the selection of suitable cutting conditions to reduce wear, tool deformation and breakage and the design of better fixing devices which improve the product quality. Basic models cutting forces in milling with ball-end milling cutter, presented in researches, are determined by means of theoretical and practical knowledge and experiments (Zuperl et al., 2005). Input parameters such as: cutting parameters, cutter geometry, cutter and workpiece material (Kopac et al., 2001) are needed for the determination of the model of cutting forces in ball-end milling. The output parameters and/or the model results are the cutting force. The analytical cutting force model for ball-end milling cutter is presented in our work. The cutting force on cutting edge of the cutter is: (Eq. (1) and Eq. (2)):

$$[T] = \begin{bmatrix} -\sin \kappa \sin \Psi & -\cos \Psi & -\cos \kappa \sin \Psi \\ -\sin \kappa \cos \Psi & \sin \Psi & -\cos \kappa \cos \Psi \\ \cos \kappa & 0 & -\sin \kappa \end{bmatrix}. \quad (1)$$

$$\begin{bmatrix} F_X \\ F_Y \\ F_Z \end{bmatrix} = [T] \begin{bmatrix} K_R \\ K_T \\ K_A \end{bmatrix} f_z \cdot \sin[\Psi] \cdot dz. \quad (2)$$

dz - thickness of axial differential element [mm]

f_z - feeding per tooth [mm/tooth]

Ψ - angular position of cutting edge during cutting in the direction of rotation of the milling cutter [°]

κ - angular position in the direction of Z axis from the center of the hemispherical part to the point on the cutting edge [°]

K_T - tangential coefficient of material [N/mm²]

K_R - radial coefficient of material [N/mm²]

K_A - axial coefficient of material [N/mm²]

4. OPTIMIZATION OF CUTTING CONDITIONS WITH GA

The selection of optimal machining parameters plays an important part in intelligent manufacturing. The optimization of machining parameters is still the subject of many studies. Genetic algorithms (GA) have been applied to many difficult combinatorial optimization problems with certain strengths and weaknesses. In this paper, genetic algorithm GA, is used to determine optimal machining parameters for ball-end milling operations. In a traditional CNC system, machining parameters are usually selected at the start according to handbooks or people's experiences, and the selected machining parameters are usually conservative so as to avoid machining failure. Even if the machining parameters are optimized off-line by an optimization algorithm, they cannot be adjusted in the machining process, but the machining process is variable owing to tool wear, heat change and other disturbances. To ensure the quality of the machined products, to reduce the machining costs and to increase the machining efficiency, it is necessary to optimize and control the machining process on-line when the machine tools, are used for CNC machining. The machining parameters must be adjusted in real-time so as to satisfy some optimal machining criteria. Intelligent manufacturing achieves substantial savings in terms of money and time if it integrates an efficient automated process-planning module with other automated systems such as production, transportation, assembly, etc. Process planning involves determination of appropriate machines, tools for machining parts, cutting fluid to reduce the average temperature within the cutting zone and machining parameters under certain cutting conditions for each operation of a given machined part. The machining economics problem consists in determining the process parameter, usually cutting speed, feed rate and depth of cut, in order to optimize an objective function. A number of objective functions by which to measure the optimality of machining conditions include: minimum unit production cost, maximum production rate, maximum profit rate and weighted combination of several objective functions. Several cutting constraints that should be considered in machining economics include: tool-life constraint, cutting force constraint, power, stable cutting region constraint, chip-tool interface temperature constraint, surface finish constraint, and roughing and finishing parameter relations Milfelner et al., 2001)

5. AN ILLUSTRATIVE EXAMPLE

The simulation experiments were performed on material 16MnCr5 and 16MnCr5 (XM) with improved machining properties. The solid ball-end milling cutter type R216.64-08030-AO09G 1610 with four cutting edges, of 8 mm diameter and 45° helix angle was used for machining of the material (Fig. 3).

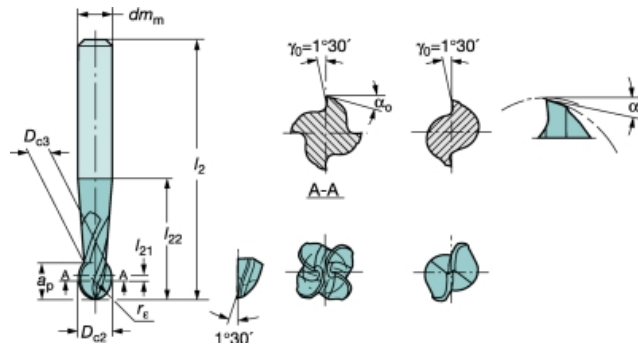


Figure 3- Ball-end milling cutter

For the determination of optimal cutting conditions the optimization of two variables (feeding f_z and cutting speed V_c) was used. The evolutionary parameters for the genetic algorithm were: population size 500, number of generations 30 and number of genes of each chromosome 10. The genetic operations crossover and mutation were used. Probability of crossover was $p_c = 0,65$ and mutation $p_m = 0,1$. Optimal cutting conditions were found in 16 generation with average error 0,28% (Fig. 4).

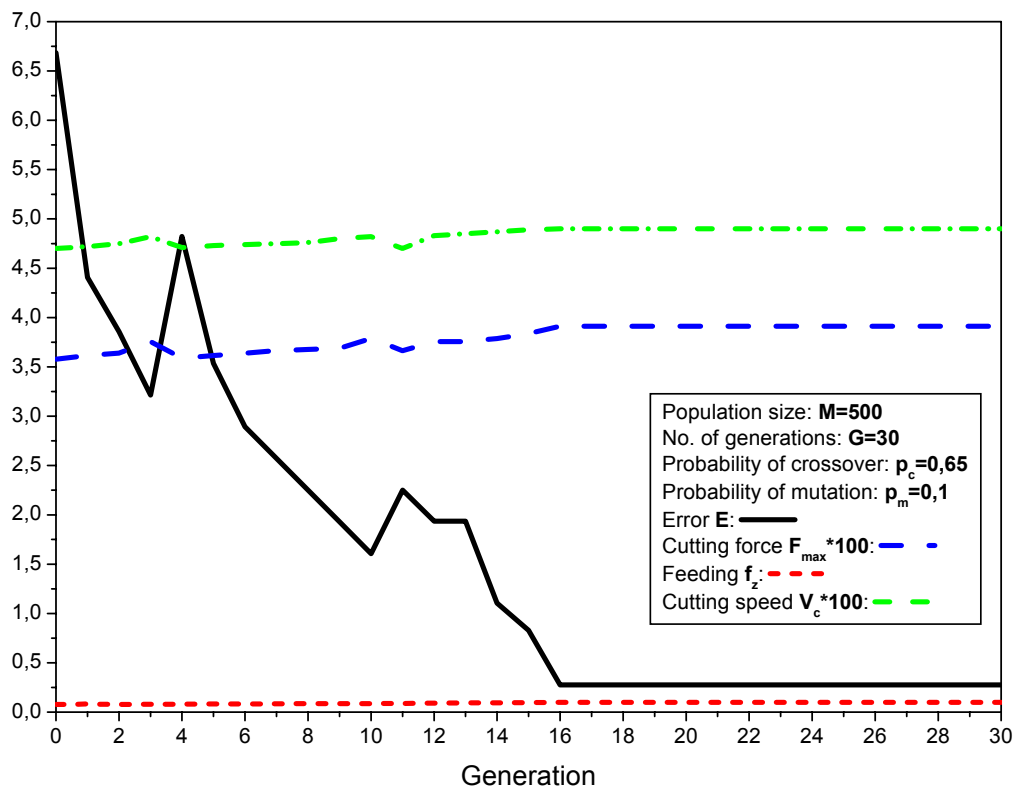


Figure 4- Evolution of the genetic algorithm

With the optimal cutting conditions the machining time was reduced for 22,4 %. The present model provides excellent optimization of the cutting conditions. It accurately predicts fine details of the measured force signals. The present model has proven to provide reliable optimization of the cutting process for 3D ball-end milling. This model has great potential to be used to develop optimization technologies for sculptured surface machining with ball-end mills. Experimental results show that the proposed genetic algorithm-based procedure for solving the optimization problem is effective and efficient, and can be integrated on-line into an intelligent manufacturing system for solving complex machining optimization problems.

6. DISCUSSION OF RESULTS

For the optimization of the cutting conditions the genetic algorithm was used. The genetic algorithm gives accurate results and it is very fast. Precision of results is very reliable. Clearly, the genetic algorithm-based optimization approach provides a sufficiently approximation to the true optimal solution. Due to the changes of the cutting conditions, it is predictable that the life of the cutting tool will be prolonged. We assume that the life of the cutting tool can be increased by 1,5 to 2 times.

7. CONCLUSION

The paper presents the development and use of machining system which is applied in a high speed machining robot with on-line monitoring and optimization of the cutting conditions in ball-end milling. The system is based on computer programme, acquisition system, and theoretic knowledge of technological processes, machines and tests performed. All influencing factors: tool geometry, workpiece material, and cutting conditions were considered. Genetic algorithm optimization approach was used for solving the machining operations problem with ball-end milling. The results obtained from the proposed genetic algorithm optimization 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. Since the genetic algorithm-based approach can obtain near-optimal solution, it can be used for machining parameter selection of complex machined parts that require many machining constraints.

REFERENCES

- Cus, F., & Balic, J., 2000. Selection of Cutting Conditions and Tool Flow in Flexible Manufacturing System. *The International Journal for Manufacturing Science & Technology*, vol. 2, pp. 101-106.
- Kopac, J., Sokovic, M., & Dolinsek, S., 2001. Tribology of coated tools in conventional and HSC machining. *Journal of Materials Processing Technology*, vol. 118, pp. 377-378.
- Milfelner, M., Kopac, J., Cus, F., & Zuperl, U., 2005. Genetic equation for the cutting force in ball-end milling. *Journal of Materials Processing Technology*, pp. 164-165
- Zuperl, U., Cus, F., Mursec, B., & Ploj, T., 2004. A hybrid analytical-neural network approach to the determination of optimal cutting conditions. *Journal of Materials Processing Technology*, vol. 157-158.