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METAL CUTTING MACHINES STRAIN BEHAVIOR MATHEMATICAL MODELS BASED ADAPTIVE CONTROL

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Summary: *The current study presents a CNC lathes mechanical processing cutting force induced errors adaptive control technique. Cutting force strains mathematical models based software adaptive control possibilities have been analyzed. The adaptive system here presented has been software-based implemented without any extra units installed within the machine work space. An experimental study of the system offered on holes processing via turning has been carried out.*
Keywords: *Mechanical engineering, CNC machine tools, adaptive control, forces induced errors.*

1. INTRODUCTION

The modern mechanical engineering requires new approaches toward the adaptive control. Manufacture flexibility requirements and the ever-growing CNC machines usage demand it. These conditions provide new possibilities resulting from the progress in metal-cutting machines development and computer technologies application. Certain prerequisites have been created for the adaptive control to be handled by the controls of the direct computer controlled machine. No special sensors are needed for the cutting-force induced errors data to be obtained. This is a computer models based process to predict real-time cutting-force strain [1, 2]. The study of metal-cutting machines strain behavior and the obtaining of cutting-force induced errors mathematical models under different operational conditions are carried out in a experimental way. This results in an aggregate of mathematical models to represent the technology variety and a data-base for the particular machine. The computer control system adopts the right strategy and mathematical model for the adaptive control under a particular processing configuration. To stabilize and make up for the cutting-force strains and to carry out complex adaptive control the known strategies are applied [3, 4, 5]. Specialized software to implement the particular strategies algorithms is required in order the software adaptive control to be carried out.

2. TECHNICAL REQUIREMENTS

2.1. Software adaptive control strategies implementation principles

Cutting-forces induced errors mathematical models for the software adaptive control aims are used of the following type:

$$y = b_0 + b_1 a + b_2 f + b_{12} af + b_{11} a^2 + b_{22} f^2 , \qquad \textbf{(1)}$$

where: y is the strain brought about by the cutting force;
b_0, b_j, b_{jj}, b_{jg} - the ratios of the mathematical model;
a – the depth of cut;
f – the cutting feed.

This is a double-factor computer model to give the interrelation between the depth of cut, the cutting feed and the strain. The double-factor models are applied toward the local areas of the work space for which the strain is insignificantly affected by the cutting zone coordinates being altered.

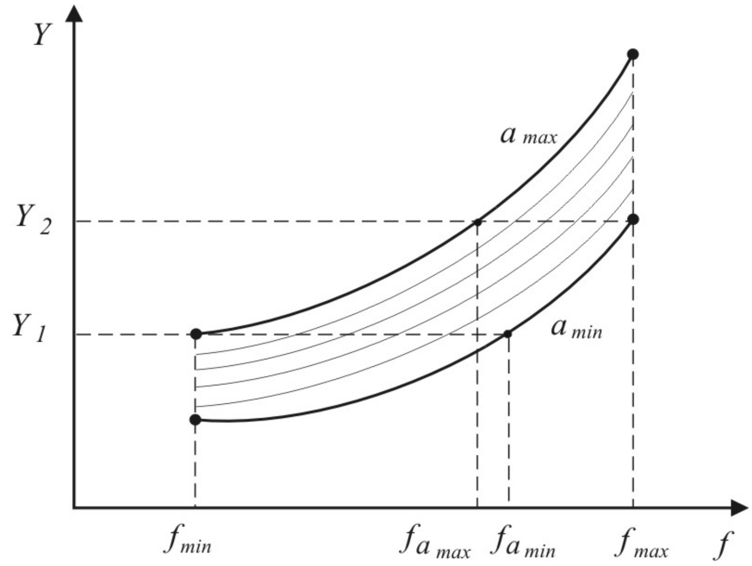

Figure 1: A cutting-forces induced errors model and specific stabilization levels

Fig.1 shows the graphical model interpretation. 2-D graphics is used with the depth of cut *a* being represented by the curves family within the scope from $a_{\min}$ to a_{max}.
The cutting-force strain stabilization software adaptive control technique [4] is implemented setting the cutting feed *f* depending on the particular depth of cut thus satisfying the condition $Y = const$. The solution of the problem is the plane cross-section $Y=const$ and the regression area defined by (1). The equation for the cutting feed *f* is reduced to the following form:

$$b_{22} f^2 + \left(b_2 + b_{12} a\right) f + \left(b_0 + b_1 a + b_{11} a^2 - Y\right) = 0 . \quad \textbf{(2)}$$

The quadratic equation root to satisfy the particular condition is as follows:

$$f_{\min} \le f_i \le f_{\max} , \quad \textbf{(3)}$$

is the solution under the depth of cut a_i and the selected value $Y = const$. The selection of the stabilization level $Y = const$ is determined by the processing efficiency indices as follows: output, cost-efficiency, dimensional accuracy and shape precision. As all requirements are simultaneously impossible to be complied with a priority index of efficiency is being picked over for every particular case. To take an example, when we have rough turning the output is assumed to be the priority and the maximum strain level should be picked over to satisfy the equation (1) for $f = f_{\max}$ in all depths of cut. This is the level Y_2 in Fig.1. If the accuracy is assumed to be the priority the Y_1 level should be observed.
The software adaptive control to make up for the cutting-forces strains [5] is reduced to determining the strain value Y_i under the depth of cut a_i within the scope $a_{\min}$, $a_{\max}$ at the cutting feed $f = const$, picked over within the scope $f_{\min}$, $f_{\max}$. The solution of the equation (1) Y_i gives the needed compensation value under the conditions thus set. The error Y_i determined value is used as the particular size correction. The graphic interpretation of the technique is represented in the Fig. 2. The selection of the cutting feed $f = const$ is determined on the base of the processing efficiency indices. The process output is the maximum one if the largest cutting feed $f_{\max}$ for the model has been selected.

2.2. Prerequisites and possibilities of the software adaptive control implementation

The computer models-based adaptive control implementation on CNC metal-working machines is carried out via the CNC system and because of it can be referred to as software adaptive control.
This control can be associated with the open loop adaptive systems. A flow-chart of such adaptive control system is represented in Fig.3 with no extra sensors and actuators needed on the machine. A control over the workpiece size is exerted in order to achieve data for the depth of cut for the processing to come. The data are entered into the computer system. A model for the particular process of mechanical processing and operational conditions is being retrieved from the data-base.

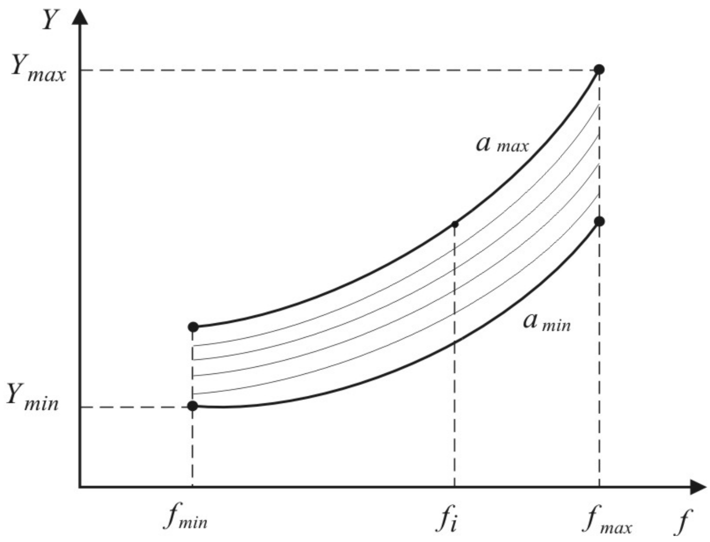

Figure 2: A cutting-force induced errors model under compensation adaptive control

A model and work-piece control based solution to reduce the cutting-force induced errors is to be worked out. This can be achieved via determining the necessary cutting feed or the size setting correction based on the computer model.

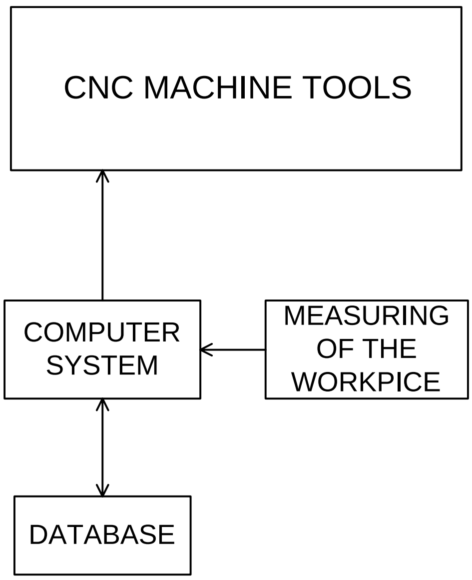

Figure 3: Flow-chart of software adaptive control

A cutting feed adjustment solution is preferably to be sought as in particular cases the sizing change introduces additional errors due to the inaccuracy of the actuator. When the complete cutting force strain stabilization is impossible to achieve via cutting feed adjustment it is imperatively that the sizing needs also to be altered i.e. complex adaptive control is to be implemented.
The software adaptive control implementation requires control algorithms development and software dealing with numerous mathematical models designed for different operational conditions. The CNC systems automated programming software creation approach was applied in the current development. The adaptive control software develops an executive program for the machine depending on the input disturbing factors (workpiece sizes) and the cutting-force induced errors mathematical model. A specific NC program is developed for every workpiece so that to minimize the cutting-force induced errors effect upon the final workpiece sizes. The software can develop executive programs for cylindrical surface, shaft section or hole.

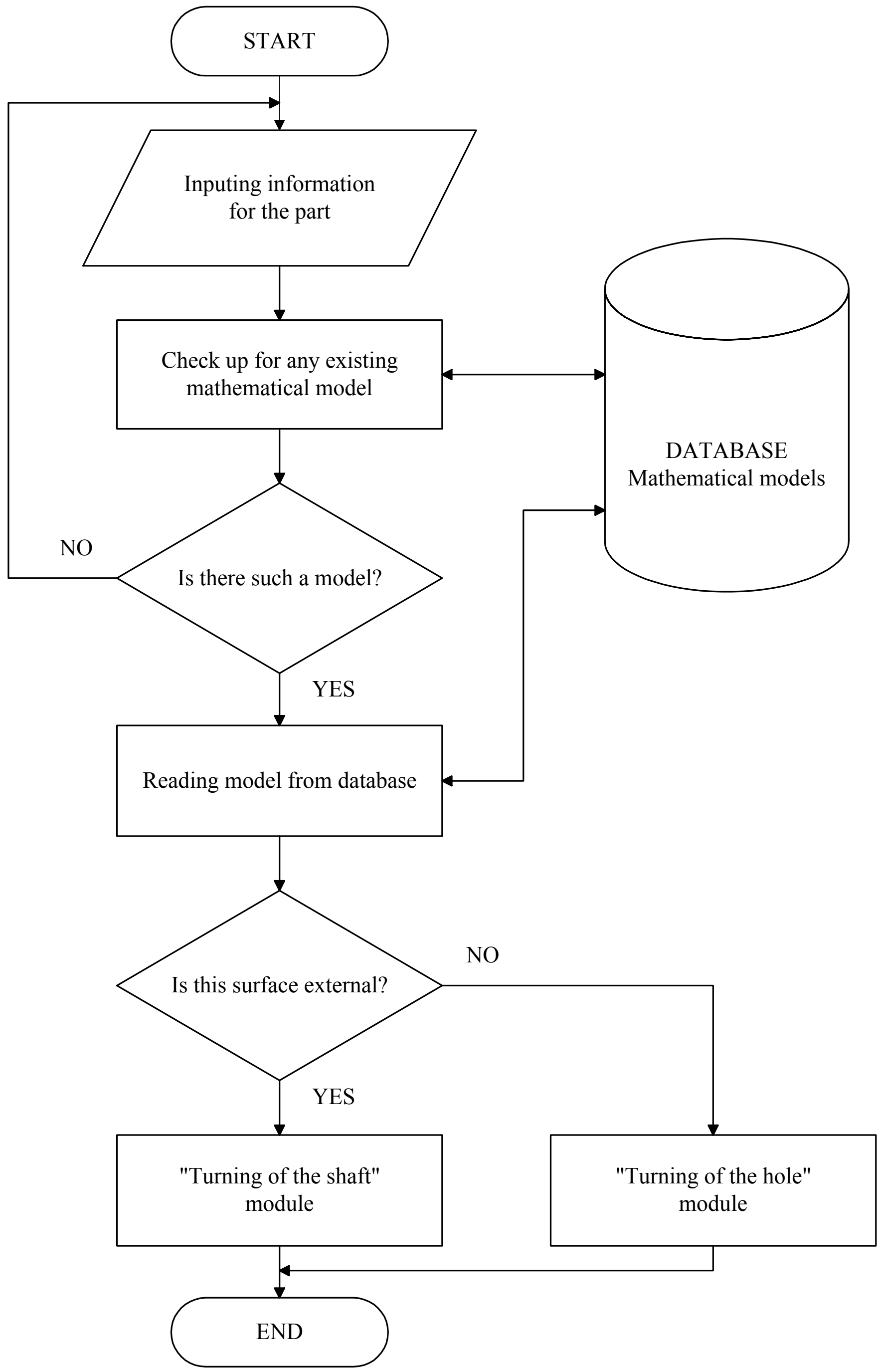

Figure 4: Flow-chart of the adaptive control program

AutoCAD is used as the graphic tool for visualization of the workpiece drawings and geometric dimensions information. The adaptive control program has been developed in accordance with the principles of the automated programming systems for a concrete machine. Algorithms for adaptive control are used to create a possibility for the correction of the tool trajectory coordinates values and the pick-over of the optimal cutting feed in view of the workpiece size accuracy. This possibility makes the adaptive control program substantially different from the existing automated programming systems. The AutoCAD built-in programming language Auto LISP has been used to develop the software. The program was developed on modular principle and is a user function in AutoCAD. The CNC ZIT 500T programming specifics and those particularly for the ST 161 lathe were taken into account when developing the adaptive control program. The communication between the computer and the CNC metal-cutting machine is based on the software for DNC.
A data-base (DB) for cutting-force induced errors mathematical models was built up to assist the system operation. Models have been classified with each model being assigned an identifying code. The code under study is a basic data-storage medium within the database. The program thus developed automatically

identification the involvement of a certain model with the workpiece processing operational conditions being transmitted by the input data on the base of individual components of the code being processed and compared against the set criteria. A message indicating the lack of the model being searched through is displayed if no record of the model parameters is available. A model conforming to the entered input data is being retrieved from the database, if available, its factor being assigned to the corresponding variables in the program.
The flow-chart of the adaptive control program generalized algorithm is represented in the Fig.4. The workpiece, material, cutting tool and input data and plan of operation are entered at the start. Upon retrieving the corresponding computer model a verification of the type of the processing - shaft or whole - is carried out. Next you go the corresponding module to perform the automated programming.
Once the metal-cutting machine and computer are switched on you launch the AutoCAD and open a drawing of the part to be machined. Then you should launch the adaptive control program. The part data and the type of processing should be entered. Data for the tool and for the definition of the operational coordinate system is being entered in a dialog mode. The machine is being set up. The work pieces diameters at the beginning and at the end of the processed area should be entered into the adaptive control program. A message that the machining program has been created and a question to "end" or continue working are displayed. The workpiece machining program is executed via the software for the DNC. The next work pieces sizes are entered and a new executing workpiece machining program is generated if the work continues.

2.2. Experimental study of the program adaptive control

The study is implemented on the base of the developed adaptive control program. A batch of work pieces with varying whole diameter is machined. An experimentally cutting-force induced errors generated mathematical model of the following type is used by the program to adapt the process:

$$Y = 8 + 71,4a_p + 8f + 925a_p f - 120,4a_p^2 - 219f^2 \quad \textbf{(4)}$$

The material is steel EN 10083-2 C35. The tool is a boring bar with a diameter of the stem 20*mm* and length of the cantilever 100*mm*. The main setting tool angle is χ_r=90°. The cutting rate is $V_c = 100\ m/min$. The boundary levels of the variable factors of the planned experiment are as follows: $a_{p\min} = 0,25mm$; $a_{p\max} = 0,75mm$; $f_{\min} = 0,1mm/tr$; $f_{\min} = 0,5mm/tr$.
Fifty experiments at five depths of cut are carried out totally. Ten experiments for each depth of cut are carried out. The depths of cut a_p are selected in such a way as to cover the entire scope the computer model has been specified for. Once the machining is over the resulted work pieces sizes are put to measurement and the probable dispersion field is calculated. The study gives the following $\omega = 0,218mm$. The common dispersion field is obtained provided no adaptive control is implemented. The common dispersion field is calculated on the base of the cutting-force induced errors mathematical model and in our case is as follows: $\omega_{Dm} = 0,602mm$.
The study results are represented graphically via a point diagram in the Fig.5. The probable dispersion field of the machined work pieces with applying the software adaptive control is thus seen to have been reduced 2, 75 times.

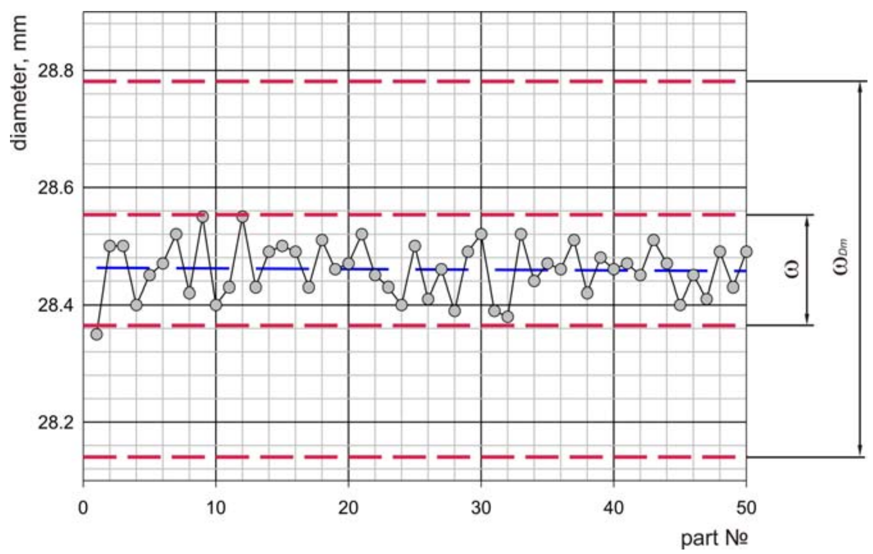

Figure 5: Point diagram when turning holes with applying the program adaptive control

3. CONCLUSION

The represented results prove a possibility of modern CNC metal-cutting machines software adaptive control to be implemented. Computer technologies give rise to accumulation of knowledge bases and adaptive control implementation involving a great variety of machined work pieces and technologies. This makes the technique applicable under flexible manufacture conditions and frequent switch of the manufacture object.

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