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Model reference adaptive force and surface roughness control in milling

F. Cus, U. Zuperl *
Faculty of Mechanical Engineering, University of Maribor,
Smetanova 17, 2000 Maribor, Slovenia
* Corresponding author: E-mail address: uros.zuperl@uni-mb.si

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ABSTRACT

Purpose: of this paper. The paper presents the model based mechanism of control assuring constant quality of surface finish by controlling the cutting forces in the end milling process. By dynamic adaptation of feeding and speed the system controls the surface roughness and the cutting forces on the milling cutter. The purpose of developing such a mechanism is to find the limitations of such control which maintains constant cutting force by adapting the cutting parameters.
Design/methodology/approach: The model based system of control has been developed by the evolutionary method of genetic programming (GP). A drawing of experiments has been made in order to determine the empirical correlations between the quality of surface finish and the cutting force. Genetic programming method has been applied to derive empirical relationship of the surface finish and cutting force values for steel material. These relationships have been applied to develop the proposed evolution simulation model in which the cutting force is adjusted to improve the required surface quality.
Findings: The system eliminates the problems related to assurance of quality of machining, efficiency of machining and prevention of tool damages.
Research limitations/implications: While force control approach performed satisfactorily in a laboratory environment, it can be generally concluded that their implementation should be dictated by the economics of the production environment.
Practical implications: The results provide a means of greater efficiency by improving the surface quality, minimizing the effect of the process variability and reducing the error cost in finishing operations.
Originality/value: An adaptive system of control which controls the cutting force and maintains constant roughness of the machined surface during milling by continuous dynamic adjustment of the cutting parameters is devolped.
Keywords: Machining; Model-based control system; Genetic programming

1. Introduction

The control of milling processes is presently receiving significant attention due to potential economic benefits associated with automated machining [1]. Milling processes are interesting from a control perspective due to difficulties such as system nonlinearities, time-varying parameters and tool wear [2,3]. Control techniques that have been developed for machining traditionally require some form of parameter adaptation [1,4]. Solution to this problem is adaptive control. Adaptive control system is introduced in cutting process by Stute and Goetz [5]. The most frequently used systems are MRAC (Model Reference Adaptive Control) [6] and STR (Self Tunning Regulations) [7]. MRAC, developed from adaptive control theory, is widely used for its robustness and disturbance rejection capability. Numerous forms of MRAC system have been developed [8,9].

Another solution to this problem are some intelligent control strategies [1]. The drawback of intelligent strategies is that neural network and genetic algorithm based calculation takes time, so it limits the response of the intelligent control system. In spite of initial difficulties in the development a trend towards equipping the CNC milling machine with modern adaptive systems can be noticed. For effective automatization, where the process takes place without interference of the human, continuous monitoring of the milling process is necessary. Most frequently that is materialized by measuring the cutting forces because they contain most information about the process and the tool condition. By analyzing the cutting force characteristics it is possible to assess the changes of the quality of surface finish [10]. The abovementioned facts are the bases for the development of the model based system for dynamic adjusting and optimization of cutting parameters (SDNRP). That is an adaptive system of control which controls the cutting force and maintains constant roughness of the machined surface during milling by continuous dynamic adjustment of the cutting parameters. Within the frame of the research a simulation model for testing of stability and harmonizing of parameters of the adaptive system (SDNRP), has been developed. The SDNRP changes its reactions in response to disturbances and changes in the dynamics of the cutting process. After execution of simulations the system SDNRP is fully ready and harmonized for the use in real milling process. The simulation diagram of the proposed system is presented on Figure 2.

2. Model based milling process control

Model based control system is a regulator that can modify its behaviour in response to change in the dynamics of the process and the disturbances. If the cutting force maintained constant during the process of machining process, then the surface finish also remain stable. In the previous research work [11] the cutting force resultant is obtained using a Kistler force Transducer, which provides of three orthogonal components of dynamics forces F_x, F_y, F_z and these forces were measured on-line using LabView software. These measured cutting force signals are used in model controller to regulate the cutting force. The main objective of this research is to develop genetic model based control system, which can solve such difficult machining control problems.

The objective of the proposed control system is to regulate the milling process operation parameters such as the feed rate and the spindle speed, and maintain the cutting force constant, to achieve on-line the required value of the surface finish. The Heller BEA01 milling machine was used in connection with the fees drive controller

3. CNC machine feed drive system

The tests were carried out on the CNC milling machine Heller. That is a four-axes machine tool allowing 3 translations along the X, Y and Z- axis and rotation of machine table in the horizontal plane. It is fitted with CNC controls FAGOR 8040-M. Feeding axles are driven through ball screw drives by AC servomotors synchronized with permanent magnets. The type of the servo-drive is: Heller S 044/82 8-A20-2220-001/02C. The block diagram (simulation model) of the feeding servo-system is shown in Figure 1.

4. GP based models of cutting quantities

Learning of models of cutting quantities is effected with experimental results stated in previous researches [12]. The purpose of models is to define functional dependences between the influencing cutting parameters: spindle speed, surface roughness and cutting force. The genetic programming (GP) method is used for the determination of mutual relations between the rotating speed and feeding and between cutting force and roughness. In case of GP the result is the mathematical formula consisting of a series of prescribed operations.

In simulations the GP models are used because, in the simulation package Simulink, they can be easier transformed into the block recording. 185 experimental data are used to develop each genetic model. The experimental datum contains the value of the predicted (modelled) quantity and the appurtenant influencing parameters (cutting parameters). On the basis of the input and experimental data and with selected series of calculation operations the models: K1, K2, K3, K4, K5 = K6 are generated. The series of the following basic calculation operations $\mathcal{F}$ = {+, -, *, u^v, ln} and arguments $\mathcal{P}$ = {2, 2, 3, 2}is selected. The set of terminals ($\mathcal{T}$) is given beside the block diagram of the individual model. Usually, the set of terminals consists of input data and variables of the system.

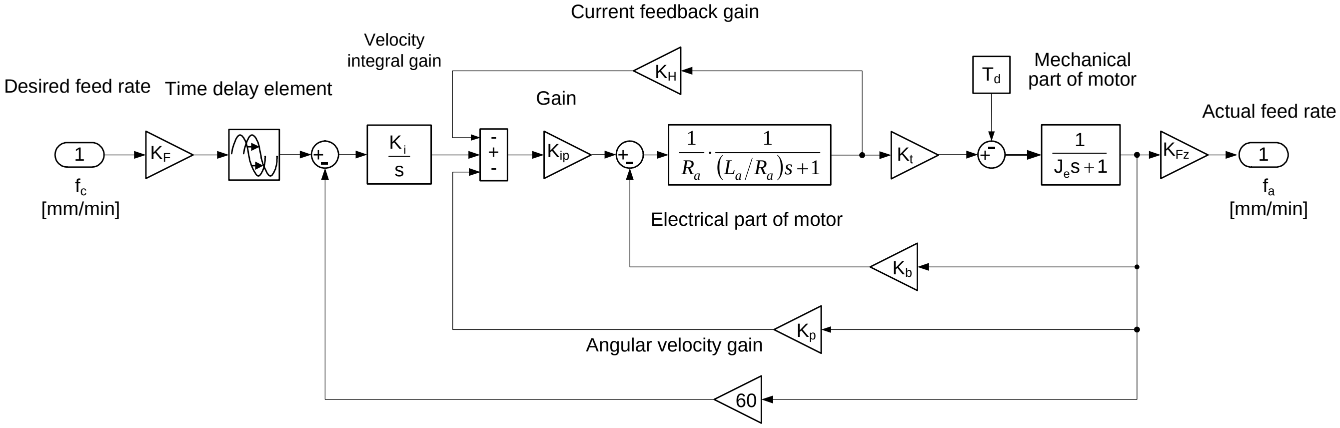

Fig. 1. Block diagram of feed drive servo system

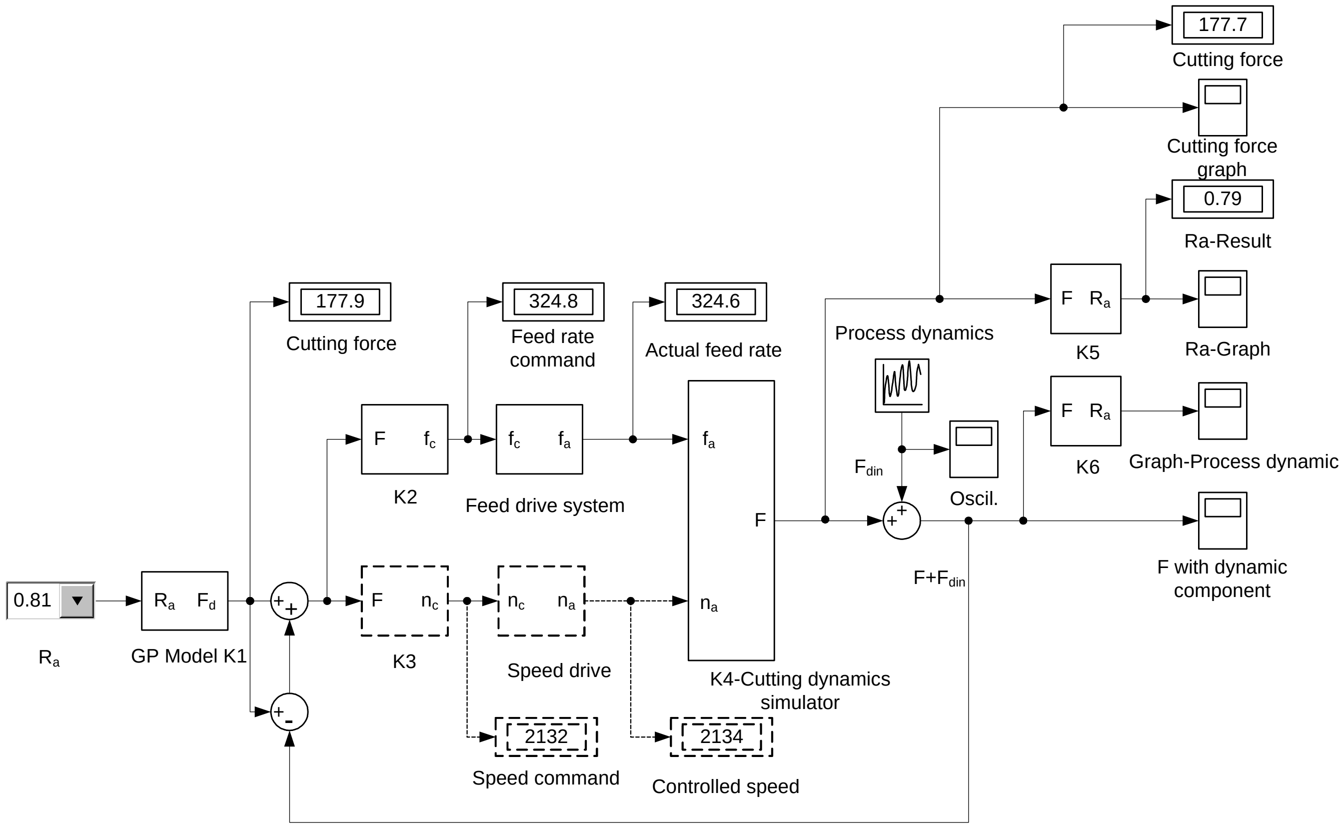

Fig. 2. Block diagram of the system for dynamical adjusting of cutting parameters. (Control system block diagram)

Table 1.
Simulation experimental results

Sim no.:	Desired surface roughness R_a [μm]	Initial cutting conditions before simulation [13,14]			Servo drive system after 15s			Produced surface finish R_a [μm]
		F_d [N]	f_c [mm/min]	n_c [min^{-1}]	F [N]	f_a [mm/min]	n_a [min^{-1}]	
1	0.38	161.4	357.12	1974	166.5	264.92	2443	0.50
2	0.51	166.67	379.98	1895	169.9	282.19	2356	0.58
3	0.64	172.1	414.53	1704	173.0	297.94	2272	0.66
4	0.76	176.8	435.26	1563	175.9	313.94	2189	0.74
5	0.81	178.5	430.41	1571	177.7	324.61	2134	0.79
6	0.89	180.9	462.19	1437	178.6	329.95	2108	0.81
7	1.02	184.7	485.14	1377	181.6	350.52	2007	0.91
8	1.14	188.1	507.75	1270	183.9	355.60	1925	0.99
9	1.27	191.2	539.24	1116	185.7	381.25	1880	1.05
10	1.52	196.8	592.58	825	195.2	411.99	1716	1.18

The size of the population of organisms M = 1500 and the number of generations G = 100 have been selected for the determination of the model of cutting (K4). On other models M = 850 and G = 100. The standard genetic operations of reproductions, crossover and mutation have been used. The reproduction probability pr = 0.15, the crossover probability pc = 0.5 and the mutation probability pm = 0.1. The development of the model is stopped when the prescribed number of generations has been reached or when fitness of the organism is more than 97 %.

5. Simulator of SDNRP

The block diagram of the simulator of the SDNRP is shown in Figure 2. If in the block diagram the model K4, the simulation model of the feed servo-drive and the model of main spindle rotation are replaced by the real machine tool, a harmonized system for dynamic adjustment of cutting conditions, ready for immediate use, is obtained. The system with regulation of the cutting force assures the required surface roughness. The simulation diagram comprises: simulator of CNC controls, simulator of the feed and main servo-drive, simulator of cutting, reference block and the models determining the mutual relations between the influencing cutting values. The simulation models of the machine dynamics are made on the basis of the technical specifications of the maker Heller.

5.1. The realization course of SDNRP simulation

The SDNRP capacity is tested by simulations. The Matlab simulation package Simulink has been used.

The simulation is initiated by the adjustment of the reference value R_a, afterwards desired cutting force F_d is predicted according to the model K1. When the force F_d is known, the values F_c and n_c are calculated within a moment according to the model K2 and K3. The dynamic response of the servo-system to the signal fc is simulated by the block diagram given in Figure 1. The two transfer functions of the servo-systems generate the actual feeding (f_a) and speed (n_a) so that the cutting force, predicted according to model K4, is constant.

The simulated Ra is determined by the transfer function of the model K5.

6. Analysis of the results

By simulation the efficiency and stability of the SDNRP with different requirements of the surface quality are tested. The criterion for efficiency of the system is the difference between the desired and simulated Ra. The starting cutting parameters and the desired Ra are the input data. In table 1 the requirements and the results of simulations are indicated. 10 simulations have been carried out. The simulation results (table 1) confirm that the SDNRP is efficient in the control of the tool loading and surface roughness. It is efficient in fine machining; this is particularly favourable, since it is intended for the operations of end milling with shank end mills, where the requirements for the quality of machining are strict. In machining, where the roughness exceeds 1.1 μm, the responsiveness of the system is slowed down. Its sensitiveness for reaching the desired roughness is reduced.

7. Conclusions

The paper presents the model based system of dynamic adjusting of cutting parameters. By dynamic adaptation of feeding and spindle speed the system controls the surface roughness and the cutting forces on the milling cutter. The correlation between the surface roughness and the cutting forces is determined by the GP method. By simulations the adequacy and stability of the control system are confirmed. It has been proved that the surface roughness which is an important indicator of the process quality can be successfully controlled by the control of cutting forces. By maintaining constant cutting force constant quality of surface finish is assured. On the basis of results of numerous simulations it has been decided to realize experimentally the described system of control. The system has been conceived for the end milling operation, although it can be modified for all process of machining by cutting.

References

[1] U. Zuperl, F. Cus and M. Milfelner, Fuzzy control strategy for an adaptive force control in end-milling, Journal of Materials. Processing Technology 164-165 (2005) 1472-1478.

[2] J. Kopac, M. Sokovic, Cutting properties of the PVD and CVD coatings on the ceramic substrates, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 278-285.

[3] F. Cus, U. Zuperl, E. Kiker and M. Milfelner, Adaptive controller design for feedrate maximization of machining process, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 237-240.

[4] C. Chen, M. Zhibin, An intelligent approach to non-constant feed rate determination for high-performance 2D CNC milling, International Journal of Manufacturing Technology and Management 9 (2006) 219-236.

[5] G. Stute, F.R. Goetz, Adaptive Control System for Variable Gain in ACC Systems, Proceedings of the Sixteenth International Machine Tool Design and Research Conference, Manchester England (1975) 117-121.

[6] M. Tomizuka, J.H. Oh, D.A. Dornfeld, Model Reference Adaptive Control of the Milling Process, Proceedings of the Symposium on Manufacturing on Manufacturing Process and Robotic Systems, New York (1983) 55-63.

[7] S.J. Huang, C.C. Lin, A self-organising fuzzy logic controller for a coordinate machine, International Journal of Advanced Manufacturing Technology 19 (2002) 736-742.

[8] W. Grzesik, J. Rech and T. Wanat, Surface integrity of hardened steel parts in hybrid machining operations, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 367-370.

[9] S. Zhang, A. Xing, L. Jianfeng and F. Xiuli, Failure analysis on clamping bolt of milling cutter for high-speed machining, International Journal of Machining and Machinability of Materials 1 (2006) 343-353.

[10] J. Kopac, Influence of high speed cutting on the structure of machined high speed steel material, Proceedings of the 11th Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science CAM3S'2005, (2005) 40-44, (CD-ROM).

[11] L.A. Dobrzański, K. Gołombek, J. Kopac and M. Sokovic, Effect of depositing the hard surface coatings on properties of the selected cemented carbides and tool cermets, Journal of Materials Processing Technology 157-158 (2004), 04-311.

[12] J. Balic, Optimization of cutting process by GA approach, Robotics Computer Integrated Manufacturing 19 (2003) 113-121.

[13] M. Sokovic, M. Cedilnik and J. Kopac, Use of 3D-scanning and reverse engineering by manufacturing of complex shapes, Proceedings of the 13th Scientific International Conference “Achievements in Mechanical and Materials Engineering”, AMME'2005, Gliwice-Zakopane, 2005, 601-604.

[14] E.C. Lee, C.Y. Nian, Y.S. Tarng, Design of a materials processing technologies, Archives of Materials Science and Engineering 28/1 (2007) 48-56.