KOMPUTEROWO WSPARTY SYSTEM DO BADAŃ SIŁ I TEMPERATURY SKRAWANIA W TOCZENIU

COMPUTER AIDED SYSTEM FOR INVESTIGATION OF CUTTING FORCES AND TEMPERATURE IN TURNING

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Przedstawiono komputerowo wsparty system do badań doświadczalnych składowych sił i temperatury skrawania podczas obróbki toczeniem. Do pomiaru temperatury zastosowano metodę naturalnej termopary. Siły skrawania określono za pomocą analogowo-indukcyjnego siłomierza. Opisano budowę stanowiska badawczego, poszczególne jego moduły a także oprogramowanie.

This paper presents development of an original computer aided system for experimental investigation of cutting force components and temperature in machining process with turning. Method of nature thermocouple has been used for temperature measuring. Cutting force components have been measured by modernized analog inductive dynamometer. Hardware structure development and software have been also described.

Introduction

Analysis of cutting process physical phenomena in machining with turning by using new materials and new metal cutting machines has shown that changed conditions for machining with material removal exists because of increased cutting speeds. Under those conditions, characteristics of the machined surface depend on more intensive mechanism for constitution of the surface layer, which directly depends on machining conditions and machining parameters.

Different conditions of surface layer constitution result in different technological effects in the surface layer, which are given by certain parameters that could be measured (roughness, mesohardness, residual stress...). This is a result of simultaneously fluctuate influence of the cutting force and temperature in the cutting zone. Identification of cutting forces and temperature in cutting process during intensified conditions is possible only using the computer aided research systems. They are expected to decrease the errors which appear when the signals are transmitted, to possess a possibility for recording of a sufficient number of data in relatively short period of time, to visualize and graphically interpret and also process the received signals (data).

Computer aided research systems should support the new research objectives, which depend on the full access to the hardware and the software of the research systems. Possessing research equipment, that could support those objectives could be solved by purchasing new expensive equipment or by development of own equipment and modernization of the available equipment. Modernization of the available equipment creates full access systems, which could be upgraded according to the changeable requests by small investment.

This paper presents outcome of the cooperation during research activities realized by the Faculty of Mechanical Engineering – Skopje, the Faculty of Electrical Engineering – Skopje and the Institute of Mechanical Engineering and Automation of the Wroclaw University of Technology, Poland.

Description of the research stand for investigation of cutting force and temperature in machining process

Figure 1 presents experimental stand of new computer aided research system for measuring the tangential, axial and radial cutting force component as well as the temperature in machining process with turning. For measuring the forces the investigation system uses upgrade of an analog inductive dynamometer model FISHER MESSTECHNIK TYP EF2 D3 NR 24570.

The dynamometer has a cutting tool holder with inductive measurement cells for forces conversion into an electrical signal. For temperature measuring natural thermocouple method workpiece-cutting insert is used. There are two transmition lines for the generated thermovoltage from the natural thermocouple. One line uses a device [3] for transmitting the thermovoltage from the workpiece if there is not possibility to put line wire in the lathe main spindle, figure 2. Second line for

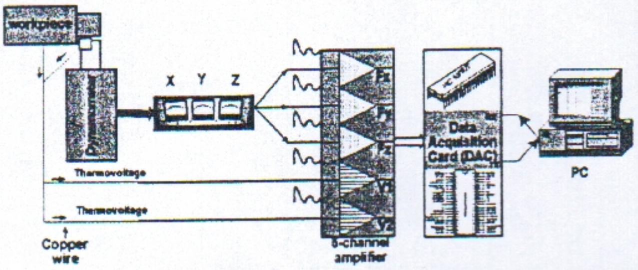

Fig. 1. Experimental stand for investigation of cutting force components and temperature in machining process with turning

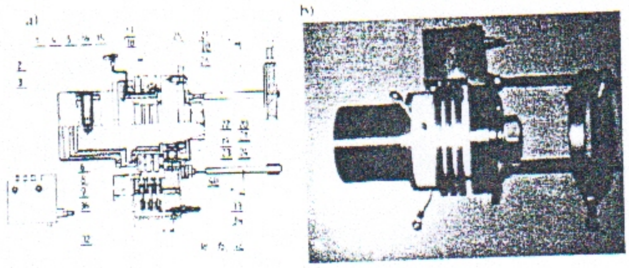

Fig. 2. Device for workpiece thermovoltage transmission: a) device construction, details [3], b) device picture

transmitting the thermovoltage from the workpiece uses a Hottinger-device and it is used when there is a passable main spindle. Reconstructed cutting insert holder is used for transmition the thermovoltage from the cutting insert, figure 3.

Thermovoltage transmission device setup on a lathe is presented on figure 4.

The experiment example in this paper uses workpiece material C 1630 and mixed ceramics MC2 cutting inserts, which are manufactured by Hertel Company.

Interface for PC is designed for connection between the source of the signals (from dynamometer and nature termocouple) and personal computer (PC).

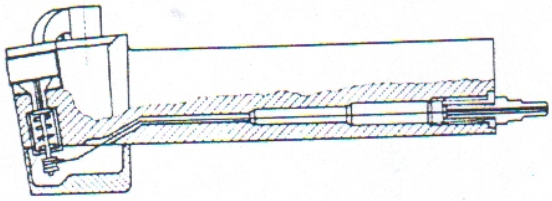

Fig. 3. Reconstructed cutting insert holder

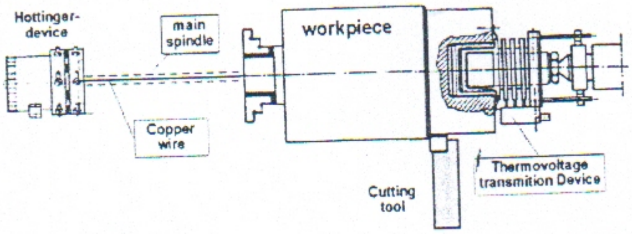

Fig. 4. Thermovoltage transmition device setup

Development of the system hardware

The designed interface consists of a 5-channel amplifier of the signals and data acquisition card (DAC). The amplifier has three roles as a part of the interface. At first, to amplify the thermovoltage that is generated by the natural thermocouple workpiece-cutting insert and the signal from the analog dynamometer to the required level. That means that the signal after amplifying complies within the domain of the A/D converter. The second role of the amplifier is a galvanic separation of the thermocouple electric circuit from the DAC and the PC. The role of this galvanic separation is to protect from eventual current pulses that could damage this part of the measuring system. The third role is to remove the influence of the electrical circuit consisting of the DAC and PC to the electrical circuit with the thermocouples and the dynamometer. Cutting forces amplifier channels and the system DAC-PC represent an upgrade of an already existing inductive dynamometer model FISHER MESSTECHNIK TYP EF2 D3 NR 24570. The principle work of the existed measuring system is an imbalance of measuring bridge for every component separately. Because of the fact that the mentioned installation is an old-fashioned type, where the influence of the human factor during the reading and recording of the values is not excluded, the installation is being modernized. Another reason for the modernization is the obstructed performance of the experiments and even an impossible reading of the values of cutting force components simultaneously. During the modernization of the inductive dynamometer, we were guided by the new technological trend called mechatronics, which denotes a multi-disciplined approach towards the integral projection and development of new products and systems. It can also be used in the creation of science researching systems. In this case, because of the specific construction of the measuring system for measuring the tangential, axial and radial cutting force component, the measuring system was upgraded without any disruption of its funcionality in any of its parts and just using it as a source of signals. From the dynamometer analysis, it is concluded that the most convenient way to take the information on the size of the cutting force component, which is transformed into an electrical signal with a change of the opening of the differential transmitter is taken from the indicators leads. The signal has a pulse form and its voltage level is on +2.2 V in reference to the ground point, figure 5a and 5b.

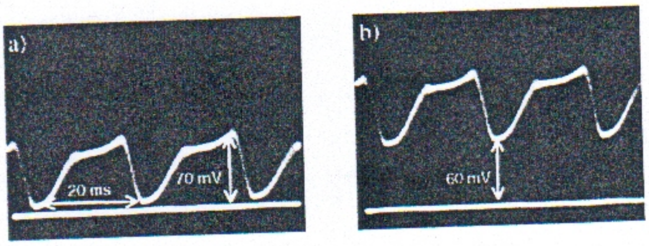

Fig. 5. Waveform of the signal on the ends of the indicator: a) when in null position of the arrow, b) when in drift of the arrow

The design of the electrical scheme of the cutting force amplifier channel, which task is to prepare the signal for acquisition is performed with the CircuitMaker Demo Software, figure 6. The signal, shown on figure 5, is taken from the indicator leads by a voltage follower constructed with the operational amplifier TL084. Infinite high input impedance of the voltage follower enables connection on the measuring bridge without any influence on it. After this, the signal is taken to the differential amplifier. The differential amplifier outputs voltage level that is proportional to the difference of the voltage levels on the indicator leads. That provides a signal, which is proportional to the change of the opening of differential transmitter, because the indicator current is proportional to the imbalance of the measuring bridge, which integral components are the differential transmitter and the indicator. The highest voltage level that will appear on the output from the differential amplifier corresponds with the biggest voltage difference, which can appear on the indicator leads. The indicator is an ammeter, which characteristics are: maximum current of

100 µA and internal resistance of 1750 Ω. That means that the biggest voltage difference, which will appear on the indicator leads is 17.5 mV. To amplify this voltage level for the needs of the acquisition, which is performed in the interval of 0–5 V an inverting amplifier consisted of the operational amplifier TL084 is used with a nominally adjusted gain of 21. The expected maximum value of the signal on the output of the inverting amplifier is 3.7 V. There has been a possibility for an occurrence of negative values of the voltage on the output of the inverting amplifier, when an eventual displacement of the differential transmitter occurs in an opposite direction (out of the cutting process). The blocking of the negative values of the signal with a purpose of protecting the components for acquisitioning which does not function with negative values is performed with the construction of precise diode consisted of the operational amplifier LM741 and the 1N914 diode.

On the end of the amplifier, another voltage follower is set, but in this case it is supplied with power of ±5V to provide a limit for the maximum level of the output signal on +5V. With this voltage follower the influences of the circuit for the acquisition on the amplifier's work are removed. On the input of the voltage follower the capacitor is connected with a purpose

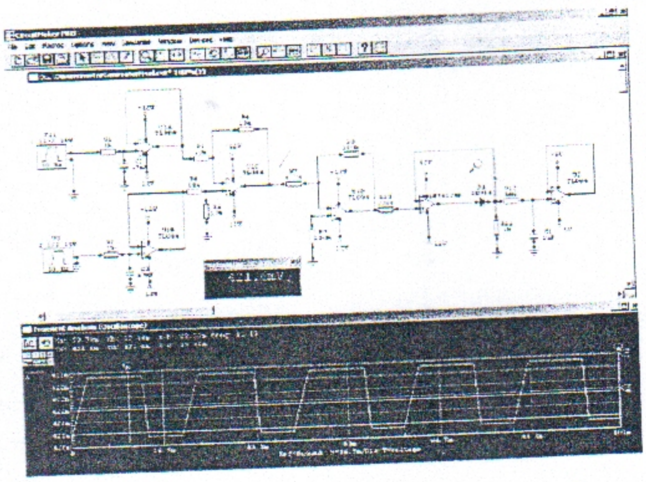

Fig. 6. Screen dump of the simulator that is used for designing the cutting force amplifier channel

to level the pulse form. Then the signal is acquisitioned with A/D converter.

The thermovoltage amplifier channels use the ISO100, an optically-coupled isolation amplifier. ISO 100 and the support electronic components are represented on the electrical scheme on figure 7. Amplifier nominal gain of 148 is defined by the ratio of the resistors values R_{f+}/R_3. The nature thermocouple thermo voltage is connected on the pins 15–17 and amplified signal from Vout proceeds to A/D converter.

Data acquisition card integrates Microchip microcontroller PIC16F877 and microcontroller support electronic components. The microcontroller has 10-bit build in A/D converter. The maximum frequency of the tact generator is 20 MHz. The nature of our research allows the cutting force and the temperature to be considered as a static dimension for a certain conditions of machining and it imposed a need for taking a few samples of the signal per one turn of the work piece. For adopted maximum 2000 turns per minute and 5 samples of the signal per turn, the system should perform a conversion and acquisition on 2000·5/60, that is to say 167 samples per se-

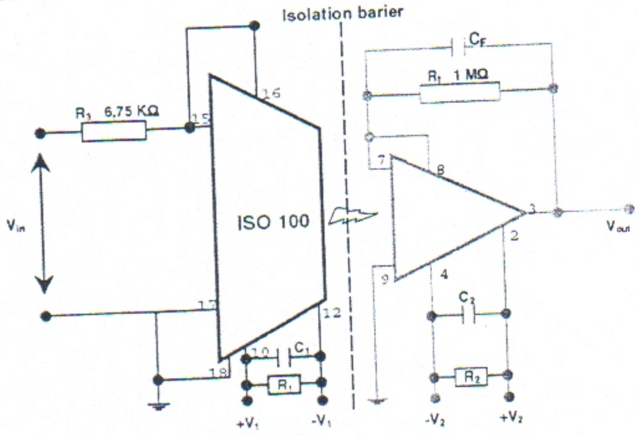

Fig. 7. Optically-coupled linear isolation thermocouple amplifier

cond for every channel, which is far below the possibility of the chosen system. The microcontroller contains an integrated module for serial synchronous and asynchronous communication simultaneously in both directions, USART (*Universal Synchronous Asynchronous Receiver Transmitter*) with ability for easy adjustment of the speed of communication. It was decided that the speed of communication of 115200 bps is going to be used because this speed enables the flow of a maximum number of data through the line of communication. According to the fact that every sample takes 2×8 =16 bits, in this regime we could "in real time" transport 115200/16 =7200 samples, which is more than the number needed, using even 4 channels simultaneously. This way of sending the data to the personal computer avoids the procedure of temporary recording of the data in the micro controller's system and enables the data flow to be performed in "real time".

In the process of designing of the DAC we were using software for design and simulation Proteus 6.3 Demo. This software has a library of analog and digital components including micro controllers, virtual terminals, signal generators, measuring instruments, oscilloscopes, logic analyzers and generators, figure 8. The user-friendly screen interface provides very easy designing and simulation of the DAC's construction. The micro controller in the simulation performs a function that is given with software for the micro controller. Connecting the micro controller and the certain program could be

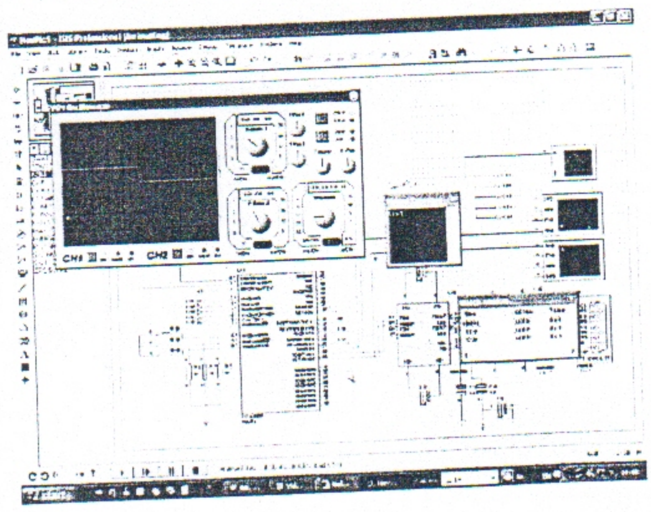

Fig. 8. Proteus 6.3 Demo Screen dump

done with simple browse option. This software was used for simulation process including debugging and tracing of eventual logic errors, execution of the micro controllers program "step by step", preview of the values of the micro controller's variables in "real time" and simulation of the serial communication by connecting the simulation with the hardware RS232 interface of the computer.

The program, which operates the micro controller's work, is written in the language C for micro controllers. The prototype version of the described interface of the measuring system is presented on figure 9.

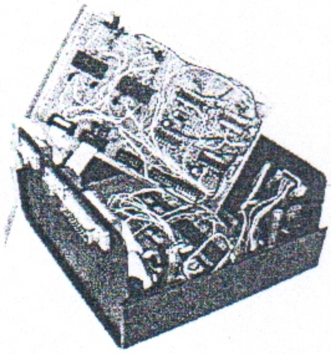

Fig. 9. Prototype version of measuring system interface for PC

Description of developed system software

Designed application in Microsoft Visual C++, receives the data through RS232 interface of PC and displays graphical interpretation. The window of the application shown on figure 10 is divided into two parts. One of the parts has a grid that enables a graphical interpretation of the dynamic character of the thermovoltage, figure 10a, the dynamic character of the cutting force components, figure 10b and determining the length of the time axis in which the average values are calculated. On the figure 10a number 1 denotes the thermovoltage signal obtained with usage of the device showed on figure 2. On the figure 10a number 2 denotes the thermovoltage signal obtained with usage of the Hottinger-device. The other part of the window, denoted with an arrow on figure 10, contains a set of controls designed for adjusting and showing average values on a previously chosen length of the time axis. Graphics properties are also controlled by these controls.

Measuring system calibration

In order to determine the system output, the measuring system was calibrated. Force component calibration was made in three directions for tangential, axial and radial component of the cutting force and the 10-bits A/D output values were averaged for each direction. The loads up to 1500 N were applied and the A/D values were recorded for each load intervals, figure 11. Thus calibration curves were obtained to convert the output readings into cutting force values. Figure 12 shows the calibration curves for cutting force components. The measurements were repeated five times and very close values were obtained. The effect of loading in one direction on the other force components was also examined and minor fluctuations were observed. Thermo voltage channels calibration was

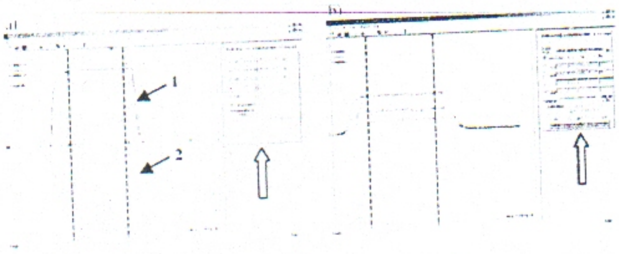

Fig. 10. Screen dump of the measuring system software: a) temperature measuring, b) measuring cutting force components

made by applying different voltage levels on the input of the thermo voltage amplifier channels and recording A/D output values transformed into voltage levels. Thus real amplifier thermovoltage channels gain was determined. Linear mathematical models for the cutting force components and thermovoltage were adopted in the software for their adequate representation. Correlation between the thermovoltage and the temperature that is calculated by the software on the selected length of time axis was determined by the mathematical model, which was obtained in experimental way. Functional verification of the new computer aided measuring system for cutting force components and average temperature measurement in machining process with turning is done by a comparison of results of experiments series in Faculty of Mechanical Engineering – Skopje and results of experiments, that were obtained during machining with same conditions in Institute of Mecha-

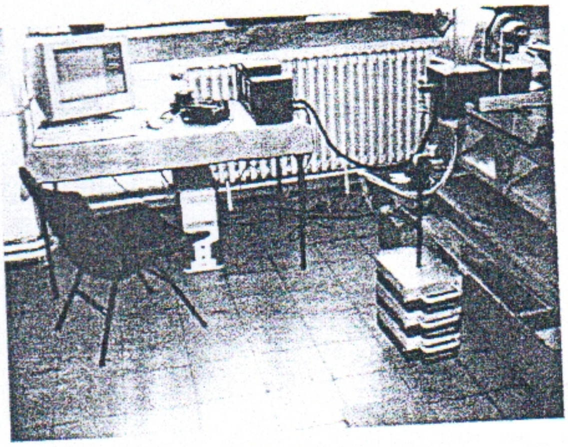

Fig. 11. Measuring system calibration

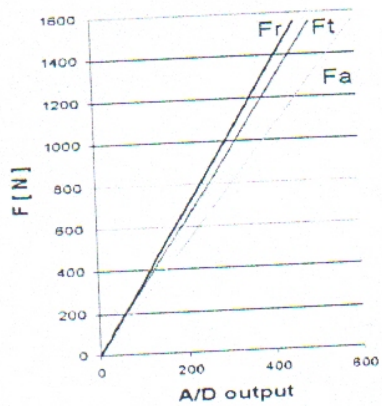

Fig. 12. Cutting force components calibration curves

nical Engineering and Automation of The Wroclaw University of Technology – Poland. Obtained results are within the interval of ±5%.

Conclusion

Developed computer aided measuring system can be assumed as reliable as appropriate results obtained in experimental investigation of cutting forces and temperature in machining process at intensified machining conditions. It is easy to upgrade the modernized system by changing components in developed hardware and software modules. Calibration process results of the experimental stand for investigation of cutting force components and temperature in machining process with turning showed high stability of the hardware solutions. The decision about needs of additional upgrades of the modernized system arised from the results of analysis of obtained signals and final data.

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