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MONITORING SYSTEM FOR AUTOMATION OF EXPERIMENTAL RESEARCHES IN CUTTING

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A b s t r a c t: This study presents procedures being performed when projecting and realizing experimental scientific researches by application of the automated measurement system with a computer support in all experiment stages. A special accent is placed on the measurement system integration and mathematical processing of data from experiments. Automation processes are described through the realized own automated monitoring system for research of physical phenomena in the cutting process with computer-aided data acquisition. The monitoring system is intended for determining the tangential, axial and radial component of the cutting force, as well as average temperature in the cutting process. The hardware acquisition part consists of amplifiers and A/D converters, while as for analysis and visualization software for PC is developed by using MS Visual C++. For mathematical description of researched physical phenomena CADEX software is made, which in connection with MATLAB is intended for projecting, processing and analysis of experimental scientific researches against the theory for planning multi-factorial experiments. The design and construction of the interface and the computerized measurement system were done by the Faculty of Mechanical Engineering in Skopje in collaboration with the Faculty of Electrical Engineering and Information Technologies in Skopje and the Institute of Production Engineering and Automation, Wroclaw University of Technology, Poland. Gaining own scientific-research measurement system with free access to hardware and software parts provides conditions for a complete control of the research process and reduction of interval of the measuring uncertainty of gained results from performed researches.

Key words: monitoring system; automation; forces; temperature; cutting; turning

1. INTRODUCTION

Cutting process by turning is one of the most widespread machining processes by material removal. The surface layer constitution at these machining types is in many cases various. Variety results from insufficient number of data and insufficient knowledge of physical phenomena in cutting area upon characteristics of the technological surface layer.

It is familiar that during the transformation of the removed layer into chips as a result of energetic transformations, significant quantity of heat discharges in the cutting area.

Heat created during the cutting process is on one hand a result dependent on applied machining parameters ($v, f, a,...$), machined material condition and stereo metric cutting tool characteristics ($\kappa, \lambda, \gamma, \rho_\varepsilon,...$). On the other hand, this created heat (max. temperature) is a significant factor, which has a dominant effect on the mechanism for chip creation, the processes that occur during cutting tool wear (abrasive, adhesion, diffusion, heat, oxidizing), magnitude of cutting forces during the cutting process. Cutting process resistances are in direct correlation (dependence) with the force and the thermal model of residual voltage creation. All this effects upon creation of resultant characterristics in the newly constituted technological surface layer /TSL/ [1,2,3,4].

Therefore, it is vital in machining processes by material removal to be precisely aware of the temperature and forces magnitude that occur in the cutting zone, particularly on the working surfaces of cutting tool.

Temperature in the cutting process can be determined analytically and experimentally, for which a large number of methods were developed [5,6]. One of experimental methods that is mostly used is the method of the natural thermo-couple, where the cutting tool and the workpiece constitute the natural thermo-pair. Methods with the natural thermo- couple are simple for application, however require knowledge in thermo-electrical characterristic of the natural thermo- couple, while its determining is performed exclusively in the experimental way [2,7].

Occurrence of contemporary cutting machines and cutting materials, especially the cutting ceramics, provided pre-conditions for application of significantly higher cutting speed. High temperatures and dynamics of material removal in conditions of higher cutting speed more intensively act onto mechanisms for chip creation and wearing processes of the cutting tool, as well as onto technological effects in /TSL/. Increased stiffness is required from the system Machine-Device-Workpiece-Cutting tool (MDWC). Error reduction is required from the system for cutting temperature measuring, which occures when transferring signal from the workpiece and the cutting tool. The temperature and resistance measurement system in the cutting process has to provide recording of sufficient data for relatively short time interval. The application of the computer technique has to provide measurement uncertainty interval reduction on results gained from measurements. Measuring uncertainty interval reduction on gained results shall contribute to more valid determination of temperature and cutting process resistances.

Identification of researched phenomena (physical phenomena in the cutting area and technological effects in the surface layer) in intensified conditions is possible only by implementation of monitoring systems for automation of experimental researches. Resolving these types of tasks is mostly performed by connecting mechanical engineering with electronics in combination with informatics. Informatics has to provide methodical approach when performing experiments, adequate transfer of signals and their processing, which ends with mathematical modeling of researched phenomena.

Reaching argumentative conclusions for the cutting process occurrences is possible only if the monitoring system has opened access to hardware and software modules and provides simultaneous identification of cutting process resistances and temperature.

The solution of such a complex process as temperature and cutting forces process determination, which is presented in this study, is result of many years mutual research activity performed by the Faculty of Mechanical Engineering in Skopje in collaboration with the Faculty of Electrical Engineering and Information Technologies in Skopje and in collaboration with the Institute of Production Engineering and Automation, Wroclaw University of Technology, Poland.

In such conditions the following is created: possibilities for identification of physical phenolmena in the cutting process, data bases for selection of optimum parameters in machining by cutting, data for forecasting wearing process of cutting tool and determining time frame for cutting tool replacement. Possibilities are created for quality management of the workpiece surface layer, optimization of the cutting tool stereometry, management of the chip shape and its removal, updating cutting inserts manufacture technology and their cutting properties, as well as determining errors in machining, etc.

2. CONTRIBUTIONS FROM SCIENTIFIC RESEARCH AUTOMATION

The high science development nowadays contributes to intensifying and spreading out of scientific researches, increasing number of researchers involved and increasing costs for their conducting.

Experimental scientific researches have significant meaning in comparison with theoretical scientific researches. Theoretical researches are characterized by high approximations and difficulties in determining limiting conditions and precise description of research process changes by means of mathematical models [1].

This justifies the automation implementation in all stages of the scientific-research process. By automation of experimental scientific researches is the following expected: reduction of time needed for research performing; experiment results presented in a form suitable for quick implementation in industrial practice; cost price reduction for research preparation and conducting; cost reduction for electricity, compressed air and other energetic resources, reduction of number of people involved. Automation provides possibilities for conducting new types of experimental researches, finding optimum solutions for given tasks, creating economically justified technologies; machines with high technical characteristics, high-quality materials, etc. Automation increases reliability of systems for scientific research conducting, providing terms for gaining precise and reliable information for min. number of experiments and excluding the possibility for occurrence of undesirable interruptions in the research process till the moment of gaining needed data. This excludes the need of repetitive and additional researches. Monitoring and automation shall provide adjustment onto changed conditions in next scientific researches and multiple equipment use for conducting various experimental researches and multiple time reduction for experiment conducting. Raising research quality level, getting rid of manual activities and providing terms for higher creativity are possible only by automation of all processes.

3. EXPERIMENTS PLANNING AND ANALYSIS

When analyzing experimental scientific researches the experimenter mostly always performs majority of activities that are presented with a chart on Figure 1.

Initially it is necessary to define the researched object; number of independent variables (input factors), researched hyperspace and form of output function (research objective).

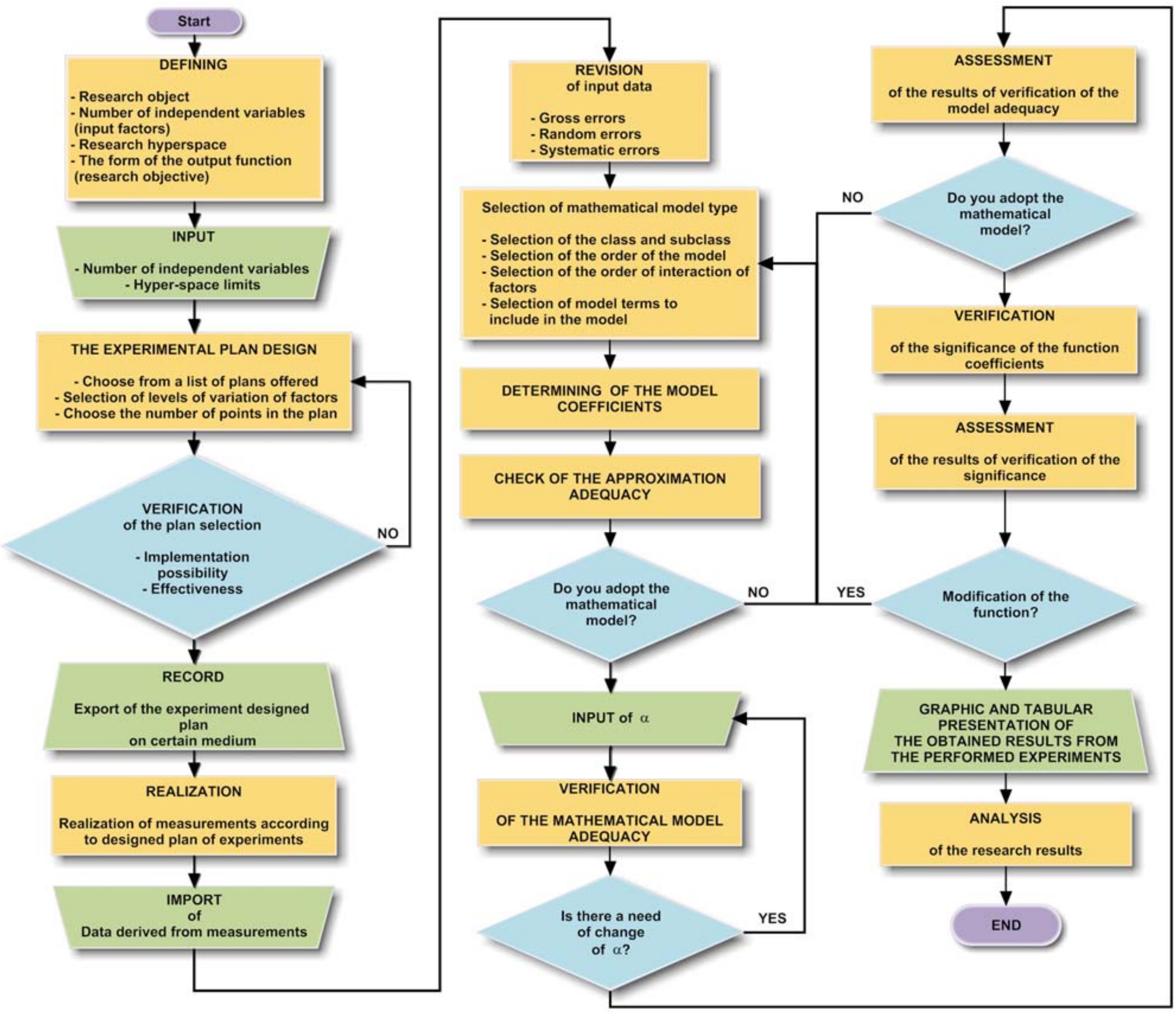


Fig. 1. Experimenter activities when planning and analyzing experimental scientific researches [3].

Basic pre-condition for gaining desired results i.e. research objective is the clear formulation of the researched problem. Often the formulation of the researched problem is done in two stages.

In the first stage direct value determination of researched variables is done through evaluation of the acceptability of measured values of responses, which are in functional dependence with researchhed variables.

The second stage is characterized by gaining mathematical models as result of the evaluation of certain constants or parameters, which are in function of input independent variables.

Such mode of problem formulation can be done exclusively by an expert excellently familiar with the researched field. For the purpose most often methods of prior inquiry ranking are applied, where the Delphi method mostly represented and effective.

When using this method successful preparation of activities in the first stage can be done. Namely, preparation is performed based on the analysis of opinions gained by experts, hired as competent in the researched field. Within the frames of this stage also simultaneously check of criteria for acceptability of multifactorial experiment is done [3]. Simultaneously, as a result of prior performed activities the initial mathematic model is adopted, the number of variables and the hyper-space limits are accepted.

Then, the experimental matrix-plan design is initiated, where the experimental plan is possible to be selected from the offered list of plans. Further on, the factor variation levels are selected. Then, experimental plan changes are possible to be done in sense of determining necessary experiments number by supplementing or reducing the number of experimental points in the plan.

In further activities, verification of criteria for the plan selection is done i.e. check of its efficiency and possibility for realization. As a result of this verification the selected experimental plan is confirmed (approved). If the criteria from the previous stage are not met, certainly a new plan is selected and previous stages are repeated. Once an experimental plan is selected, the same is recorded in a certain medium or exported in the certain form.

In the next stage a realization of conducted measurements is performed against the selected experiment plan. Data gained from performed measurements are archived in the computer hard-disc or automatically stored in certain data bases, formed when performing measurement in real time. The sequence of entered data, gained from experiments, is checked for the purpose of identifying presence of random, systematic and gross errors. Selection of the mathematical model type, which is in correlation with the selected experiment plan, is done in the following stage. The model class and the sub-class, the model order and the factor interaction order are selected. Selection of model terms that we include in the model is done for the purpose gained function to approximate researched phenomena in the sufficiently reliable mode.

There is a possibility selected function to be standard (not to deviate much from the mathematical model defined in the beginning) or to be non-standard. Selection of a new function is available also that shall fully differ from the initial mathematical model.

In the following stage the coefficients for the selected function are determined and the approximation acceptability check is done. If the experimenter accepts the selected function then in the next stage the adoption of the significance level i.e. coefficient α is done. If experimenter does not accept the selected function, the returns to the stage selection of the mathematical model type, which is always in correlation with the selected experiment plan and a selection of a new approximation function is done.

Then the stage follows when the significance level value α is entered and the model adequacy verification is done. If the significance level value α is not satisfactory, then a new significance level value α is selected and the procedure is repeated. If the selected significance level value α is satisfactory, then evaluation of coefficient significance in the adequate mathematical model is done in the next stage.

After performed evaluation of coefficient significance in the mathematical model, the experimenter has a possibility to modify the function. Then he defines a new form, however then the procedure returns backwards onto the selection of the approximation function type and he implements a new function. If he is satisfied by the gained function, the mathematical model, then in the following stage the starts with graphical and tabular presenting of results gained from experiments performed and in the end the performs their analysis.

4. EXPERIMENTER ACTIVITIES WHEN PROJECTING AND REALIZING EXPERIMENTAL SCIENTIFIC RESEARCHES

Experimental scientific research stages with implemented automation are presented in Figure 2 [3, 8]. The first activity is adopting a corresponding language (1) with strictly defined terms, which serves for describing the issue, the subject of research.

Defined terms of the language provide performing quantitative measurements of determined quantities, which are not always directly measurable.

For defining values of those quantities it is necessary to find out relations that provide their indirect quantitative interpretation.

In the next stage the experimenter selects correspondent methods and measurement techniques (2), when the experimenter disposes with a possibility to act upon the researched object and measure correspondent output quantities.

Output and input quantities are concrete values of physical quantities.

In the third stage (3), the experimenter determines the experiment objective, recording it in the form of a function and at the same time defining input and output quantities. Analysis of researched hyper-space follows which is a realistic mathematical model on input and output in terms of input and output values.

This is realized by dimensional analysis implementation. If the postulates for dimensional independence of input variables are met, then the selected function can be considered as a quantitative-qualitative function (4).

In the fifth stage (5) the function form is selected as a function with a given form; a function selected from the function menu, a differential equation with a given form and differential equation selection from the equation menu.

Determination of the interval of changes of independent variables follows (6), where the experimenter reaches decisions based on his own experience, consultations made with experts and literature sources. Measurements points (7) are determined in defined hyper-space i.e. the experiment is planned.

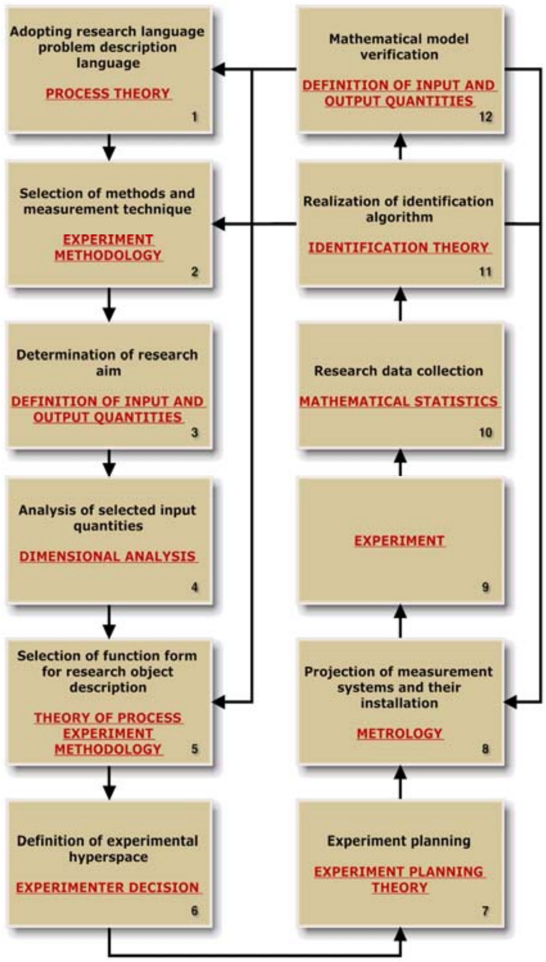


Fig. 2. Experimenter activities when projecting and realizing experimental scientific researches [3, 8]

Experiment planning is possible to be performed in two modes. The first mode is issue of a plan prior the experiment conducting and its realization against the plan independent of gained information. The second mode is so called real time planning when the plan changes are foreseen even on its strategy in dependence on current gained information from measurement processes. This mode requires a higher automation level of the whole experiment and implementation of fast computers with large memory.

Functions for data accumulation, planning, commanding control systems and transformation of data have to be linked and integrated in one system. Such planning is rather more rational.

Taking into account the information gained from (2) and (7), measurements systems (8) are selected and installed. The whole measurement system realization is possible only after performing the planned experiment, since then the number of necessary accessories is known. The selection of accessories, measurement systems and methods and measurement techniques, which have effect on the value of estimated model parameters, is crucial for precision of measured quantities. When performing an experiment the experimenter knows the required precision for the process describing and permitted error, as well as the form of the condition against which the gained mathematical model is going to be verified. Then, the experimenter applies correspondent algorithms, programs and technical means.

Automation of all activities is not possible, if the specifics of tasks and the significant participation of heuristic procedures is taken into account. Here the dialog between the experimenter and the computer is welcomed, when the computer is supplied with programs and corresponding devices for input and output. Experiment projecting, actually, presents a whole of activities of the experimenter, until the moment when he is able to perform the experiment, and those are the activities from (1) till (8). The technical realization is performed by implementing measurement systems and systems for computer commanding and control. During the time of experiment performing signal transfer is required from measurement systems into the computer for the purpose of storing data and enabling numerical signal transfer from the computer onto units for management with executive devices.

For the purpose analogue-digital and digital-analogue converters are applied. The installation of the program support and correspondent technical systems provides realization of the following functions: registering measurement data; transformation and transfer of registered measurement results; experiment planning and conducting; as well as controlling technical devices of researching apparatuses. Alternatively, this is going to provide interventions during research progress and transforming of its results.

Once these activities are the performed experiment realization (9) can initiate. Measurement data are accumulated in an orderly mode, when two possibilities exist, accumulation of statistically unverified data and accumulation after correspondent statistical data processing (10). Experiments are required, which are going to inform us in which degree or in which case it is possible to trust the experiment. Based on certain statistical procedures whole program libraries are built to serve for verification of measured quantities.

Those programs can be used for measurement results conversion by means of a computer. Programs can be applied for measurement control when repeating static measurements for getting estimators of mean values and dispersion with corresponding characteristics.

In such cases it is more convenient to present only the storing of estimators of required quantities, not the measurement results, as well. Further on, measurement results are processed in accordance with the algorithm of the identification theory (11). The identification algorithm is performed by application of correspondent programs. After each function order change within frames of its class, for instance, polynomial class, it is checked whether the number of adopted, during planning, measuring points is larger than the number of required parameters in the function. If such non-equation is not met then planning is repeated. If this procedure exhausts the possible function orders and measurement basis and then gained mathematical model requirements for precision are not met, it is returned to procedure (5), when a different function form is selected. If the identification procedure with return link does not lead towards reaching a „correspondently precise" model then be has to return to procedures (2) and (8), analyzing the measurement methods and measurement technique, or onto activity (1). In the last case, the experimenter concludes for the non adequate description of the process to the reality, mostly that some quantity in the description is missing, which significantly influences the research. In the end, the gained mathematical model (12) is verified by checking the precision with which it describes experiment results into defined researched hyperspace, not only in measuring points. If precision is smaller than the foreseen one, further procedure is identical as in part (11).

5. POSSIBILITIES OF COMPUTER ORIENTED SYSTEM CADEX FOR AUTOMATIC PROCESSING OF DATA FROM RESEARCH

The computer oriented system **CADEX** (**C**omputer **A**ided **D**esign and analysis of **EX**periments) is intended for conducting experimental researches and is made against modular principle (Fig. 3). The same allows upgrade with programs and creation of new data bases. The main menu consists of modules for: additional auxiliary activities, file name listing, new file creating, changes, processing of data from experiments, printing empty templates, tabular results presenting, graphical result presenting, exit from program.

For protection from misuse a special program LISDAT1 is implemented in the program package CADEX, which serves for software placing in function of the CADEX system. By its start initializing and preparing of all necessary data bases for results' processing is performed. The CADEX system is out of use without LISDAT1.

The module POMOS contains sub-programs for performing following activities: forming coded matrix plans (LISDAT2), creating files with values of the Fisher's and Student's distribution (OFFIST), test of file function with Fisher's and Student's distribution (TEST) and performing dimensional analysis (DIMANAL).

The program DELFI is also made within the CADEX, which assists in performing ranking of independent variables.

The program LISDAT2 provides: new file opening – coded matrix plan DVOPRED, DVOVRED, TRIPRED, CETPRED, PETRED, and control i.e. change of entered data with an option for program ending.

The program OFFIST provides file creation with values of Fisher's and Student's distribution for various significance coefficients α and degrees of freedom.

The program DIMANAL includes calculation of determinant and matrix rank, which actually is basis for analysis performing.

Formed files with their names could be found in the data base DATIME, in which could be entered through programs LISTDAT and FORDAT.

The program FORDAT serves for new file creation, when previously a correspondent experiment plan is selected, which was earlier entered in a coded form. After accepting certain experiment plan from suggested matrix plans, automatically an individual table is generated in which values of independent variables are entered. Experiment hyperspace is formed. Possibility exists to supplement the CADEX system with a new experiment matrix plan.

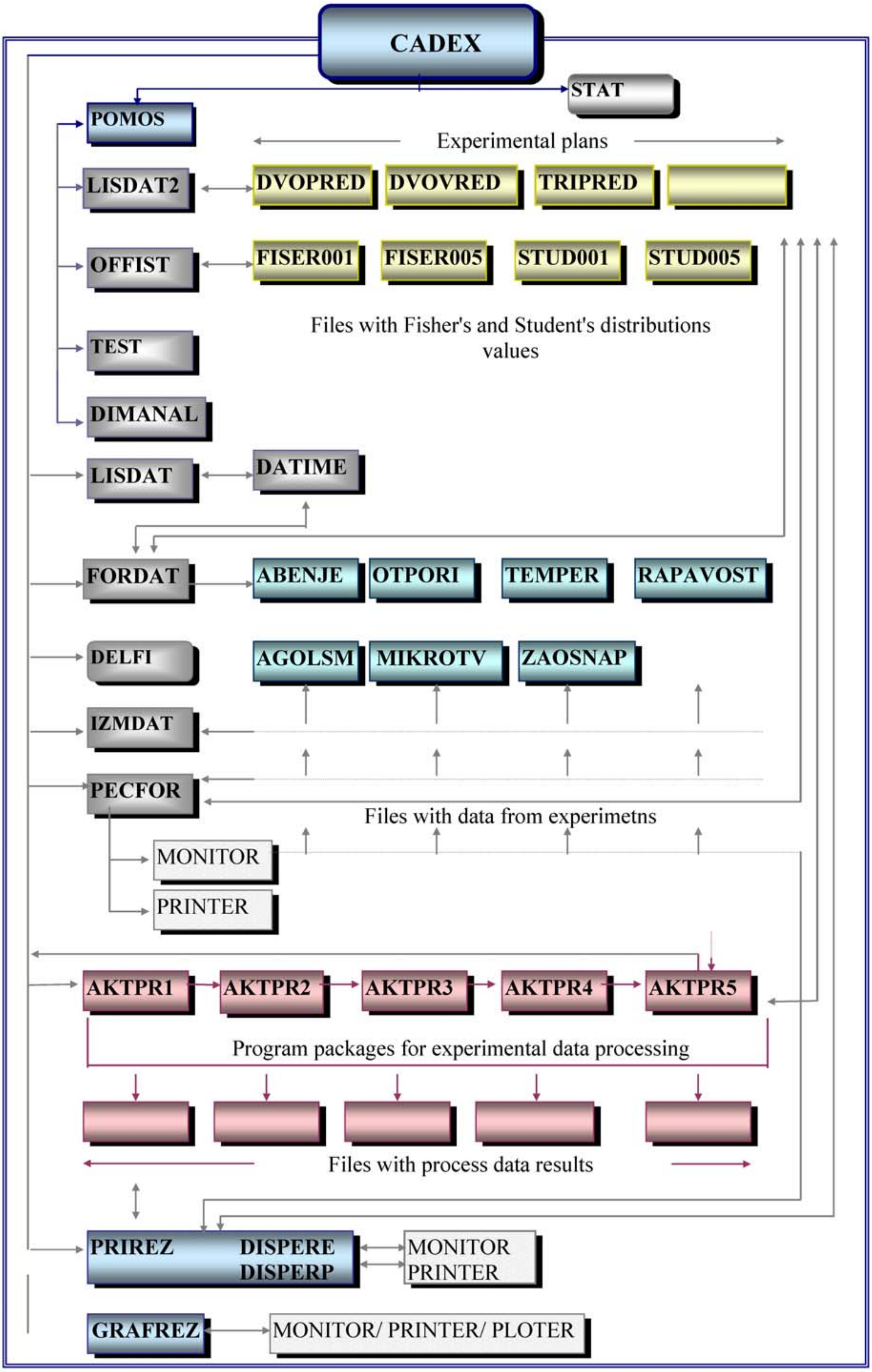


Fig. 3. Computer oriented system for automatic research data processing, CADEX [3]

IZMDAT is a program for performing changes in already formed files if some mistakes are made.

RECFOR is a program for printing empty templates – charts with data of input independent variables and charts with data necessary for experiment – matrix plan conducting.

Programs AKTPR1, AKTPR2, AKTPR3, AKTPR4 and AKTPR5 provide experiment data processing and mathematical models' gaining. These programs provide defining of coefficients in mathematical models with and without correlation, evaluation of coefficient significance, correlation of input-output information, dispersion analysis, as well as a review of characteristics for the mathematical model variant selection. Mathematically processed results presenting can be done on a display or on a printer, as a table or as a graphical interpretation. The program PRIREZ serves for this. Graphical interpretation is achieved by means of the professional program **MATLAB** (Fig. 4).

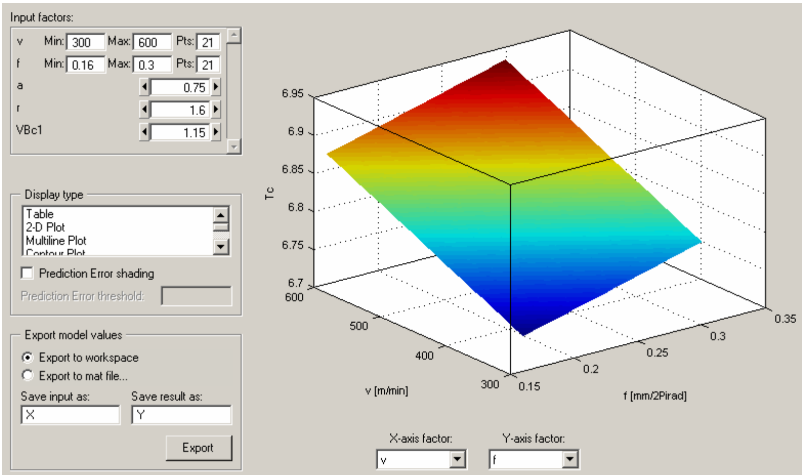


Fig. 4. Window for graphical interpretation of mathematical model

6. DEVELOPMENT OF THE MONITORING SYSTEM FOR EXPERIMENTAL SCIENTIFIC RESEARCHES IN THE CUTTING PROCESS BY MACHINING WITH TURNING

The monitoring system for performing experimental scientific researches at the cutting process is based on the usage of a Personal Computer (PC) as a fundamental unit of the system. The procedure for creating a monitoring system in this case consists of developing interface hardware and software modules which are going to connect the research process to the PC. Hardware interface parts have a task to adjust and make acquisition of signals information that come from the process then submit the same to the PC.

Reviewing various solutions stated in literature for the purpose of providing experimental research in the cutting process, the newly created monitoring system for investigating force components and temperature in the cutting process consists of:

– interface for the personal computer intended for signal adjustment and acquisition;

– software in MS Windows surrounding intended for a PC;

– modernization of the analogue-inductive dynamometer for force components measuring in the cutting process;

– two paths for temperature measurement in the cutting process using the method of natural thermo-pair.

6.1. Signal acquisition and data processing

Digitalization of analogue signals, which are interpretation of physical quantities intensity, is a task of the acquisition card that is part of the PC interface as part of the described monitoring system [9, 10]. Signal digitalizing is performed by acquisition and recording in a binary form. Afterwards binary sequences are transmitted into the PC.

This procedure is managed by means of a microcontroller. As initial criteria for interface design are the input transport mediums or modes for information transmission into the PC. Those can be through *USB, RS232*, the parallel or *PCI* ports on the PC. Design of protocol for data transfer from the microcontroller into the PC follows. *Windows* application design with a possibility to directly communicate with the microcontroller using selected transport medium has to provide compatibility with the PC operation system. Projecting of microcontroller software is also necessary for management of the acquisition with certain frequency of data collecting and enabling data submission to the PC in “real time”. Instead of individual A/D converter for whose management an additional system should be used, it has been decided to use the *Microchip* microcontroller *PIC16F877*.

This microcontroller is the latest generation and has a 10-bit A/D converter built-in with a possibility to define internal or external referent voltage levels and it can do 8-channel digitalizing. For 10 bit conversion needs 12 conversion tact within a time period shorter than 1,6 µs or it uses 20 µs as total time for conversion. In real conditions this time is a little longer because of time needed for the channel selection, test of conversion completion, adding control bits for the channel and low and high bit.

Max frequency of the tact generator is 20 MHz. Then, in accordance with the above stated, microcontroller provides 50000 conversions per second.

The nature of our researches defined a need of collecting several samples per one revolution of workpiece. For max. speed of 2000 revolutions per minute and 5 samples per revolution the system should perform conversion and acquisition of 2000*5/60 i.e. 167 samples, which is far below the possibility of the selected system. The microcontroller contains a built-in module for serial synchronous and asynchronous communication both ways simultaneously, the USART (Universal Synchronous Asynchronous Receiver Transmitter) with a possibility for easier communication speed adjustment. It is decided to use communication speed of 115200 bps since this speed provides flow of max number of data through communication line. For the communication protocol an 8 data bits with start and stop bit at frequency of 20 MHz of tack generator is selected. Against the fact that each sample includes $2 \times 8 = 16$ bits, at this regime it could transfer $115200/16 = 7200$ samples in “real time”. If four channels are simultaneously used, three for monitoring of cutting force components and one channel for temperature monitoring, 4000 samples need to be sent.

In the procedure for design of an electrical scheme of acquisition card we used the program package for design and simulation *Proteus 6.3 Demo*. This software has a library of analogue and digital components, including microcontrollers, virtual terminals, signal generators, measuring instruments, oscilloscopes, logistic analyzers and generators (Fig. 5). The friendly screen interface provides easy design and construction of A/D converter. The microcontroller connection to a program that manages its work can be done by simple “browse” option. After electrical scheme realization and successful logic control of links, a designed assembly function simulation is initiated. This program package allows use of the option for performing the program step by step with a possibility to track the values of all registers and defined variables as well as the “real time”.

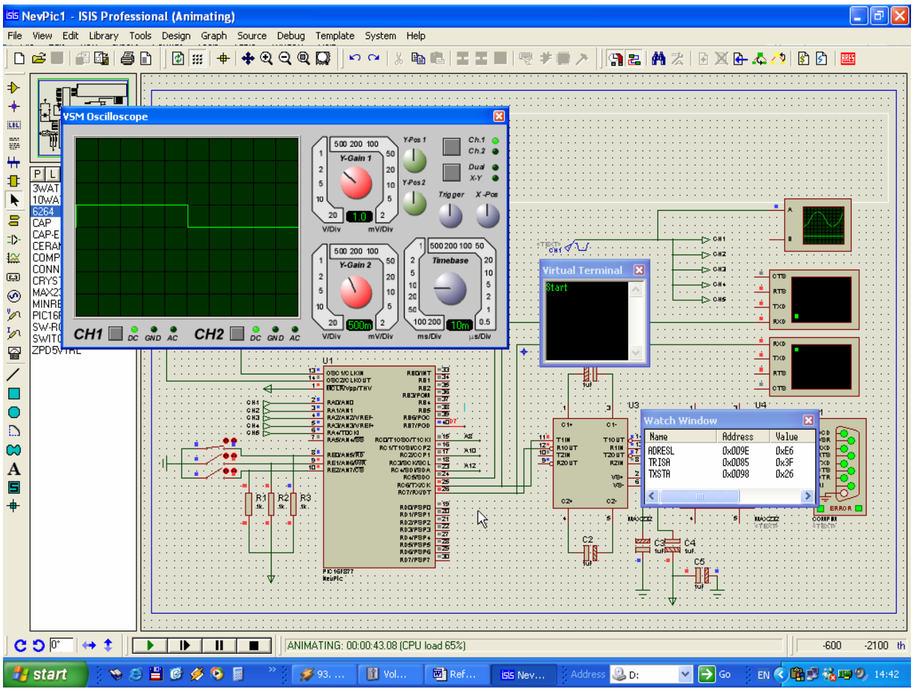


Fig. 5. Window of the software Proteus 6.3 Demo

Particularly underlined is the use of a virtual terminal for serial communication with which we easily simulated the personal computer as integral part of our assembly. The program that manages the microcontroller function is written in C-language for microcontrollers. The compiled program in the mechanical code is recorded in the microcontroller with a realized programmer for microcontrollers.

The electrical scheme for the microcontroller *PIC16F877* connecting to serial interface *RS232* is shown on Figure 6. The microcontroller is powered by 5 V power supply. The integral circuit *MAX232* is connected to pins *RC7* and *RC6*. These pins are connected to the microcontroller *USART*.

The reason for using the integral circuit *MAX 232* is adjustment of the voltage level of the communication to *RS232* interface of the personal computer. Logistic "0" at *RS232* is the voltage level of +3 till +12 V, while as on the microcontroller it is 0 V. Logistic "1" at *RS232* is the voltage level of –3 till –12 V, while as on the microcontroller this is 5 V. On three bits of the port *E, RE0-RE2* switches are connected on the mutual end thereby providing the high or low voltage level. The microcontroller function speed is selected with certain combination of switches. The tact generator is made by connecting a quartz crystal and capacitors on the pins *OSC1* and *OSC2*. The 9-pin connector is marked with *P1* on the electrical chart serves for connecting with *RS232* interface through a cable. The connector *P1* (Fig. 6) makes this simulation interactive since the provides connecting of simulated communication to real *RS232* interface of the personal computer. Thereby, possibilities are given for checking i.e. simulation of the communication protocol with the personal computer software.

A prototype version of the personal computer interface, which is integrated in the monitoring system, is presented in Figure 7.

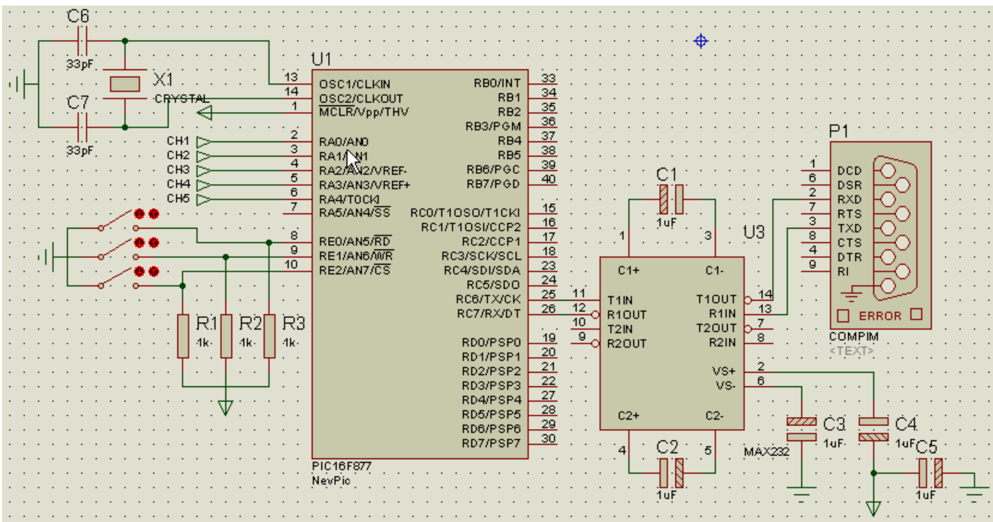


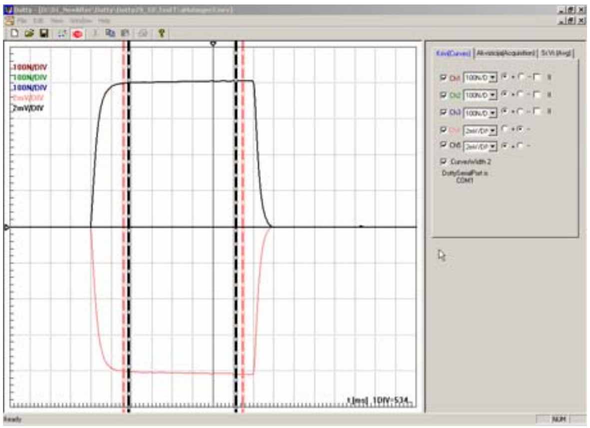
Fig. 6. Electrical scheme of microcontroller PIC16F877 connection

Fig. 7. Prototype version of personal computer interface

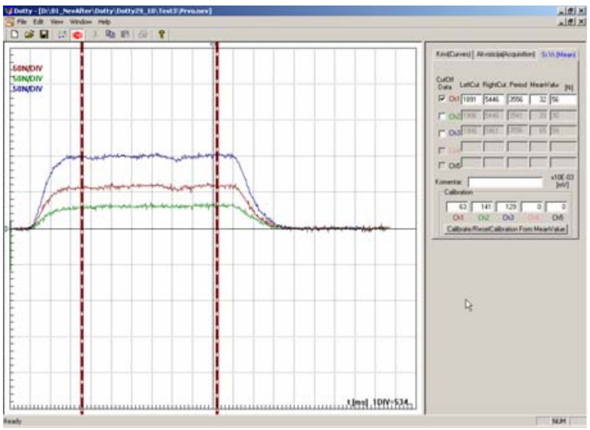
6.2. Software for data processing and presentation

The software that is developed for the monitoring system support has the name **FORTMON**, acronym from *FORce & Temperature MONitoring* (Fig. 8). The **FORTMON** window is divided in two parts. The left one is intended for graphical interpretation of forces and thermo-voltage dependent on time, while as the right one contains a multiple controls selection. Besides the standard status and the title line also contains a line with tools and menu in its window.

The part intended for graphical interpretation is divided into a network with dimensions 20x10. Horizontal divisions of network present the time axis, while as on vertical divisions overlap axis of 5 signals for force or thermo-voltage, correspondingly. The network is dynamic and flexible. If the application window size is changed, the network size also changes. Controls are located in the first tab of the selection intended for signal selection. The first three channels refer to cutting force components.



a)



b)

Fig. 8. Appearance of monitoring system software screen a) temperature measurement b) cutting force measurement

The fourth and fifth the channel contain sequences of values of thermo-voltage, which is gained in two various paths.

The next controls right next to the channel marks are the selectors for values of divisions of the network for each signal of the vertical axis.

Selected values of these selectors are shown in the left upper corner of the network. Then selections for vertical axis orientation for each of the signals follow.

This tab has also selectors for the work mode of a dynamometer for each component individually, since the same has a possibility to work in two modes. Signals can be drawn with two various line thicknesses, which is changed by the option *CurvesWeight2* in this tab.

In the second tab controls are located in four groups. The first group shows information for the network size expressed in pixels, which the user has available for presenting data in sequences. Currently it is selected network to show each *n* point so the whole sequence would be included in the network. If the user makes other adjustments, reset can be made to this view by clicking the key marked as *ToDisplayWidth.* Screen width and selection of each *n* point determines the value of the division for time axis, which is shown in the bottom right part of the network. The second group is a selection for the acquisition type in terms how long it lasts. It could be continuous by selecting option *Loop* or periodical by selecting option *Manual*. This selection adjusts the value of the constant that is sent to the interface by pressing the key *Start* in the tool menu for acquisition start. This signalizes to the microcontroller software to perform data acquisition in order to fill-in sequences once or the same to continue with the acquisition in a cycle until pressing the key *Stop* from the tool menu. The third group is for selection whether acquisition is performed on the first four ports of A/D converter wherein the signals for force components and the signal for thermo-voltage arrive or on the fourth and fifth wherein the signals for thermo-voltage arrive against the two paths.

The last control in this tab is the slider with which signals that are shown on the network can be scrolled.

The last tab is intended for data processing. It has possibility for activating or deactivating lines for limiting part of time axis. Right columns in this tab are intended for presenting the average value of points that are located over the selected part of time axis. This tab also includes a field wherein a comment that is recorded along with the data of the sequences can be write. Last in this tab is the group of controls intended for vertical axis calibration. Here it can be determined which values shall be presented as initial i.e. shall be positioned on the center vertical line for each channel.

Standard functions for recording and recalling data from sequences are located in the tool line and menu, while as with standard functions for copying in work memory of the PC the part with graphical interpretation is copied. This allows the same to be transferred onto other software for further graphical presentation.

There are two icons  in the tool line, which are used for signal submission onto the microcontroller, which controls acquisition start and end.

The application supports simultaneous opening of multiple windows in which various adjustments and views of graphical interpretation can be select and it is also possible each channel to be processed individually or in combination.

Linear interpolation is used for drawing acquisition signals over the network.

7. ANALYSIS OF EXISTING SYSTEMS FOR TEMPERATURE MEASUREMENT IN THE CUTTING PROCESS AT TURNING

If we review the existing systems for temperature measurement in the cutting process [6, 11, 12, 13, 14, 15, 16], we shall determine that various solutions with various applied automation exist i.e. a signal transfer from the workpiece and the cutting tool into the PC by application of certain interface. Various solutions have certain advantages and disadvantages and are linked to the level of measuring uncertainty of gained results from measurements, as well as to the cost price of measurement equipment.

Two ways are applied in terms of getting signal from workpiece. One way is by application of a sliding device i.e. the Hottinger device, product of the company Hottinger Baldwin Messtechnik GmbHa, which is positioned contrary of the clamping head, on the main spindle Figure 9 [11, 13] and Figure 10 [5, 13]. Figure 9 presents the connection of cutting machine elements to measuring analogue accessory for temperature measurements in the cutting process, as well as the limited application of the Hottinger device, which is conditioned by the pass-over through the main spindle and the accessibility till its opposite end. The inaccessibility till the opposite end of the main spindle, seen contrary from clamping head, is clearly expressed on numerically controlled /NC/ lathes, which limits the Hottinger device application. Figure 9, workpiece (1) is clamped in a clamping head (2), insulated by means of special washers (4).

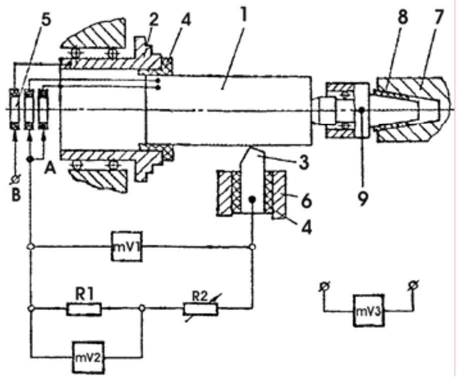


Fig. 9. Scheme for connecting cutting machine elements to measuring analogue accessory by using of a Hottinger head; Bobrovskii, V.A, Afanaseev F.E. [11, 13].;

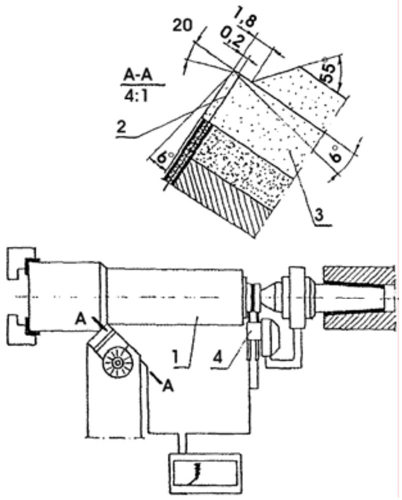


Fig. 10. Scheme for connecting cutting machine elements to measuring analogue accessory by using sliding rings onto the machined object. Detailed description of coding is given in [5, 13]

The Hottinger device is marked with (5). The cutting tool (3) is positioned in a holder (6) insulated with a washer (4) in order not to disturb the thermo-couple workpiece-cutting tool in case of contact with other machine parts. The center (9) is insulated from tailstock (7) with foil (8). Foil reduces contact stiffness between the center (9) and the tailstock (7) resulting into vibration occurrence in the cutting process. Additional influencing factors that can disturb the test process are implemented in this way.

Another way for signal transfer from the workpiece is with sliding rings placed on the workpiece and brushes placed on the stationary part of the machine (Fig. 10) [5, 13]. This mode is applicable when the main spindle is inaccessible, which is the most common case on the NC machines.

For the purpose of reducing the interval of measuring uncertainty of results gained from performed temperature measurements a special device is designed for signal transfer from the machined object (Fig, 11) [2, 17].

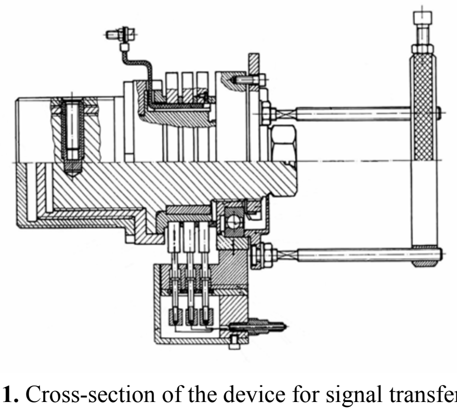


Fig. 11. Cross-section of the device for signal transfer from the machined object. Detailed description of coding is given in [17]

7.1. Installation of the newly created monitoring system for temperature measurement in the cutting process by machining with turning

Realized two paths for thermo-voltage transfer from the natural thermo-pair workpiece-cutting tool and their connecting to the monitoring system for temperature measuring at the cutting process are presented in Figure 12. Two ways are applicable, as already mentioned, for signal transfer from the workpiece. One way is by application of the Hottinger device, product of the company *Hottinger Baldwin Messtechnik GmbH,* which is positioned on main spindle opposite the clamping head.

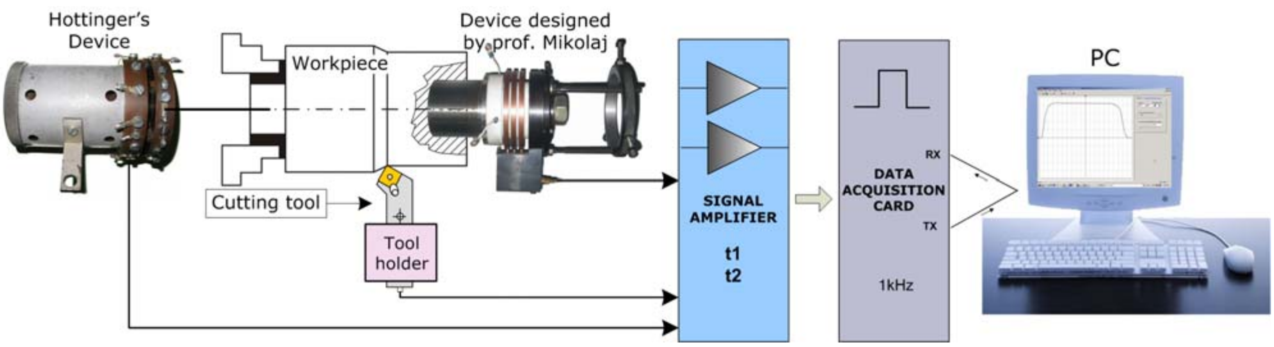


Fig. 12. Scheme for the signal path in the monitoring system for temperature measuring

Other way, for the purpose the monitoring system to be able to determine the path influence upon the signal for the signal transfer from the workpiece, a special device the designed by professor Mikolaj Kuzinovski (patent solution) [17]. Thermo-voltage transfer by cutting tool is performed by means of a redesigned cutting tool holder, which provides contact from the bottom side by means of a strained copper needle (Fig. 13).

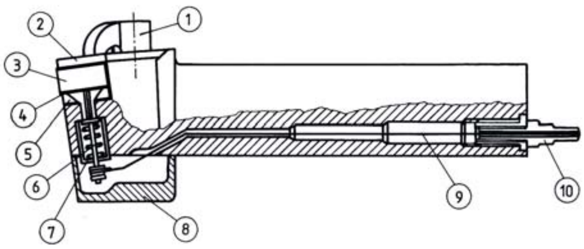


Fig. 13. Cross-section of cutting tool holder, specially adjusted for temperature measuring [2].
1 – thumb, 2 – Al_20_3 chip breaker, 3-ceramic cutting insert MC2, 4 - mica, 5 – washer, 6- mechanism, 7 – insulation bush, 8 – safety cap, 9 – signal conductor, 10 – connection

Temperature signals' amplifier consists of two channels that have a task to perform amplification of transferred thermo-voltage that is generated in the natural thermo-couple. It also performs galvanic separation of the thermo-couple circuit from the circuit, which consists of the acquisition card and the personal computer. Additionally, galvanic separation serves to protect the acquisition card and the personal computer from eventual electric shocks that might occur in the installation of the natural thermo-couple and to remove acquisition card effects upon the circuit with the natural thermo-couple.

Galvanic separation serves to protect the acquisition card and the personal computer from eventual electric shocks that might occur in the installation of the natural thermo-couple and to remove acquisition card effects upon the circuit with the natural thermo-couple. For the purpose, channels have an optocoupler insulation amplifier *ISO100* and electronic components for supporting its function (Fig. 14).

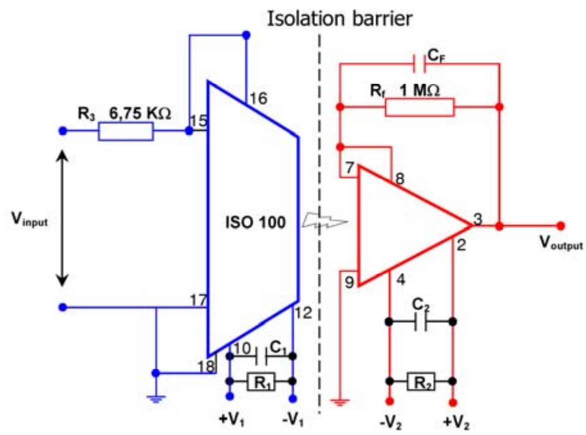


Fig. 14. Electrical scheme of the thermo-voltage amplifier channel

Such a positioned amplifier has nominal given amplification of 148 times given with value ratio of resistors R_f / R_3. Transferred thermo-voltage from the natural thermo-couple is brought at input of connections 15–17, while as the amplified signal from V_{output}, connection 3 is transferred to the acquisition card. Vital properties of ISO100 are high precision, linearity and temperature stability. This is gained by coupling a LED diode in the feedback of the internal primary operation amplifier with the LED diode at input of the secondary operation amplifier. It is powered with max ±18 V, while as due to the existing galvanic separation the powering of the primary and the secondary operation amplifier is necessary to be performed with two individual galvanic separated sources. For max foreseen amplifier output, which has to be in the range of A/D convertor 0–5 V, two galvanic individual power supplies are used with the value V_1 = ±12 V and V_2 = ±12 V. The optical feedback can segregate voltage difference of 750 V.

Nominal given amplification depends upon tolerance of marked resistors' value with which ratio the amplification is defined. The determination of real amplification is performed by defining the supposed linear mathematical model on the amplification curve. For the purpose familiar voltage levels are charged on input, while as results presented in Table 1.

Table 1

Results of thermo-voltage amplifier calibration (mV)

Input	Output 1	Output 2
0.0	0	0
5.0	754	757
6.0	906	912
10.0	1464	1473
14.0	2158	2174
k	151.42	152.45

The tangent of the inclination angle of the line presents real amplification and it is determined against the method of least squares of experimentally gained points.

7.2. Functional test and verification of interface for temperature measurement in the cutting process by machining with turning

Interface functional check is done in three stages. Initially amplifier check is done in a way that familiar voltages are brought to amplifier input from a signal generator and by means of a two-channel oscilloscope input and output voltages are simultaneously recorded in time range. It is concluded that the amplifier amplifies the signal, while as the amplification coefficient is correspondent to the value defined with the ratio R_F/R_4. Satisfactory non-linearity is concluded, which amounts 0,01% as given in factory data for the integral circuit ISO100.

Then check of a A/D convertor is performed by getting periodic signals at its input with various frequencies and wave forms when gained values correspond to the defined precision of 5/1024 Volts (Fig. 15).

In the end measuring of generated thermo voltage at the turning process is done (Fig. 16) [13], with cutting speed v = 300 m/min, feed f = 0.16 mm/rev and cutting depth a = 1.0 mm. Machined material is carbon steel (C 1630), cutting inserts are type SNGN 120712 manufactured from mixed ceramics MC2 (Al_2O_3 + TiC) from the company HERTEL. Average thermo-voltage of 9.54 mV is measured. Using previously defined relation for describing the dependence of thermo-electrical characteristic for the natural thermo-couple C1630-MC2 ($T = 104.426 - 42.646u + 44.734u^2 - 4.937u^3 + 0.17u^4$) [8, 11, 14] average temperature of 890.95 °C is gained.

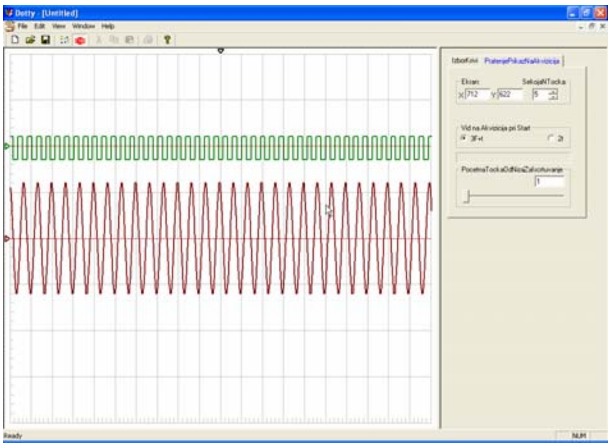


Fig. 15. Time form of periodic signals gained when checking A/D convertor with periodic signals

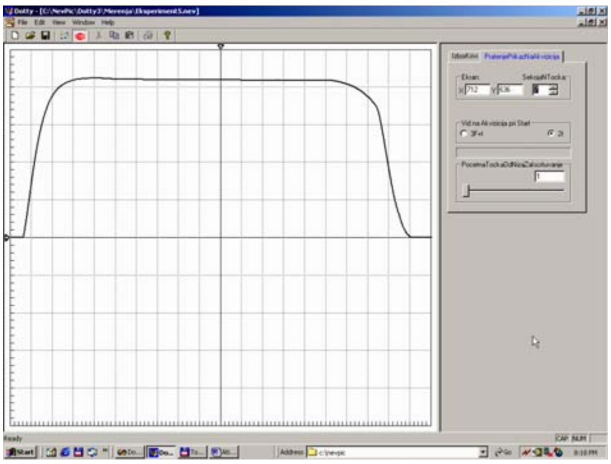


Fig. 16. View on the thermo-voltage signal and the application window

Verification of the newly created computer-aided temperature measurement system in the cutting process by machining with turning is confirmed by performing the same such an experiment in ITMiA in Wroclaw University of Technology, Poland. Measured average temperature of 881.59 °C differs for approximately 5% in terms of our measurements [13, 15].

If it is taken into account that another interface type is used for measurements performed in ITMiA in Wroclaw University of Technology, Poland it can be concluded that newly created interface fully meets the needs for temperature measurement in turning processes.

8. INSTALLATION OF A NEWLY CREATED MONITORING SYSTEM FOR FORCE MEASUREMENT IN THE CUTTING PROCESS BY MACHINING WITH TURNING

Faculty of Mechanical Engineering in Skopje is equipped with the inductive dynamometer type *Fisher Messtechnik Typ EF2 D3 NR 24570,* manufactured by the company Helmut Fischer GMBH & Co from Germany, which consists of the cutting tool holder with inductive measuring cells for a force transfer into electrical signal and an indicating instrument, which consists of a measuring bridge and signal intensity indicators. The principle of function of this measurement system is misbalance of the measuring bridge for each component individually. Since stated installation is of an obsolete type where human factor in value reading and registering isn't excluded, as well as the difficult experiment conducting, and even impossible reading of values of all components during experiment conducting, its modernization initiated [18, 19, 20]. During the modernization process of inductive dynamometer we followed the latest technological trend, which means multi-discipline approach to integral projection and development of new products and systems, which is also applied in creation of scientific-research areas. The trend called mechatronics integrates expensive mechanical parts of systems by using intermediate electronics, computers and software, while as results into a cost-effective, computer modernized system with properties as latest contemporary units applied in the same field [21].

In this case, due to the specific design of the force measurement system, upgrade was performed without disturbing its functionality in neither one segment and using it only as a signal source (Fig. 17). It is connected to a personal computer by means of an amplifier and a signal adjuster and the already described data acquisition card.

The design of electrical scheme for the circuit, whose task is to prepare the signal for acquisition, is done by means of the software *Circuit-Maker Demo.* The signal from indicating instrument is transferred by means of a voltage follower designed with the operation amplifier TL084. Marked with U1A and U1B on the scheme shown on Figure 18.

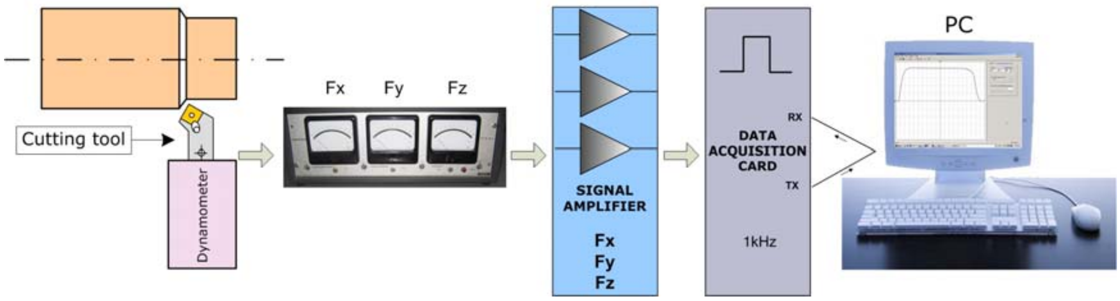


Fig. 17. Schematic layout of the monitoring system signal path for cutting force measuring

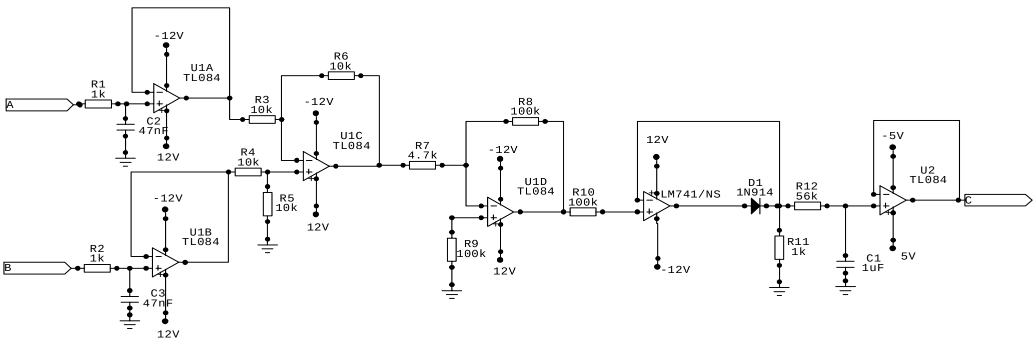


Fig. 18. Electrical scheme of analogue signal amplifier

The voltage follower has infinite large input impedance thereby providing its connecting to the circuit of measuring bridge without any effect upon it. The signal is then transferred to the following connection made of operation amplifier marked with U1C and resistors R3, R4, R5 and R6, which present a differential amplifier. Its task is to provide a resultant the voltage level which is the difference between voltage levels on indicator ends. In this way a signal is provided proportional to voltage drop on the indicator, which is proportional to the current that flows through the indicator. In that way a signal is gained proportional to difference in value from a differential sensor, since through the indicator current flows proportional to the difference in value from the measuring bridge, of which the differential sensor and the indicator are integral part.

In the next steps it is necessary this signal to be transformed so it can be suitable for acquisition. The highest signal value that can occur on differential amplifier output correspondents to the highest voltage drop that can occur on indicator ends.

The indicator is an ampere meter, which reaches the highest arrow inclination when current of 100 μA flows through it at internal resistance of 1750 Ω. This means that the highest voltage that occurs on indicator ends is 17.5 mV. For amplifying this value for acquisition needs, which is performed in interval of 0–5 V an inverter amplifier is used, which consists of the operation amplifier U1D and resistors R7, R8 and R9 with nominal given amplification in terms of resistors R8 and R7 with value of 21 times. Expected max signal value at inverter amplifier output is 3.7 V.

A possibility exists for occurrence of negative voltage values on inverter amplifier output at eventual dislocation of the differential sensor in contrary direction (out of the cutting process). Blocking of negative signal values for the purpose of protecting connections for acquisition that do not function with negative values is performed by a connection of a precise diode consisting of the operation amplifier LM741 and the diode 1N914.

A voltage follower is positioned, as a separate connection, on the amplifier end, which consists of an operation amplifier marked as U2 on the electrical scheme, however in this case it is charged with ± 5 V in order to provide max level limitation of output signal onto ± 5 V. This is due to the possibility higher current flow to occur through the indicator than the permitted one, which can create a signal within the amplifier with higher voltage value than calculated operating values. This voltage follower removes also the effects of acquisition circuits upon amplifier function. A capacitor C1 is connected at the voltage follower input for the purpose of balancing signal pulse form thereby making it suitable for acquisition.

System calibration is performed by loading known force in direction of action of certain component and indications on the monitoring system are read. Loading with known forces by means of weights with known mass, which are positioned so that can act with their own weight in direction of individual components (Fig. 19).

Weights mass is determined by weighing in the Metrology Institute at the Ministry of Economy of R. Macedonia.

Fig. 19. Measurement system calibration by loading with known force

Once creating tables with correspondent values, the same are graphically presented (Fig. 20), and a force dependence model is created from the monitoring system indications. A linear function is adopted for this dependence $y = kx$. Readings can be expressed in force measuring units by a model implementing into the monitoring system software.

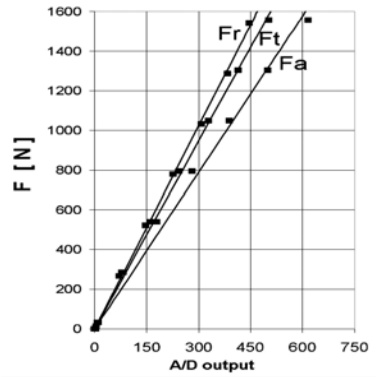


Fig. 20. Calibration diagram

9. CONCLUSION

Application of the automated monitoring system intended for performing experimental researches fully justifies the idea for its creation. Such conclusion is based on the fact that by application of the newly created monitoring system in researches simultaneously more output values in real time are recorded, which the researched phenomena are described with.

In our case these are temperature and the resultant force in the cutting process expressed through the tangential, axial and radial components. In this way more creative actions are possible to be performed by the experimenter, as well as analysis of applied methods for experiment planning, analysis of gained results, experiment error defining, analysis of gained mathematical models for description of researched phenomena and verification of the same.

Test results and verification confirm successful realization of interface. The application of an integral circuit ISO100 for signal amplifying exhibited as an excellent choice since the same meets specific amplifier requirements. The small nonlinearity given in factory data during test performing was confirmed and thereby led to dispersion reduction of the gained results. The possibility for amplification defined with external components makes the integral circuit ISO100 suitable for application since it provides easier transfer of amplified signal within A/D converter range for various thermo-elements and various max temperatures. The use of the microcontroller PIC16F877 to act as an A/D converter evidenced as an exclusive advantage in the whole interface since most vital functions as A/D conversion and communication with RS232 interface are integrated in it. It is easily programmed, while as an electrical scheme design software with its implementation in them is worldwide applied. The use of the program package for design and simulation of Proteus 6.3. Demo is particularly underlined as software offering all desired possibilities in these procedures.

The created monitoring system characterizes with open access to hardware and software components, thereby providing analysis of the adequacy of selected hardware components and software solutions in terms of signal acquisition.

It is determined as necessary to perform upgrade and modernization of old systems by supplementing electronics and software. Actually, the mechatronics approach is applied in modernization stages of the existing research equipment. Results, which are gained by calibration of experimental area for research of components of the cutting force and temperature in cutting process during turning, exhibited high stability of hardware solutions.

Verification of experimental methods and applied methods for conducting experimental researches showed concordance with the gained results from researches done in ITMiA in Wroclaw University of Technology, Poland, against the same terms of experiment conducting.

The created CADEX system in connection with the MATLAB provides use of partial experimental plans as a justified solution that allows time shortening for experiment conducting and savings in economic aspect.

Applied logarithm transformations of data when determining dependences in mathematical models of cutting processes implement a “mistake” however its use is justified in terms of detected changeable dispersion of data gained at research of cutting processes’ phenomena.

The computer aided process for physical phenomena research in cutting processes makes the creation of basis for knowledge easier by gaining information for machining of various machined materials and with various cutting materials.

In this way pre-conditions are created for the optimum selection of machining parameters in cutting processes and management of mechanical and heat model for creating residual stresses, which effect surface layer properties.

The more intensive actions performed in sense of reducing uncertainty of results gained from measurements and effect defining certain factors is justified, all with a purpose to reduce or eliminate its negative effect in research hardware equipment and software.

Basic pre-disposition for gaining recognizable results in researches is development and possessing own hardware scientific-research equipment and software for research of physical phenomena in cutting processes and technological effects in the surface layer with an open access to hardware and software components.

Possibilities are created for conducting continuous development actions in the monitoring system structure.

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Р е з и м е

СИСТЕМ ЗА МОНИТОРИНГ ЗА АВТОМАТИЗАЦИЈА НА ЕКСПЕРИМЕНТАЛНИТЕ ИСТРАЖУВАЊА ПРИ ОБРАБОТКА СО СТРУЖЕЊЕ

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Во трудот се претставени постапките кои се изведуваат при проектирање и реализација на експерименталните научни истражувања со примена на автоматизиран мерен систем со компјутерска поддршка во сите етапи од истражувањето. Посебен акцент е даден на интегрирањето на мерните системи и математичката обработка на инфрмациите од експериментите. Процесите на автоматизацијата се опишани преку реализираниот сопствен автоматизиран мониторинг систем за истражување на физичките појави во процесот на режење со копјутерски потпомогната аквизиција на податоците. Мониторинг системот е наменет за следење на тангенцијалната, аксијалната и радијалната сила на режењето, како и на средната температура во процесот на режење. Харверскиот дел за аквизиција се состои од засилувачи и А/Д претворувач, а за анализа и визуелизација развиен е софтвер за персонален компјутер во MS Visual C++. За математичко опишување на истражуваните физички појави создаден е софтвер CADEX во спрега со MATLAB наменет за проектирање, обработка и анализа на експерименталните научни истражувања, согласно теоријата на планирање на повеќе факторните експерименти. Изведбата на интерфејсот и компјутеризираниот мерен систем се изработени на Машинскиот факултет во Скопје во соработка со факултетот за Електротехника и информациски технологии во Скопје и со Институтот за Технологија на Машини и Автоматизација при Вроцлавска Политехника, Полска. Создадениот сопствен научно- истражувачки мерен систем со отврен пристап до хардверскиот и софтверскиот дел создава услови за целосна контрола на истражувачкиот процес и за намалување на интервалот на мерната неодреденост на добиените резултати од изведените истражувања