APPLICATION OF NUMERICAL SIMULATION AND NEURAL NETWORK MODELS FOR MACHINING PROCESS CONTROL

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Abstract.
This paper presents an approach to the description of the cutting process through the use of numerical simulation results, their approximation with the neural network model, and the use of fuzzy models in the implementation of the machining control systems. Numerical simulation of the cutting process is used to obtain information about the thermal, power, and elastic-plastic characteristics of the process and allows creating a database of temperature and power parameters of the cutting process applied for training of the neural network. A neural network model approximates the numerical simulation data and describes the relationship of qualitative indicators of a workpiece with the parameters of the cutting process. A fuzzy control system for cutting mode has been proposed, which is a closed-loop control system with feedback, with a live circuit using the fuzzy controller as a regulator. Construction of the control device based on fuzzy logic allows taking into account the complex relationships of chip formation parameters and technological modes. The proposed approach allows you to control the cutting process, including adaptively, providing thereby the specified quality parameters of the product.

Keywords: Machining, numerical modeling, neural network, fuzzy logic, control system.

Introduction. The vector of qualitative indicators of the processed product (surface micro-relief, the state of the surface layer, macrodeviations) is formed in the process of machining under the influence of several factors: the elastic-plastic processes in the cutting zone, the heat flows, the stress-strain state of parts and tools, the technological system vibration, etc. At the same time, the complex interactions occur during the cutting process between the original operating modes and conditions, cutting process parameters (cutting force and temperature, strain rate, etc.)
and output qualitative parameters of the product. Traditionally, experimental methods became the most widely used [1-4] for the study of cutting processes. However, they have limitations in connection with their labor-intensive implementation and low flexibility of the results. Currently, the rapid development of computer technology and specific application software packages contribute to the popularization of numerical methods, and simulation and neural network simulation of machining processes [5-15].

**Methods.** Numerical simulation of the cutting process at adequately constructed model and correct source data allows obtaining the important characteristics of the process with a sufficiently high degree of accuracy: the components of the cutting force, cutting temperature, the speed and the amount of deformation, the value of the chip shrink, including the conditions of transition of unsteady fast processes: stroke cutting, irregular stock, high-speed cutting. The results of numerical simulation of the cutting process can be used to identify complex relations between the original technological modes, occurring temperature and power parameters in the cutting zone, and the output vector of qualitative indicators of the workpiece.

**Main part.** We have developed a technique and performed a finite-element simulation of the machining processes under different process modes in order to obtain data on the cutting temperature and force parameters (Fig. 1, 2).

![Fig. 1. Finite-element simulation of the force parameters during cutting.](image)

![Fig. 2. Finite-element simulation of chip formation process](image)
As a result of solving a set of numerical problems, we determined a database of temperature-force parameters of the cutting process, including the parameters not measured directly, but influencing indirectly the quality of the surface layer: the shear plane angle, the deformation speed, and the friction coefficient. The created database of temperature-force parameters of the cutting process was used to train the neural network and to develop a base of fuzzy rules, determine the configuration of the fuzzy controller and develop the requirements for the control parameters. The results of the finite-element model confirm previous data on the availability of optimal values of cutting speed, showing the presence of the point of extremum in the "high speed" zone and a decrease in temperature due to the increased intensity of the convection heat transfer of a workpiece with the environment and an increase in heat removal to the chips. Based on the generated training samples we conducted an approximation of the results of finite-element simulation with the use of neural networks. We constructed the neural networks based on normalized data vectors in Matlab programming environment. Speed range was 100-550 m/min, feeding range was 0.05-0.2 mm/rev. Figure 3 shows a diagram of a two-layer radial-base network: with two inputs and one output, which describes the relation between "cutting speed - feeding - cutting force".

![Fig. 3. A two-layer radial-base network](image)

Figure 4 shows the approximation results of simulation data of the centralized radial-base network, describing the relation between "cutting force - feeding - cutting speed".

![Fig. 4. The approximation results of simulation data of the neural network, describing the relation between "cutting force - feeding - cutting speed".](image)
Figure 5 shows the operation results of the neural network, describing the relation “temperature - cutting force - feeding”.

![Graph showing temperature vs. cutting force and feed rate](image)

**Fig. 5.** The approximation results of simulation data of the neural network, describing the relation between “temperature - cutting speed - feeding”.

Figure 6 shows the cut-off surfaces of response to the critical temperature of 690°C for the test type of steels and cutting force of 4500 N (by the drive power or allowable vibration criteria of the technological system).

![Graph showing cut-off response surface](image)

**Fig. 6.** Cut-off response surface with the use of a limitation of critical temperature.

The problem aggravates with the increasing dimensions of the output vector of the process state, which requires increasing the number of tests and, consequently, solving the resource-intensive tasks of finite-element simulation. The next step of using neural networks in the description of the cutting process is the optimization of the...
Optimizing the cutting process with the use of a neural network is possible from two points of view:

- to consider the disturbing influences (cutting forces and temperature) constant, that is, to solve the static problem of finding the optimal on any criterion values of technological regimes: flow, speed, number of passes;
- to build an optimal control system for cutting process in the dynamics.

On the basis of the cutting process we developed a fuzzy control system of cutting force based on the cutting process database, which block diagram is shown in Fig. 7.

**Fig. 7.** Block diagram of the fuzzy control system of cutting modes: SD - setting device, FLU - fuzzy logic unit, CO - machine tooling initiating control object, SG - strain gauge.

The proposed fuzzy control system for cutting mode is a closed-loop control system with feedback, with a live circuit using the fuzzy controller as a regulator. Control parameter is the feeding \( s \) (mm/rev), and the cutting force \( P \) (N) acts as a controlled parameter. Feed value at a first time corresponds to an optimum feed value determined during technological production preparation, based on the requirements for quality, and is subject to correction during the processing.

A fuzzy controller operating with the inference method was used as fuzzy logic unit. The input signal of the regulator - the current value of the cutting force comes from the strain gauge of the cutting force. The output parameter of the regulator is the corrected feed value.

The synthesis of fuzzy logic control algorithms was implemented for cutting force control system, during which the membership functions of input and output parameters were identified, and the base of fuzzy control rules was developed. Mamdani algorithm was used as an algorithm of fuzzy-logic inference. Fuzzy controller was implemented in MatlabFuzzyToolBox environment. We introduced the linguistic variables, defined the fuzzy rule bases, and conducted the programming of procedures of fuzzy inference system (Figure 8). We set an input variable membership functions for each of the terms. Five membership functions were used for the variable “Force P”, respectively, two of
carried out at the stage of finite-element simulation.

Similar to the input variable "Cutting force" for the variable “Feed”, two membership functions will be trapezoidal, and the remaining three - triangular. Further, we set the control rules and checked the operation of the controller (Figure 9). At a given value of the variable “Force P”, equal to 1150 N, we received the corrected output variable “Feeding S” equal to 0.865 mm/rev.

Thus, the developed fuzzy controller, based on the numerical simulation data, has demonstrated a good performance. The simulation of the control system in MatlabSimulink environment showed that using the developed system with a fuzzy controller in the metal working on the machine allows reducing the control time and improving the performance. Figure 10 shows a block diagram of the process of external longitudinal part turning on a CNC machine.
Fig. 10. Control system block diagram: ST - setting device, FLU - fuzzy logic unit, A - amplifier, E - engine, EEMS - equivalent elastic machine system, CP - cutting process, S - sensor

To build the control system model in Simulink package, we identified the transfer functions of each device of the control system. The implementation of this system in Simulink package is shown in Fig. 11.

Fig. 11. A control system model in Simulink package

The simulation results of the control system with the use of the developed fuzzy controller are shown in Figure 12, Figure 13, control time - 0.6 sec, deviation from the set value - 2%.

Fig. 12. Transition process control using the fuzzy controller.

Fig. 13 shows the characteristics of the system for modeling a random change of the removed stock from 1 mm to 1.5 mm during the first second of simulation using the fuzzy controller. As we can see, the cutting force has stabilized, and the deviation is about 15 N.
Based on these results, we can conclude that the developed cutting control system shows satisfactory performance parameters.

Conclusion. A numerical simulation of the cutting process was conducted. We obtained a dynamic picture of changes in power and temperature parameters in the cutting zone. Critical temperature points were detected on the workpiece according to the cutting speed in the range of 100-550 m/min. Based on the simulation results a total destruction base at chip formation was generated, including the parameters that are inaccessible to direct measurement.

We implemented the method of producing a mathematical model of the technological process of a weakly formalized object based on the sequential application of numerical simulation results used as training samples to construct the neural networks, with further application of standard test input and processing of the reaction in order to find the equation of motion. We developed a cutting force fuzzy control system for turning machining, showing the effectiveness of the results of numerical modeling and fuzzy control.

Summary. The proposed approach can serve as the basis for the development of mathematical models of structural materials machining, integrally considering the related physical processes occurring during the cutting: force, heat, deformation and vibration processes. Based on the detection of the inheritance and technological relations and analytical models the optimization models and algorithms for the design of processes can be identified, the theoretical basis of the functioning and structural-element performance of hardware and software that implementing the active monitoring and optimal control of technological modes with the use of automated control system were developed.
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References.


