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Original scientific paper

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).

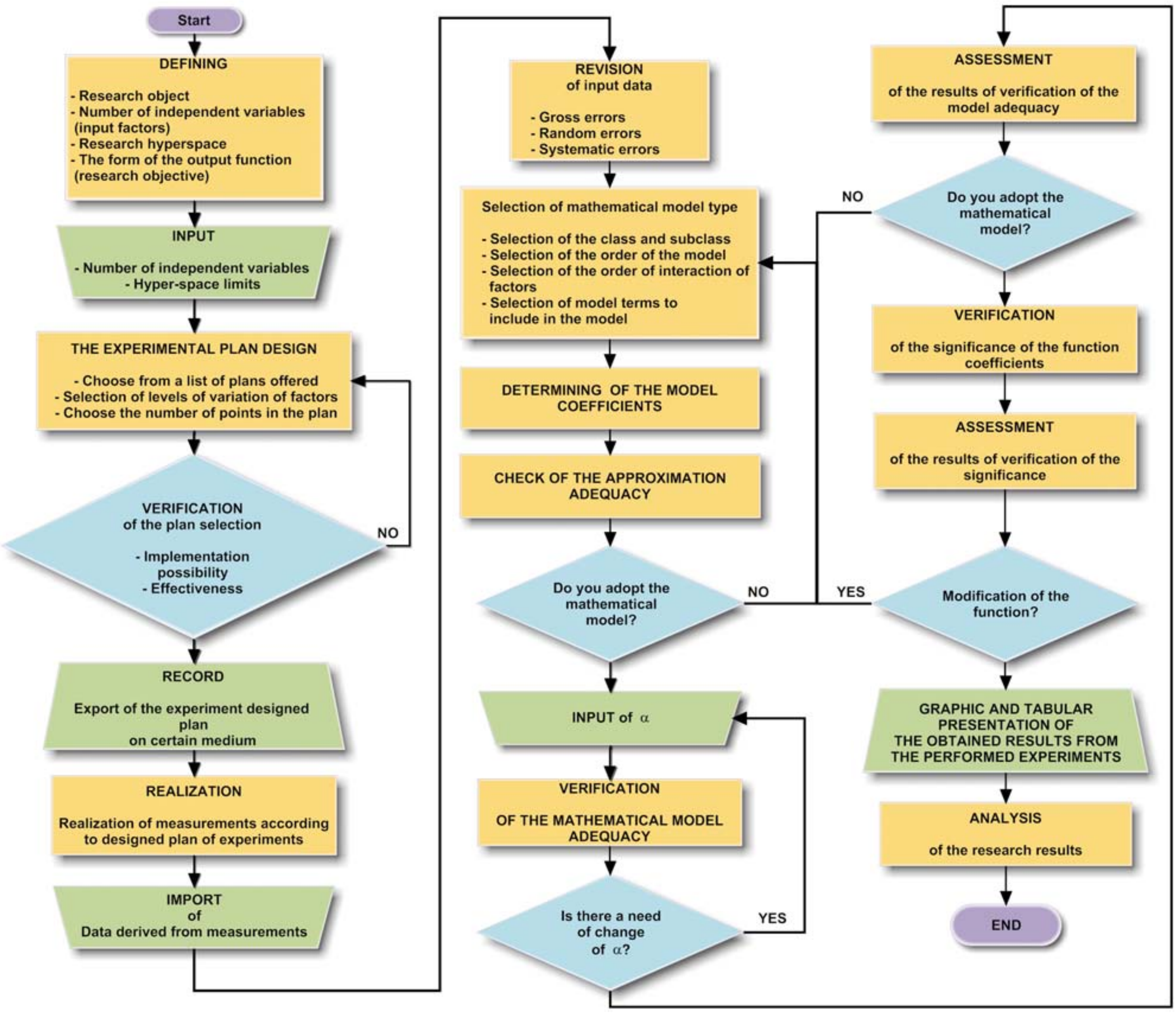


Fig. 1. Experimenter activities when planning and analyzing experimental scientific researches [3].

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.

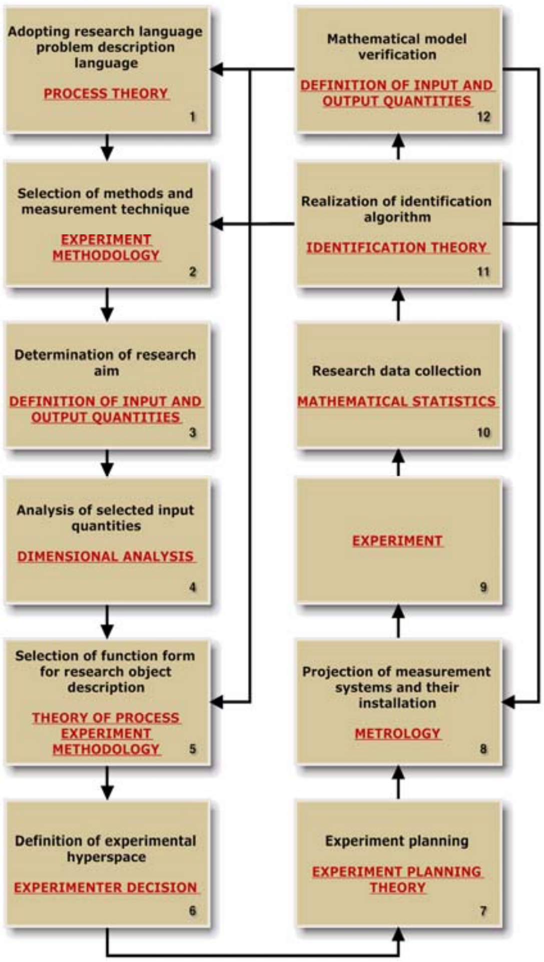


Fig. 2. Experimenter activities when projecting and realizing experimental scientific researches [3, 8]

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.

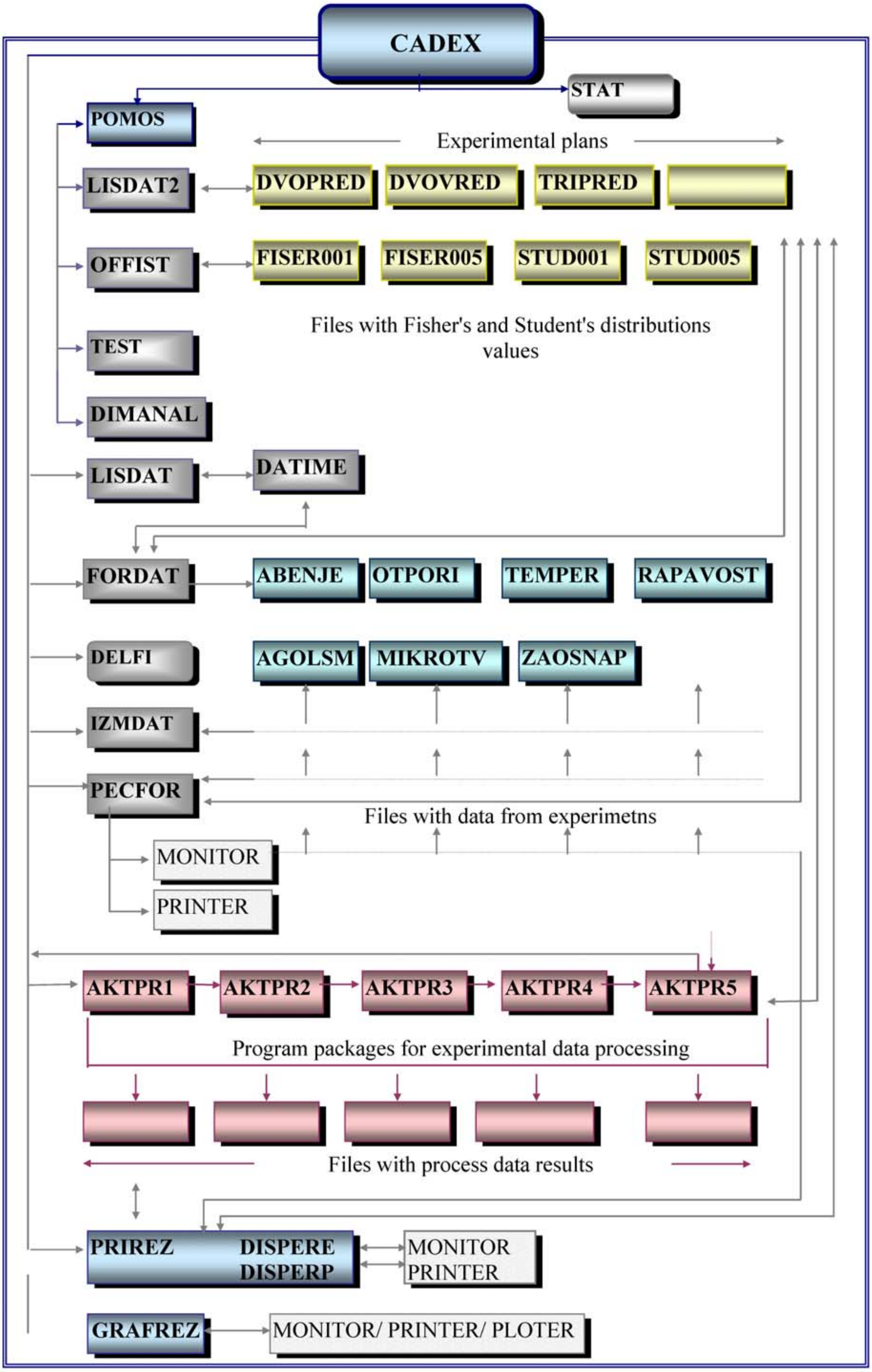


Fig. 3. Computer oriented system for automatic research data processing, CADEX [3]

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).

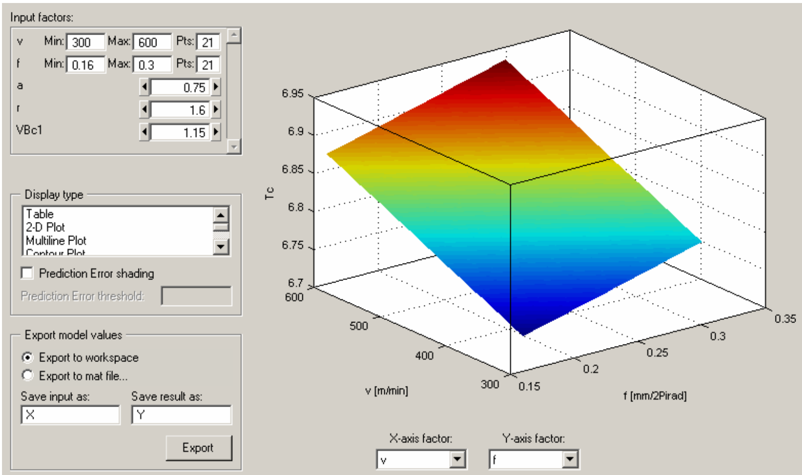


Fig. 4. Window for graphical interpretation of mathematical model

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 × 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".

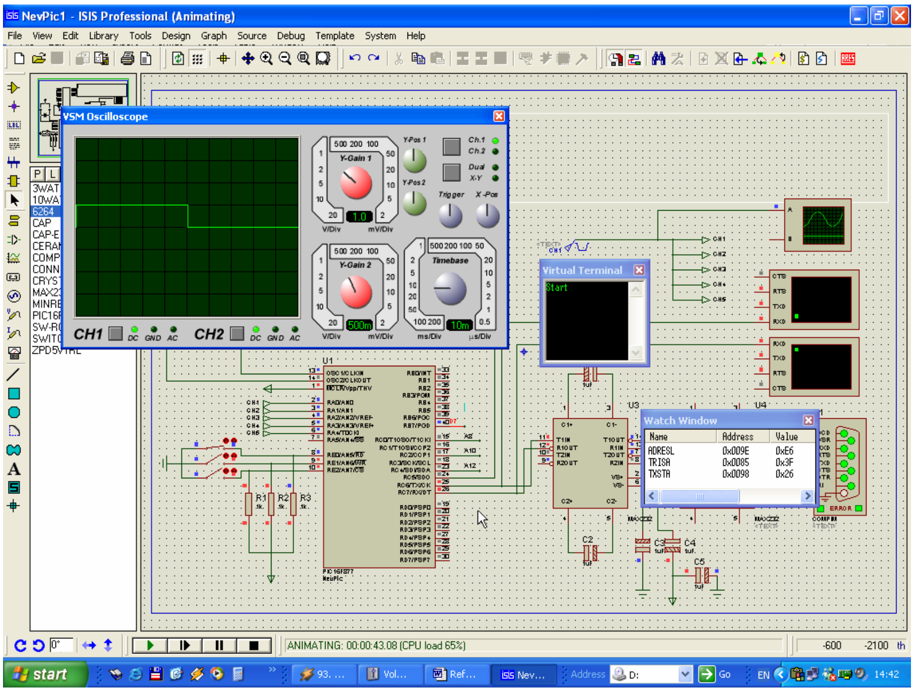


Fig. 5. Window of the software Proteus 6.3 Demo

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.

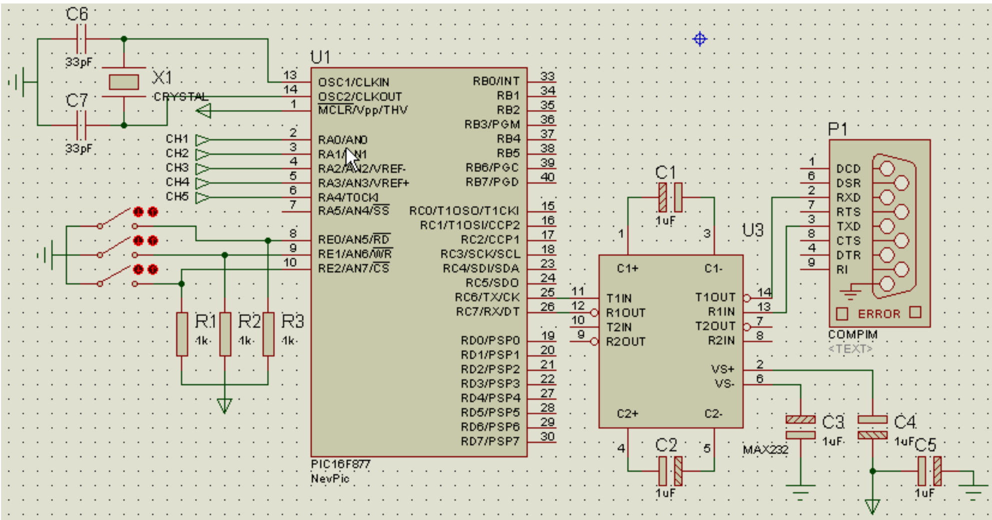


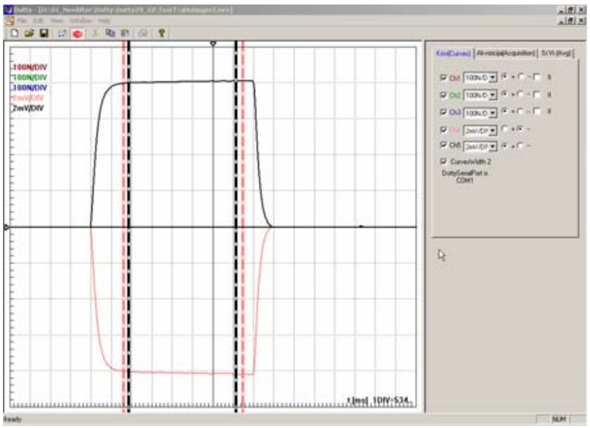
Fig. 6. Electrical scheme of microcontroller PIC16F877 connection


Fig. 7. Prototype version of personal computer interface

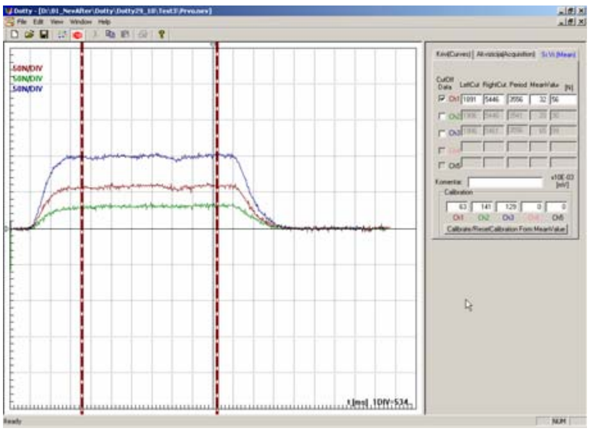
6.2. Software for data processing and presentation

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).

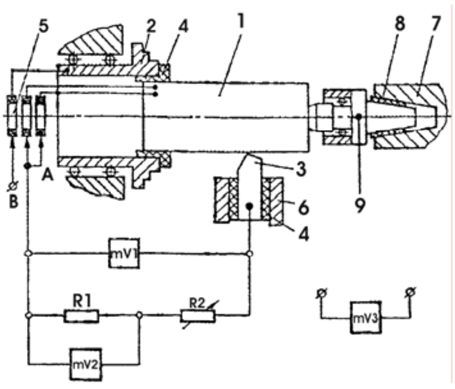


Fig. 9. Scheme for connecting cutting machine elements to measuring analogue accessory by using of a Hottinger head; Bobrovskii, V.A, Afanaseev F.E. [11, 13].;

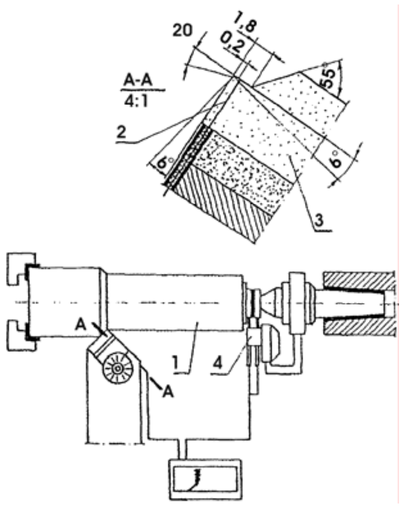


Fig. 10. Scheme for connecting cutting machine elements to measuring analogue accessory by using sliding rings onto the machined object. Detailed description of coding is given in [5, 13]

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].

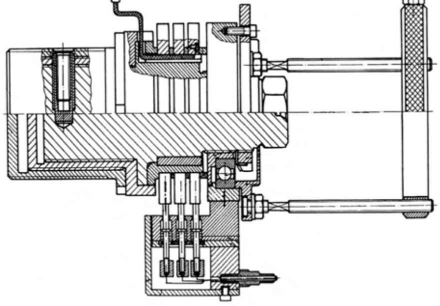


Fig. 11. Cross-section of the device for signal transfer from the machined object. Detailed description of coding is given in [17]

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.

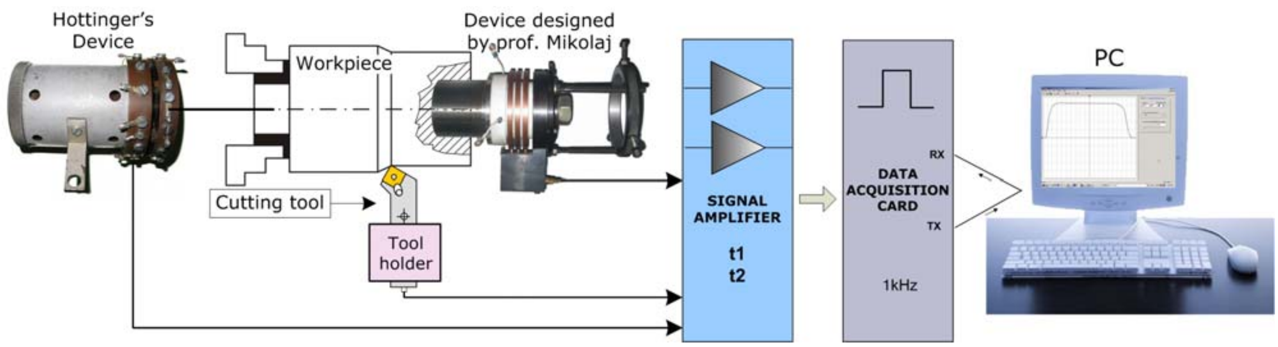


Fig. 12. Scheme for the signal path in the monitoring system for temperature measuring

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).

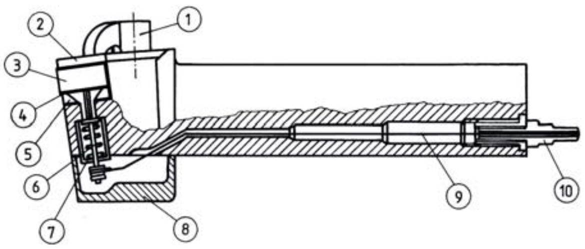


Fig. 13. Cross-section of cutting tool holder, specially adjusted for temperature measuring [2].
1 – thumb, 2 – Al_2O_3 chip breaker, 3-ceramic cutting insert MC2, 4 - mica, 5 – washer, 6- mechanism, 7 – insulation bush, 8 – safety cap, 9 – signal conductor, 10 – connection

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).

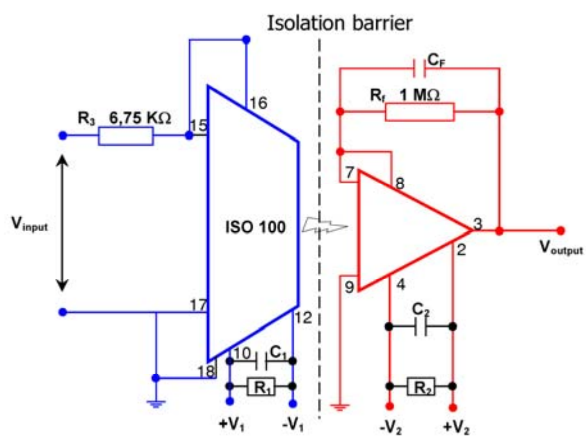


Fig. 14. Electrical scheme of the thermo-voltage amplifier channel

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.

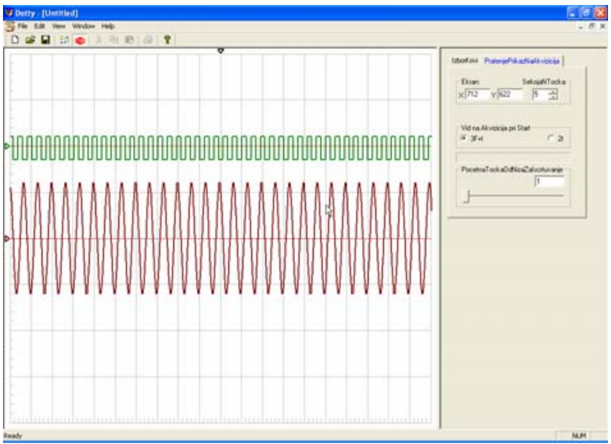


Fig. 15. Time form of periodic signals gained when checking A/D convertor with periodic signals

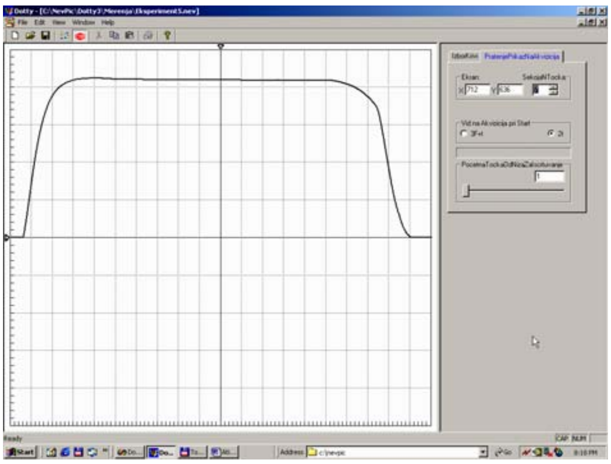


Fig. 16. View on the thermo-voltage signal and the application window

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 ^{o}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.

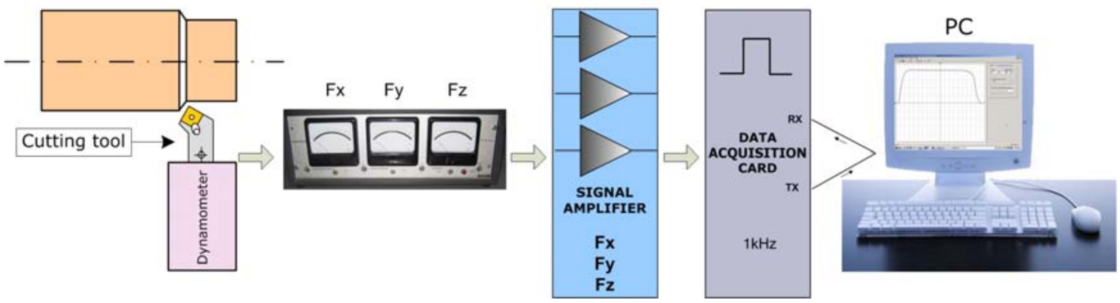


Fig. 17. Schematic layout of the monitoring system signal path for cutting force measuring

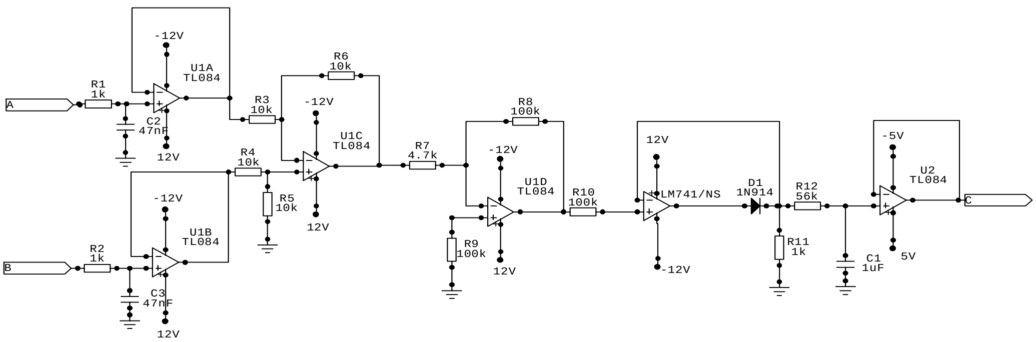


Fig. 18. Electrical scheme of analogue signal amplifier

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.

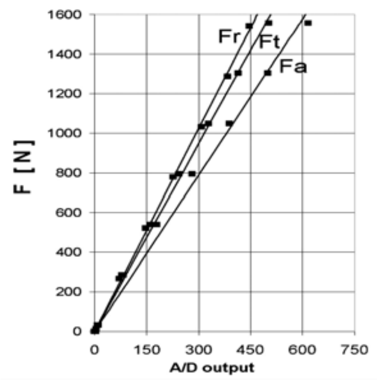


Fig. 20. Calibration diagram

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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Клучни зборови: мониторинг систем; автоматизација; сили; температура; режење; стружење.

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

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NECESSITY OF REGULATING THE BRAKING FORCES IN THE BRAKING SYSTEMS OF ROAD MOTOR VEHICLES

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A b s t r a c t: The braking systems of road motor vehicles are responsible a great deal for the active safety of road motor vehicles, participants in road traffic, and are frequent reasons for causing traffic accidents. The condition of the regulators of the braking process in braking systems of road motor vehicles has enormous influence on the active safety in road traffic. Therefore, it is considered as an area where continuous research should be conducted. This paper discusses the influence that broken regulator of breaking forces has on the stability and steerability of a heavy motor (commercial) vehicle.

Key words: Vehicle braking system; braking forces; adhesion coefficient, regulation and regulators of braking forces, steerability, stability

1. INTRODUCTION AND BACKGROUND

The braking systems of the motor vehicles are complex technical systems the operability and functionality of which greatly influence the overall performances of the vehicle; and most importantly, they are essential for the security and safety of vehicles in traffic.

Besides the full functionality and operability of all its devices and subsystems, in every braking system there is a necessity of efiicient regulation of the braking forces that are conveyed to certain axles of the vehicle. Having in mind the huge number of factors that influence the efficiency of the braking process, the largest number of which are of accidental – stochastic charachter (a stress per vehicle, weather conditions and the condition of road foundation, conditions of adhesion between the wheels and the road foundation, micro and macro relief of the road etc.) it is clear that it is a very complex problem that, besides the great advancement and development of vehicles and their technical systems, it continues to be one of the most frequent causes for traffic accidents.

This study deals with the braking systems of motor vehicles, especially the problem related to the need and the objectives of regulating the braking forces of motor vehicles, and describes the most important segments derived from the experimental tests of the braking system of one sample of the target group of vehicles, that is, heavy motor vehicles with pneumatic gear train mechanism in the braking system (pneumatic brake).

2. THEORETICAL BASIS AND SUBJECT OF EXAMINATION

The basic condition the braking system must fulfill is that in a situation of maximum possible efficiency of braking it does not jeopardize the steerability and stability of movement of the vehicle, i.e. that during the braking the vehicle moves on the track dictated by the driver. This condition could be fulfilled only if the braking does not jeopardize the main function of the wheel - its rolling on the foundation. Having in mind that *the blocked wheel is no longer in condition to provide side reactions to any external distortion,* the vehicle with blocked wheels is instable, and the external distorting forces (side wind, side gradient, centrifugal force, etc) can "throw it out" of the desired track.

The blocking of the braking wheel can be prevented only if the braking force Fk which is conveyed to the circumference of the wheel, in any moment of the braking process, is equal to the maximum possible (border) force of adhesion between the wheel and foundation φ_{max} (which depends on the vertical stress of the wheel G_t, that is, the vertical reaction of the foundation Z_t and on maximum border value of the adhesion coefficient φ_{max}).

The subject of our examination is what happens in case of drastic distortion of conditions of stability during braking, or more precisely, when the wheels on the rear axle of the tractor are blocked in circumstances of articulated vehicle.

The challenge to conduct this research originated from a real traffic situation, more precisely a heavy traffic accident between an articulated vehicle composed of tractor with harnessed semitrailer and a passenger motor vehicle.

It was clear that the interrupted traces of the trailer (Figure 1) originated from blocked wheels, that peridocally, or one large portion of time of the braking process, did not have a contact with the road.

Fig. 1.

Such traces, which are often seen on our roads, were an indicator of defectiveness of the device for regulation of the braking forces of the rear axle wheels of the tractor.

The state of the articulated vehicle after the stop was an indicator that the driver lost his control over it which resulted in heavy traffic accident, as shown in the Figure 2.

For the purposes of our tests, the objective of which was the possible link between the defectiveness of the regulator of the braking forces of the trailer and the catastrophic consequences on the road safety, we used a tractor (tow truck) make "FAP" type "1935" (Figure 3) foreseen to harness semitrailer.

Fig. 2.

Fig. 3.

It was a tow truck with a pneumatic braking system and a mechanical suspension system (steel leaf springs). The regulation of the braking forces on the rear axle of the tractor was carried out with the **device for Automatic Regulation of the Braking Forces on the rear axle wheels depending on the exerted stress (ARBF)**. This device, was attached to the rear axle as shown on Figure 4.

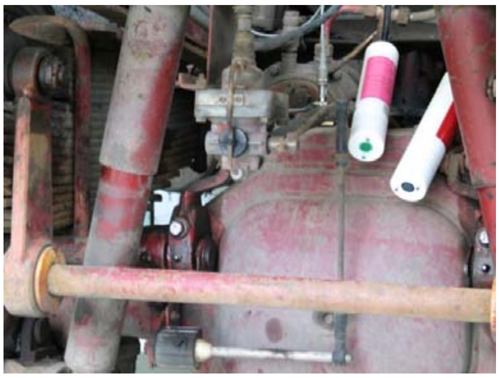


Fig. 4.

For the purpose of the tests we chose a vehicle with these characteristics because of the possibilities to simulate different situations by acting on the rod and thus, influence the braking pressure that was conveyed to the braking cyllindres on the rear axle wheels, in order to conduct the necessary tests.

3. RESEARCH METHODOLOGY

We conducted the tests in order to check the operability and performances of the braking system of the tractor and its device for regulation of the braking forces – ARBF. In that, the tests on output performances of the braking system of the vehicle (the braking forces of the front and rear axle) was conducted on the examination installation with rolls in the laboratory for motor vehicles of the abovementioned institute, while the polygon tests were taken over in order to assess more objectively all important characteristics of the braking system. By that, we mean the behaviour, that is, the stability of the vehicle in the process of braking. For that purpose we installed measuring devices on special positions of the examined vehicle to measure the values of acceleration on the axles of the vehicle. The positions of the measuring devices, as well as the equipment used in these mesurings are shown in the diagram in the Figure 5.

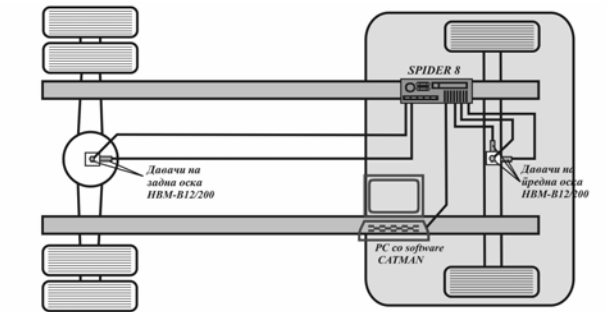


Fig. 5.

The examination of the dynamic characteristics, i.e. the behaviour of the vehicle during the braking process was carried out in two characteristic cases of braking, *braking on a straight road and braking in a curve.* In order to define more clearly and more precisely the role of the ARBF-device, that is, its proper functioning throughout the braking process, during the examination we simulated three different states of the regulator of braking forces that corresponded to different states of stress on the rear axle, such as:

– Existing (neutral) state of the regulator (no intervention on the rod of the regulator,)

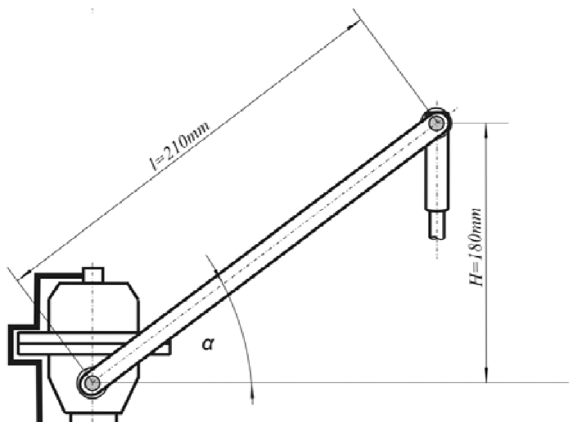
– State in which the rod of the regulator is in end lower position and

– State in which the rod of the ARBF device is in end upper position, which corresponded to the state of the regulator in circumstances of maximum stress on the rear axle of the tractor.

In each of abovementiomed states of the ARBF-device, there was an exchange of the flow of compressed air through the regulator toward the braking cylinders of the brakes on the rear axle wheels, depending on the stress exerted on the axle.

For the needs of this study, as most interesting and most specific, we chose the existing state (unloaded vehicle and with no intervention on the ARBF device) and the state of ARBF device simulating full stress on the rear axle (maximum flow of air) when the vehicle was unloaded (Figure 6 and diagram on the Figure 7).

Fig. 6



$$\alpha = \arcsin\frac{180}{210} \approx 59°$$

Fig. 7.

4. ANALYSIS AND FINDINGS

The first phase of the test dealt with the examination of the performances of the braking system in laboratory. For this condition of the regulator (braking forces) we obtained the following results:

Front axle:

$$F_{kpl} = 15974 \text{ N}, \quad F_{kpd} = 12768 \text{ N},$$

that is, total force

$$F_{kp} = 28742 \text{ N}$$

Rear axle:

$$F_{kzl} = 8689 \text{ N}, \quad F_{kzd} = 6742 \text{ N},$$

that is, total force

$$F_{kz} = 15431 \text{ N}.$$

After we noted proper functioning of the vehicle braking system, that is, satisfactory output performances (working pressure of the air in the system and final product – braking forces on the axles) we made polygon tests, when the braking was straight and when it was in a left curve.

The polygon tests on the behaviour of the vehicle and its stability in the braking process were composed of the following:

– Acceleration of the vehicle up to speed of 30 km/h and then sudden braking on a straight road and

– Acceleration of the vehicle up to speed of 30 km/h and then sudden braking in a left curve.

During these tests, through the accelerators placed on the front and rear bridge in the middle of the vehicle, we obtained information that indicates accelaration and slowdown in different directions, such as: front bridge in a vertical direction as well as lenghtwise and diagonal direction (on *x, y* and *z*-axle) and the rear bridge in vertcal direction and lengthtwise, on *x,* and *z*-axle.

After completing the polygon tests, in state of the regulator when there was production of maximum braking forces on the rear axle (in circumstances of no stress exerted) we witnessed the following:

During the tests of braking on a straight road, we noticed an immediate blocking of the wheels on the rear axle, while the wheels on the front axle were not blocked.

During the tests of braking in a curve, the front and rear axle wheels were blocked and this time we were witnesses of the most unfavourable condition, that is, initial blocking of the wheels of rear before the front axle.

It is interesting that in both cases, the blocked wheels of the rear axle of the trailer left interrupted braking traces that are shown on Figures 8 and 9:

Fig. 8.

Fig. 9.

Having in mind that the initial blocking of the wheels of the rear axle means loss of the stability of the vehicle, it was obvious that it was a question of the most unfavourable case. Especially in the case of an articulated vehicle (tractor+semitrailer).

When we speak of a combination of a tow truck and a semitrailer, the negative effects of the blocking of the braking wheels on certain axles (especilally on the rear) are more complicated.

In case of blocking of the rear – motive axle of the tractor, besides the side distorting forces that could not accept blocked rear wheels, the charge of the semi-trailer had decisive and dramatic influence. As a result of the charge of the mass of the semi-trailer, there was a break off of the pulling train in the joint connection (case 3 in a diagram in the Figure 10), which lead to irretrivable loss of control over the articulated vehicle and its stability, having in mind that the driver was not able to react fast enough in order to regain control and thus, the stability of the articulated vehicle.

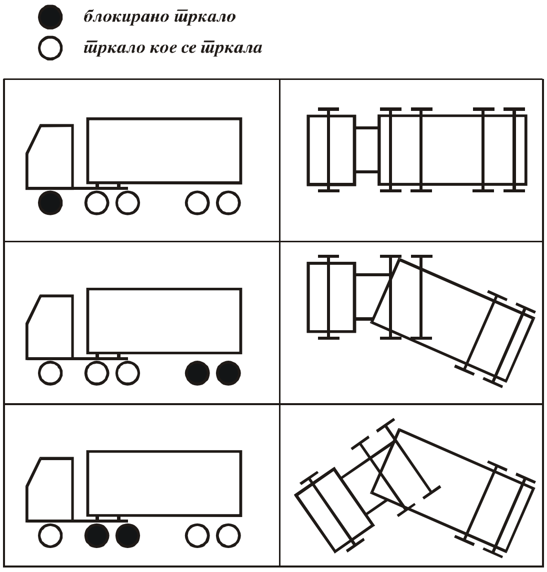


Fig. 10.

Especially interesting is the analysis of the interrupted traces of braking made by the blocked wheels on the rear axle, or more precisely, their origin. We will try to explain this through the Figure 11.

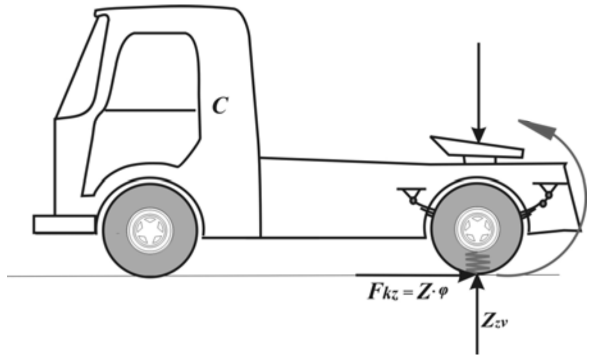


Fig. 11.

In a circumstance of defective regulator of the braking forces (with blocking of the rod of the ARBF-device in the end upper position we simulated defectiveness of the regulator), that is, its blocking in the position in which the pressure of the braking fluid towards the braking cylinders of the brakes on the rear axle wheels is maximum, on the circumference of the braking wheels of the rear axle maximum of braking forces will be exerted. In regard to the unburdened rear axle, this happens when the vertical reaction on the rear axle is minimum **“Zz”.**

In case of such extremely large braking forces on the rear wheels of the tractor, there is a torque (diagram in the Figure 11) that influences the suspension system, thus deforming (compressing) the leaf springs. When these braking forces reach certain maximum value F_{kz} (having in mind the interdependence of the curves of adhesion from gliding $\varphi = f(\lambda)$) shown in the diagram on the Figure 12, that is, after reaching the maximum value of adhesion, $\varphi_{\max}$ the same starts to decline while the gliding simultaneously increases, which results in decline of the forces F_{kz}**.** As a result, the torque that act on the strings decline, which leads to their discharge, repeated intensive contact between the wheels and the foundation (increase of the vertical reaction **“Zz”)** and hence to repeated increase of the values of forces F_{kz}. Thus, a periodical "leap" of the rear axle of the tractor takes place, which results in such interrupted traces of braking of the blocking rear wheels (Figures 8 and 9).

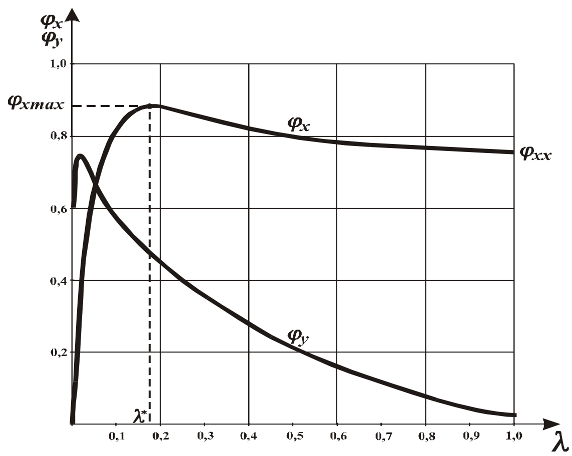


Fig. 12.

The inability of the blocked wheels of the rear axle to counter the smallest side distorting force (such as centrifugal force during movement – braking in a curve), causes slip of the wheels of the rear axle, and of the rear part of the vehicle from the desired direction.

As we can see in the Figure 8 and in the diagram on the Figure 13, the rear axle of the tractor slipped from the desired track of movement of the vehicle to the right, that is, to the outer side of the curve. In Figure 8 we can also see the continous braking traces that derived from the wheels on the front axle as well as the interrupted braking traces from the wheels on the rear axle. By comparing the traces, that is, their length we noticed the following: While the braking traces from the front wheels followed the track of movement in the left curve, the traces of the rear wheels were "straighten" in regard to the curve as a result of the slip of the rear part of the tractor toward right (to the outer side of the left curve).

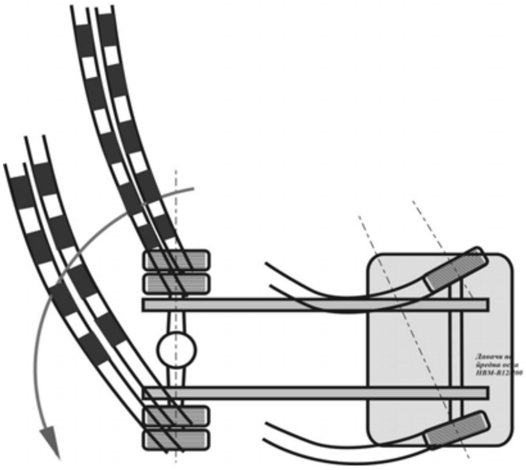


Fig. 13.

As far as the results of the measuring of acceleration of the axles of the tow truck in proper directions, are concerned, (front axle: length wise, diagonal and vertical, rear axle: length-wise and vertical), it is most favourable when the analyses are made by comparing same dimensions measured during tests in different simulated conditions of the ARBF device.

It can be concluded that the increase of values of the vertical acceleration on the rear axle (that exceed 20 m.s^2) were result of the abovementioned "leap" of the discharged rear axle when the braking wheels were completely blocked. This can be seen from a comparative description of the separated diagrams of the vertical accelerations of the rear axle of the tow truck, for two different states of the ARBF device – neutral state (upper diagram) and the state of ARBF device which enabled maximum braking force on the wheels of the rear axle of the trailer (lower diagram). Hence, Figure 14 shows the comparative diagrams of braking in a straight road, while Figure 15 shows braking in a curve.

In addition it has to be mentioned that, in both cases, the upper diagram refers to a neutral position of an automatic regulation of the braking forces device, whereas the lower diagram shows the values of acceleration in a case of the third position of the automatic regulation of the braking forces device, practically simulated its incorrectness.

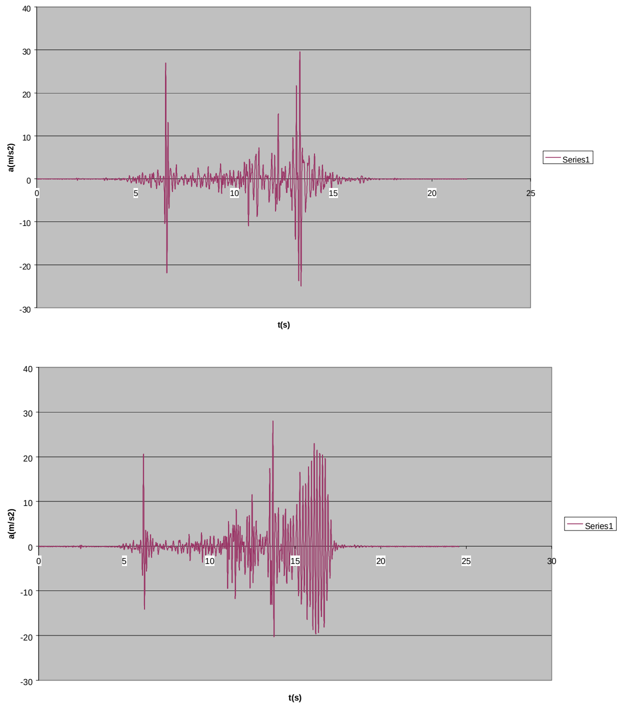


Fig. 14.

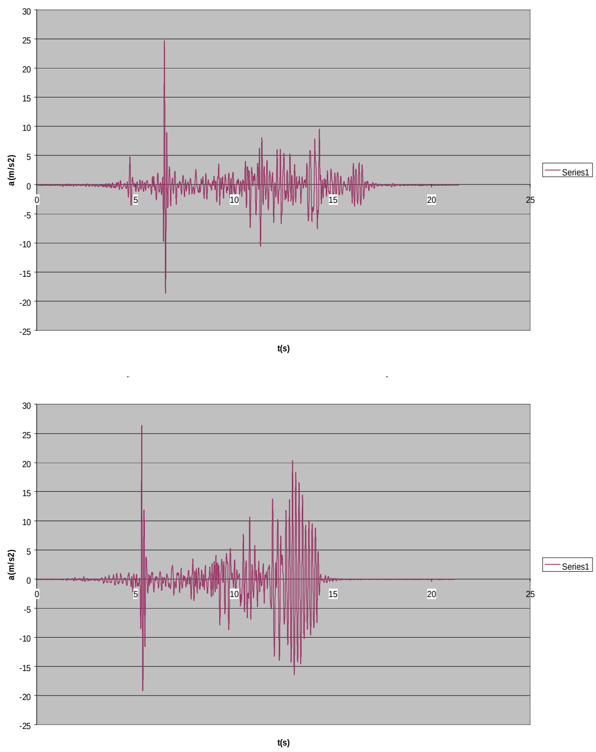


Fig. 15.

5. CONCLUSION

The results obtained by research of the breking system, the behaviour of the vehicle during the process of breking and their comparison to the traffic accident we were studying (Figure 1 and 2), clearly implicated the following:

Characteristic traces of blocked brake wheels of the tested vehicle (Figure 8 and 9), in comparison to those from the articulated vehicle (at traffic accident) refer to a very similar situation and thus to the source of unstable behaviour of the articulated vehicle.

The rear-axle of a tractor (considering the harness empty semi-trailer) was unloaded. On the other hand, in such conditions the ARBF device enabled the flow of a big pressure towards brake cylinders of the rear-axle wheels. Considering the size of a vertical reaction (“**Zz**”), brake forces produced along the perimeter of the rear-axle wheels, were bigger than the moment values of a maximum (border) forces of adhesion $X_{\max} = Z \cdot \phi$ that lead to their instant blockade.

Further on, this blockade was followed by a so-called mechanism of "leap" of the rear axle (simulated in our examination) resulted with interruption of the traces.

At the same time (Figure 1) the articulated vehicle moved on a left curve and side distorting - centrifugal force acted on it, which could not be balanced with appropriate reactions on the blocked wheels of the axle of the tractor.

In a view of the above the conclusion becomes quite observable and evident: Inaccurate ARSK device, during the process of braking, can cause a serious and irretrievable destabilisation of a vehicle, leading to catastrophic consequences against traffic safety.

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Р е з и м е

НЕОПХОДНОСТ ОД РЕГУЛИРАЊЕ НА СИЛАТА НА КОЧЕЊЕ ВО СИСТЕМИТЕ ЗА КОЧЕЊЕ КАЈ ПАТНИТЕ МОТОРНИ ВОЗИЛА

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Клучни зборови: систем за кочење кај моторни возила; сили на кочење; коефициент на прилепување; регулација и регулатори на кочните сили; управливост; стабилност.

Системите за кочење кај патните моторни возила се премногу значајни и одговорни за активната безбедност на возилата кои се учесници во патниот сообраќај Како такви, тие се чести причинители за настанување на сообраќајни незгоди. Состојбата на регулаторите на кочните сили во системите за кочење кај возилата има огромно влијание врз активната безбедност во патниот сообраќај. Поради тоа, проценка е дека тоа е област во која постојано треба да се вршат истражувања. Предмет на истражување во рамките на овој труд е влијанието кое неисправен регулатор на кочни сили го има врз стабилноста и управливоста на тешко моторно - комерцијално возило, поточно тегнач за полуприколка.

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Original scientific paper

TECHNICAL ASPECTS OF THE IDENTIFICATION OF MOTOR VEHICLES AND RESTITUTION OF REMOVED NUMBERS

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A b s t r a c t: Identification of motor vehicles is one of the most interesting, but an incredibly complex area.The number of cases of uncovering the originally imprinted number (previously removed and changed) and uncovering the original identity of vehicles is quiet immense. Considering those information as quite appalling and motivating, this paperwork treats closely those problems revealing some basic elements, several methods and procedures in order to give a short review of this area. Its intention is to give a closer approach towards a science and expert public community, since this complex area, although originates from them, still remains captured in certain strict and severe procedures of a state establishment.

Key words: Vehicle identification number (VIN); identification-type plate; deformation of the crystal grids; restitution; provoked contours of the removed number; welded joints

1. INTRODUCTION

The procedures applied in the process of identification of motor vehicles for the purpose of restitution of the imprinted, then removed numbers from metal surfaces, are as a rule, used in forensic examinations in the laboratories of institutions dealing with fight against crime (or institutions that are functionally or in any other way related to them).

Although this is so, from a technical aspect, the process of restitution of imprinted numbers is also interesting from a scientific point of view. It is known that forensics, which can be defined as a science of providing evidence, consists of many scientific disciplines, including the technical sciences.

Within the procedure for complete identification of the motor vehicles, from a technical point of view, especially interesting is the mechanism for restitution - provoking the visible contours from the removed numbers that were imprinted on the metal surfaces. In other words, besides the review on the identification of the vehicles in general, it is interesting to define what happens in the structure of the material itself, which actually provokes the contours of the elements that were previously removed by mechanical means (scrapping) to be visible again.

The author of this study, during his many years of experience as an expert for identification of motor vehicles, was countless times engaged in problems related to identification of motor vehicles of suspicious origin. It also involves restitution as a procedure, having in mind that identification numbers of these vehicles in great number of cases were changed by mechanical means. Of course, the purpose of these changes was to change the identity of the car, that is, to conceal its true (original) identity.

The identity of each vehicle is determined by the vehicle identification number (VIN), which is imprinted (or in recent years engraved) by the producer during the production process. The identification number of all passengers and commercial vehicles made more recently (more precisely made after 1981), consists of seventeen elements (combination of numbers and letters), and represents one and only bearer of the identity of the vehicle, by which the factory that produced the vehicle should be able to recognise it even after thirty years. All the elements in the positions of the identification number have their meaning, i.e. they include the characteristics and the identity of the vehicle. The same identification number that is imprinted on the certain position, almost always is also evident on a suitable identification plate that is embedded or fastened to certain positions of the metalwork of the car.

Therefore, with the change of the identification number of the vehicle (even with the change of only one of its seventeen elements), the identity of the vehicle is changed. The change of the imprinted identification number may be accompanied by removal or/and modification (forging) of the identification plate, or some other identification characteristics by which the vehicle can be identified.

2. WAYS OF CHANGING THE IDENTIFICATION NUMBERS OF THE MOTOR VEHICLES

Depending on the make and type, on the vehicles constructed with self-supporting constructions, the imprinted (engraved) identification number may be found on several positions envisaged by the producers. In cases of some vehicles, the numbers are positioned on certain places inside the engine, on others inside the passengers' cabin, but there are also models where the identification numbers are imprinted in the trunk. In the vehicles that are constructed on classic frame supporting constructions (chassis), usually the identification numbers are imprinted on one of the supporters of the chassis.

The Figure 1 shows an example of identification number of passenger car "Mercedes" type "E220", that is imprinted on the floor of the passenger cabin, while the Figure 2 shows accompanying identification plate embedded on the same vehicle.

Fig. 1: VIN number of the vehicle Mercedes type E220

Fig. 2. Identification plate on the vehicle Mercedes type E220

In the vehicle (Sport Utility Vehicle) of the type Mercedes ML with a construction of the frame supporting construction (chassis) the identification number is imprinted on the right lengthwise supporter of the chassis.

Examples of the imprinted identification number as well as the identification plate of this type of vehicle are shown on Figures 3 and 4.

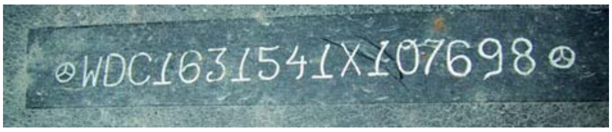

Fig. 3. VIN number of vehicle (SUV) Mercedes type ML

Fig. 4. Identification plate on the SUV vehicle Mercedes type ML

There are several basic ways of changing (forging) the identification numbers, that is, changing the identity of the vehicles:

1) Full (or partial) removal of the imprinted number by scrapping the metal and additional impressing of other number (or elements of the number).

2)The removal of the originally imprinted number by cutting off a piece of the metalwork on which it is imprinted, and additional inserting and welding of another piece with originally imprinted number.

3) Change of only some of the elements of the originally imprinted number, and

4) Welding of a piece with originally imprinted number (without previously removing the existing original number).

Further in the text, we will briefly review individually each of the abovementioned methods of changing the identification numbers of the vehicles. To illustrate the methods better, examples from the practice will be given.

2.1. Removal of the identification number by scrapping and impressing of other number

In the factories during the process of imprinting the identification number of the vehicles (in most cases done by press), under the influence of the mechanical force, the elements (borderlines, numbers and letters) composing the number are imprinted on the envisaged position.

During the mechanical scrapping with a purpose of removing the imprinted identification number (or some part of it), the layer of the removed material must be as thin as possible (in order to remove the visible signs).

Otherwise, the removal of a thick layer of the material, would distort the configuration of the foundation on which the number is imprinted, i.e. it would be visible that in the part of the imprinted number some additional mechanical intervention was made, of course, on a place where it should not have been done.

After removal of the identification number by using this method, on the processed foundation with appropriate imprinters new marks are imprinted, which, understandably, by their characteristics (dimensions and form) must be as close as possible to the removed elements. These are the marks that carry the changed identity of the vehicle. By painting the foundation, after the additional treatment with colour, that of course, must completely match the colour of the rest of the metalwork of the vehicle, as well as with the removal and change of the identification plate, it seems that forces change of the identity is completed.

2.1.1. Provoking visible contours of the removed part

As a result of the mechanical force, used to imprint the elements of the identification number into the metal, besides the visible impressed elements on the surface of the metal, the "information" about the imprinting, in a form of the change of the metal structure (that is, change - deformation of the crystal grids) is conveyed deeper to the lower layers of the metal. Or in other words, on the place where the imprinting happened, the structure of the metal is changed (deformed) more deeply.

The in-depth transfer of the information from the imprint as well as the change of the structure of the material is shown in the Figures 5 and 6.

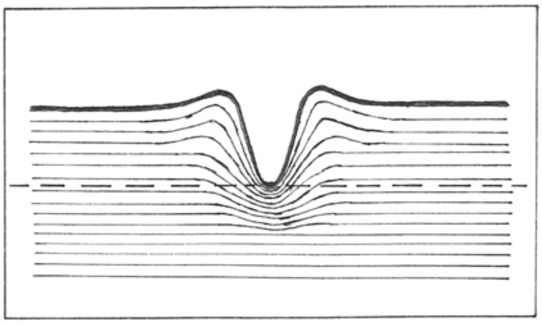

Fig. 5. In-depth transfer of the information from the imprint

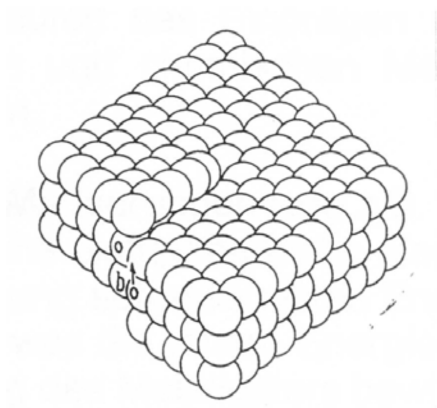

Fig. 6. Deformed crystalgrid

This layer, which has experienced deep transformation of the structure, that is, its crystal gird, gives an opportunity for appropriate treatment of the foundation in order to restitute the elements of the removed number, i.e. to recover its visibility.

There are two methods to achieve this:

– *Use of chemical reagent for restitution of the removed numbers*: After the technical preparation and polishing of the foundation from which the imprinted numbers have been removed, the foundation is treated with certain chemical reagents.

– *Thermal treatment*: After the technical preparation and polishing the foundation from which the imprinted numbers have been removed, the foundation is first warmed up to certain degree and then suddenly cooled off.

Having in mind the necessary equipment, and the difficulties when the second method is used (need of more specific equipment, greater destructiveness and danger of damaging and even burning of inflammable materials around the place of treatment), the most used method in practice is the restitution of removed numbers with chemical reagents. The thermal treatment is used in exceptional cases, that is, only when certain conditions are met and there is no danger of additional damages.

In any case, both methods cause the same effect, and that is:

– Provoking different reaction on the spots on which the structure of the metal is in different tensional state (in accordance with the abovementioned in-depth changes of the structure of the metal on the spots where the mechanical strength acts during imprint).

This shows that when the material that is removed by scrapping is thick, the deformations on the metal structures are smaller and all this diminishes the possibility to regain the visibility of the contours of the removed elements of the identification number.

The provoking of the contours of the removed originally imprinted identification numbers with a certain technical and chemical treatment can be seen in the practical examples given further in the text.

In the processing of the identification number on the chassis of the Sport Utility Vehicle make Mercedes ML (whose imprinted number of the chassis was shown in picture 3), the changes of the identification number are noticed in its serial part. On the twelfth position of the number, at the additionally imprinted element ***1,*** from the contour obtained by restitution it is obvious that the removed element is ***7*** (Figures 7 and 8).

Another characteristic example of the restitution of the removal of the originally imprinted identification number is the following example of treatment, made on the identification number of PMV Mercedes E 270 CDI. In the case of this vehicle, there was a complete removal of the original identification number, i.e. all of the seventeen elements of the identification number were removed and new ones were imprinted in their place. The existing identification number of the vehicle before the detailed treatment was **WDB2110161A014358** (Fig. 9), and after the procedure for restitution of removed numbers, the contours were obtained of the original (removed) number

WDB2110161A003711 (Figures 10 and 11).

Fig. 7

Fig. 8

Fig. 9 The existing identification number of the vehicle Mercedes E 270 CD

Fig. 10. VIN after restitution

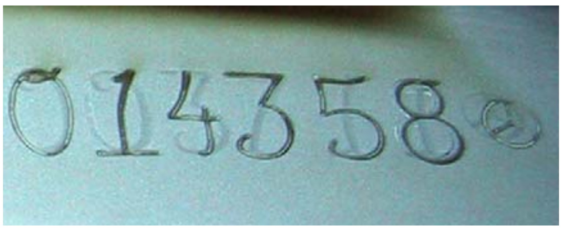

Fig. 11. Obtained contours of the original (removed) serial part of the VIN

2.2. Change of the identification number by cutting off a piece

As mentioned before, it is not a small number of cases when the change of the identity of the vehicle. i.e. of the identification number is done by cutting off a piece of metal on which the original identification number is imprinted and after that a piece with the same dimensions is inserted and welded, from a same make and type of vehicle, and in most cases, a piece with originally imprinted number. In this case, with an additional mechanical treatment the welded joint is well conceived in order to make it impossible to be discovered.

In the following example of imprinted vehicle identification number of PMV Opel Vectra (Fig. 12), after the treatment exactly such case was discovered. The closed contour of the welded joint (Fig. 13) shows that the existing identification number **W0L000036T1094445** is placed on a piece that has been additionally inserted and welded after the removal of the originally imprinted number.

Fig. 12. VIN number of the vehicle Opel Vectra

Fig 13. Closed contour of the welded joint around the VIN number

In some cases, the reagent for restitution of the removed numbers can also be used to find out well hidden contour of the welded joint (Fig. 14).

What is characteristic about these cases (at least most of them) is that the identification number itself, i.e. its features (form, dimensions of the elements, method of imprinting) completely match those imprinted in the factory (meaning they are originally made). In such cases, having in mind the inability to retrieve the removed original identification number, other, alternative possibilities for identification that are offered by every producer, must be applied (identification numbers on certain structures, production number, hidden, secret labels with identification characteristics, etc).

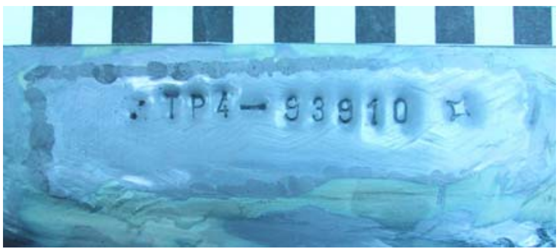

Fig. 14. Closed contour of welded joint around the VIN number

2.3. Change of the identification number by altering some of the elements of the number

Sometimes in practice there are cases when the change of the identity of the vehicle is forcibly done with the individual change of only one or two of the existing elements of the originally imprinted identification number. Usually in order to make the recognition of the changes less possible, the existing elements (numbers and letters) are altered into elements with a similar form.

For example: **3** and **8, 5** and **6, B** and **E, E** and **F**, etc.

Hence, the most part of the identification number remains in iits original (factory) shape, and this of course makes it difficult to determine the change of the identity of the vehicle.

Such an example can be seen on Figures 15 and 16. In this concrete case there has been a change of the original element **3** into the existing element **8**.

2.4. Additional insertion of a piece with imprinted number (without previously removing the existing original number)

At the end of this part, in which we gave a short review of the possible methods of change of the original identification numbers of the motor vehicles, it should be mentioned that there are also cases where simple welding, sticking (or other way of fixing) of metal piece with the imprinted number, without even removing the original identification number.

Fig. 15. The serial part of VIN number

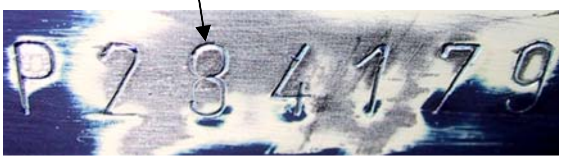

Fig. 16. Original element 3 under the existing element 8

Namely, the existing identification number **WVWZZZ3ZYP297774** of the PMV Volkswagen type Passat (Fig. 17) is imprinted on a metal plate that has been additionally inserted and fixed (attached) on the position of the originally imprinted identification number.

Fig. 17. VIN number of vehicle VW Passat

The additionally inserted plate, together with the unremoved originally imprinted identification number, are shown on Figure 18.

Fig. 18. Originally printed VIN number together with additionally inserted plate

3. CONCLUSIONS

From the many years' practice in the field of identification of motor vehicles, we can say that of all the methods for changing the identification numbers that were elaborated earlier in the text, the most common one is the method of mechanical removal (scrapping) of the originally imprinted number, that should bear the changed identity of the vehicle.

However, having in mind the skilfulness which is applied in making those amendments of the identification numbers, in most cases the technical treatment and restitution prove successful and they result in determining the removed – original number; however we have to say that this method (which is most widely used in our country) has certain shortcomings.

Considering the technical treatment of the foundation which should reveal the contours of the elements of the removed number, such as removal of the colour, scrapping and the treatment with the chemical reagent (with abrasive characteristics), it is a question of a destructive method which leads to lasting damaging of the metal foundation. Therefore, in order to overcome such a situation, in the process of restitution of the removed numbers, all over the world, new methods and techniques are being developed for improvement of the expert opinion.

One such a technical device produced by the company "Regula" LTD is the set for identification of the identity numbers of the motor vehicles applying the method for magnetic and optical visualization. The manufacturer of this device, "Regula" LTD, is a scientific and industrial company, seated in Minsk, Belarus, formed in 1992 by a group of engineers from the Belarusian State Polytechnic University.

The method of examination of this device (as shown on the Figure 19) is completely non-destructive, that is, it does not cause any damage on the examined vehicle.

Fig. 19. Regula LTD

Besides the possibility for restitution, this technical device contains a complete laboratory for examining disputable documents and other security papers, new generation of passport readers, etc. This device is designed for examination of motor vehicles for the following purposes:

– Identification of the auhtencity (genuineness) of the identification number,

– Restitution of the original numbers in case they are damaged (unrecognisable) due to corrosion, layer of gloss, paint over the number, etc.,

– Restitution of the original numbers in case it is determined that they have been changed (forged),

Determining the technology used in changing the identification numbers.

The identification of the motor vehicles as a whole, including the procedure for restitution of the imprinted (then removed) numbers, still represents a very complex problem that requires both experience and knowledge. As described in this short text and in the examples, having in mind the destructiveness of the abovementioned methods, this experience is decisive first of all in the phase when it needs to be determined whether there are enough indicators that such a treatment should be applied on the identification number, and thus to cause inevitable damages.

It is not a small number of cases when, apart from the appropriate and detailed treatment of the position, we did not succeed in restitution of the removed numbers, although we were certain that the number was changed. In such cases the knowledge and experience come forward, and the concentration is focused on series of other parameters that could additionally help in the decision whether the vehicle has its original identity or not and then to begin to determine its genuine identity.

The producers themselves adopt procedures that assist the experts in their efforts to identify the motor vehicles.

Consequently, some producers imprint the identification number on several positions (some VOLKSWAGEN models already have two imprinted numbers).Some producers offer the possibility to read the identification number of the vehicle directly from the display of the instrument panel. Many producers, besides the imprinted identification number and identification plate (that must be accessible for control) have other "hidden" identification characteristics that serve as a base to identify the vehicle (and which, of course, are available only for the experts that deal with the problem of vehicle identification).

However, as a general conclusion from a many years' experience in identification of the motor vehicles, the following can be said: if the change has been made in the identification number of the vehicle regardless of the method applied, the detailed and thorough treatment must result in revealing the changes. This is because there is no technical treatment that would result in "ideal" retrieval of the treated surface in its original state. The only question that remains is whether we should be able to find out the removed VIN number of the vehicle in order to determine it's originally identity.

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Р е з и м е

ТЕНХИЧКИ АСПЕКТИ ОД ИДЕНТИФИКАЦИЈА НА МОТОРНИТЕ ВОЗИЛА И РЕСТИТУЦИЈА НА ОТСТРАНЕТИ БРОЕВИ

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Клучни зборови: Идентификационен број (ВИН) кај моторни возила, идентификациона - типска плочка, деформација на кристална ре{етка, реституција, добиени контури од отстранет број, заварени споеви.

Во овој труд се дискутира за основите на процедурите и постапките кои се превземаат при проверка, односно утврдување на оригиналниот идентитет кај моторните возила. Ова е експертски труд кој произлегува од долгогодишното работно искуство во оваа област, со огромен број изработени предмети и исто толку утврдени идентитети на моторни возила чие потекло било сомнително. Во трудот е направен осврт за можните и најчести начини за промена на идентификационите броеви и прикривање и промена на оригиналниот идентитет кај моторните возила, што е поткрепено и со неколку практични примери.

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IMPLEMENTATION OF KaLeP EDUCATIONAL MODEL IN INTEGRATED PRODUCT DEVELOPMENT

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A b s t r a c t: **Product development is a complex and important phase of an overall creative chain of new product development. University education has big problems in making quality personnel who will give solutions to all challenges meet in the practice. Industry will confront more and more with the absence of quality personnel and will require from the university to educate personnel who will be able to respond to the today and future challenges.**

In order to improve this situation for young engineers who work in the companies, it is required for engineering education to improve the key qualification during studies.

In the framework of the KaLeP (the Karlsruhe education model for product development) educational model and its use in the higher education, an example of implementation of the integrated product development (IP) at the Faculty of Mechanical Engineering in Nis is presented it's achieved through the training of young engineers to implement KaLeP for product development in regional industries.

Key words: KaLeP educational model; product development

1. INTRODUCTION

He base of the KaLeP educational model is product development understanding. Product development is a process oriented towards integrated planning and prototype realization of new technical solution: it begins from assessment of the product profile, concept development and design of the technical system, and continues with the building of prototype and assessment of its validity during the testing. Art and science of product development introduce methods, processes, management, design of elements and subassemblies, with aim to create new technical solution. Product development is absolutely one of the most important fields of initiative and innovation performances which elevate to a successful company. The engineers must have high knowledge for processes, communication ability and high potential for ideas realization. The factor of success is not the methodology, management or information technology, but just the human idea of an individual in the team. Markets require increasing of engineer innovation performances and human idea which will be in the center of product development [1].

The engineers have to be team players, to be skillful in the technique with their knowledge, able in the business management, have to be prompt for bringing decisions and their implementation. Considering these problems A. Albers [1,5,6] from the university in Karlsruhe, Institute for Product Development (IPEK) in 1999 developed the KaLeP educational model.

2. KALEP EDUCATIONAL MODEL FOR PRODUCT DEVELOPMENT

The aim of the KaLeP educational model is to introduce occupants in product development in the engineering education. The KaLeP model comprises three approaches in giving knowledge in practical form: through lectures, practice/workshops and project work. These three approaches allow effective learning of theoretical problems through lectures, demonstration of their application through examples and practical work in workshops and intensive practice at realistic work environment (project work). Figure 1 shows these three approaches for gaining knowledge [1].

THE KARLSRUHE EDUCATION MODEL KaLeP		
Education	Environment	Key qualification
Lecture **Exercise course** Project work	**Creation of realistic Environment**	**Integrated Project work**

Fig 1. Three approaches of KaLeP [1]

KaLeP has three educational phases in training engineers. The first phase starts in the second semester in courses "Mechanical Engineering 1, 2, 3", the second phase begins in the sixth semester in the course: "Methods for Product Design" and the third and last phase with a goal for student specialization for the product design is in the course: Product Integration Development in the ninth semester. The three educational phases are characterized with their focus on important fields in product development with specific knowledge in: system, method and processes (Fig. 2) [1].

The core of the KaLeP model is the main course "Integrated Product Development", e.g. the third educational phase from engineering education. In the period of four months, 25 students in four teams realize independently product development. With use of literature, with help of the lectures, with direct contribution of specialized personnel from the industry and workshops the students develop a product for a company.

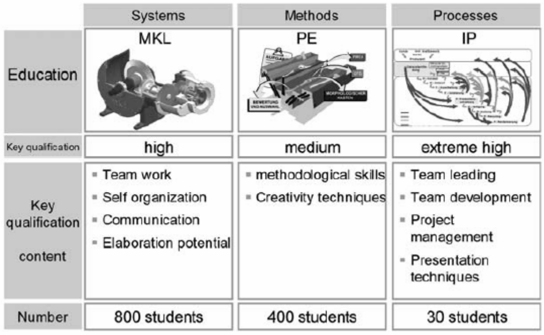


Fig. 2. Three elements of education: system, methods and process [1]

In Figure 3 a flowchart of organization of teams and their ambience is shown.

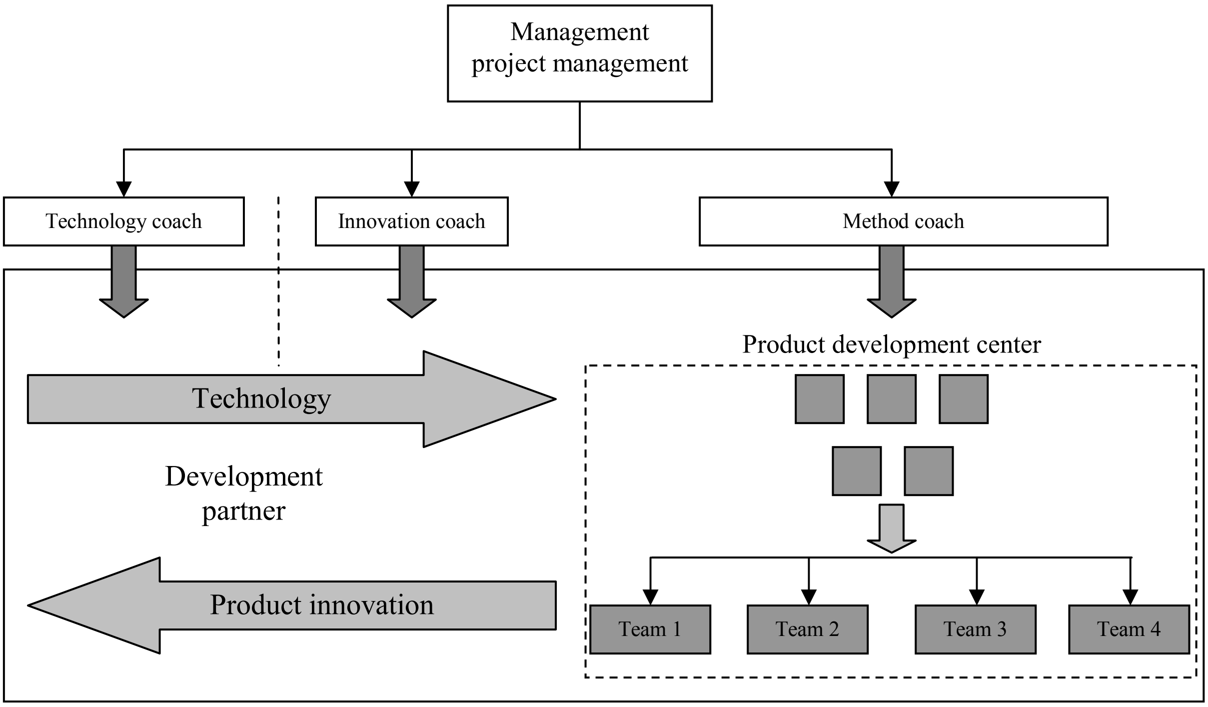


Fig 3. IP – Structure of the project [1]

Lectures for IP are oriented towards a specific goal, to help the students understand the theoretical procedures of the development process. In addition to the lectures, an important stage is the practical work, workshops and the continuous contact with the company for which the product is being developed. The acquired knowledge from the lectures, practical methods and from the workshops, are better applied in product development to be realized [1].

3. APPLICATION OF THE KALEP MODEL IN EDUCATIONAL PROCESS OF THE FACULTY OF MECHANICAL ENGINEERING IN NIS

At the beginning of the project in collaboration with a company the project task was defined and students were separated in four teams. On the base from results from testing, teams were composed. The testing was at the project beginning. Each team had equipment with computers for all team members. The teams had access to all information resources of the Center for Product Development at the Faculty of Mechanical Engineering in Nis.

Four student teams developed a project with the help of the professors, industry professionals and the results from the project were presented to the project partner and the company management on dates specified for presentations.

During the project, three presentations and one final presentation were realized (see Figure 4).

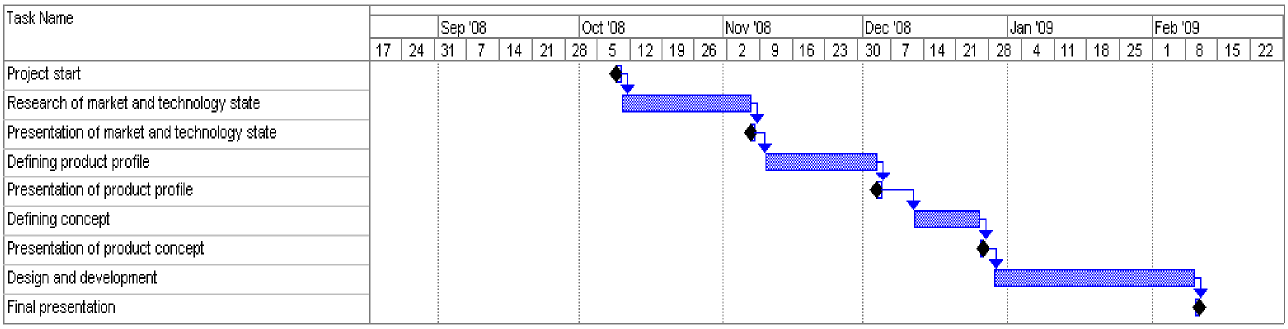


Fig 4. Project plan

The first phase from the project was research of the market situation and the available technology which resulted in the first presentation of situation on the market and current situation. The second phase of the project was defining product profiles. The third phase of the project was developing product concepts. The last phase was completely product development. The teams had different tasks for product development, two teams developed such as a products: two-stage pipe turbine and a solar tower, for the company Amiga Kraljevo, and two teams developed products: such as an automatic machine for armature bending and cutting and an automatic machine for armature straightening and cutting, for the company Profit Nis.

At the beginning of the project, the project tasks were defined in corporation with two companies interested in development of specific products and the students were separated in four teams. The teams were formed based on the results of testing organized at the beginning of the project.

4. INTEGRATED PRODUCT DEVELOPMENT

Integrated product development (IP) can be defined in the following way: IP is a systematic approach in development of high quality, market competing, efficient products or services across integrate application of overall and multidisciplinary methods, processes and organization forms, as well as manually and computer promote tools, with minimum but enduringly useful production factors and resources [2].

IP comprises fields of product development process, from product life cycle, way of thinking and work with people, team work, overall organization methods, innovation technology, also varicose shape of communication and information. IP comprises many steps from idea and identification of market requirements to making and product launch on the market [2].

As shown on the figure 5, IP consists of the following phases: start of project, determination of product profiles, development of concepts, detail of product development and prototype realization for the project task.

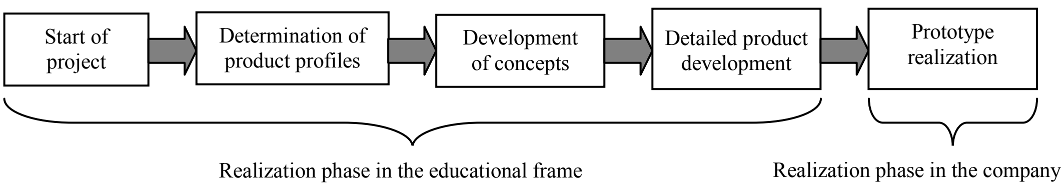


Fig 5. Phases in IP

4.1. Project task definition and project start

Armature production and sale which used in the construction is in slight increase everyday. The market requirements for large quantities of armature provoked the requirement to develop a new and totally automatic machine for big production.

The task is defined directly from the requirements of the company Profit Nis and its strategy for further development of the company in the construction field, e.g. production of short armature bended forms, long armature bended forms and straight armature.

4.2. Research of the current situation on the market

With aim to estimate objectively the market situation, two researches were conducted from the aspect of:

– products which are made on the automatic machine

– technological solutions that exist today

To define the capacity of the automatic machine we had to determine the consumption of short armature frames in the region. For that aim we made three questionaires:

– questionnaire for the storehouses that sell armature,

– questionnaire for the Chamber of Commerce,

– questionnaire for the construction institute of R. Serbia.

The results gathered with these three different methods were very similar, what give us confirmation that the results are realistic (see Figure 6).

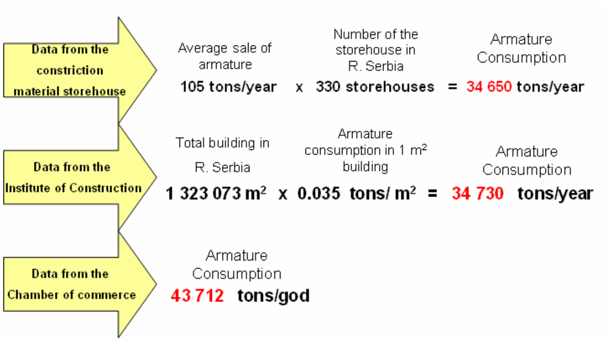


Fig. 6. The quantities of armature consumption got from the questionnaires base

From realized questionry, we established that 20 % from armature to sell in straighten form and 80 % to sell in bend form in each shape such as short bended forms and other warped shapes.

From the data collected with the market research the armature consumption distribution for R. Serbia for 2007 and the Nis region for 2007 is made as shown in the figures 7 and 8.

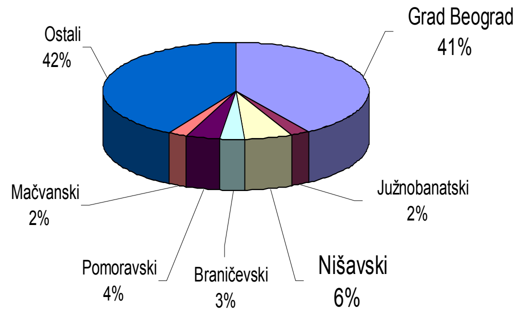


Fig 7. Assessment of armature consumption for the R. Serbia for 2007

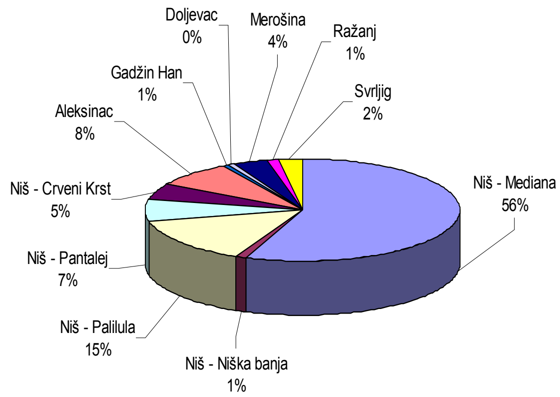


Fig. 8. Assessment of armature consumption for the Nis region for 2007

With results of the market research we were able to find the distribution of the existing mechanization that exist at the warehouses in R. Serbia which are used for armature production. The assessment is shown in Figure 9.

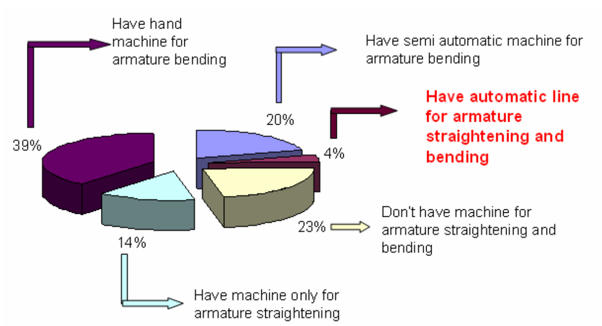


Fig. 9. Assessment of the distribution of different types of mechanization available at warehouses in R. Serbia

The market research of the existing technical solution helped to determine some features of the existing machines that is not adequate in correlation with the demands on this market. The existing machines are mainly expensive, have big machine universality which means making of bend form in different shapes and underused possibilities of the machine, for machine control high specialized personnel, is needed the machine has a waste etc.

The results from the market research and analysis of the company give the following conclusions:

– the automatic machines on the market are much expensive,

– the machinery on the market has high universality,

– most of the time is spent for production of short rectangle forms,

– dominant product of the market is short bend armature forms,

– specialized machines for production of short rectangle forms do not exist in the region,

– capacity of specialized machine needs to be 1.3 tons/day to satisfy the Nis region,

– in correlation with company management we decided to use the existing machine for armature straightening,

– we can make the line system from the existing armature straightening, the new cutting machine and the bending machine.

4.3. Definition of the product profile and selection of the product profile

The company Profit Nis has machines for bar armature straightening and also has two manual machines for armature bending. We will make five profiles from the existing machines and additional new machines. We know that the company task is production of short armature bended forms, long armature bended forms and straight armature.

On the base of the market analysis five product profiles were determined.. The profiles are the following:

Product profile 1:

– Develop a new system which is composed from the machine for bar and rebar armature straightening and the machine for bending of short forms. The system has line processing. It is shown on the first flowchart in figure 10.

– Two existing manual bending machines to be used for bending of long bend forms. It is shown on the second flowchart in Figure 10.

– The existing machine for straightening will be used only for bar straightening. It is shown on the third flowchart in Figure 10.

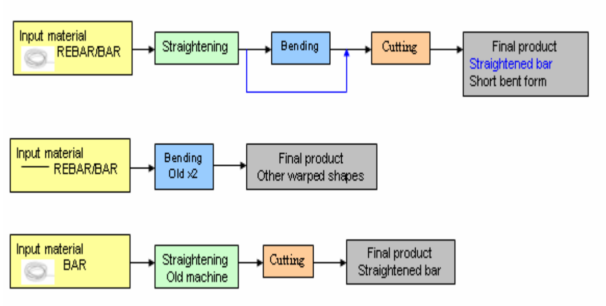


Fig 10. Product profile 1

Product profile 2:

– Develop a new system which is composed from the machine for bar and rebar armature straightening and the machine for bending of short forms. The system has line processing. It is shown on the first flowchart in Figure 11.

– From two existing manual bending machines we will make a machine only for long bend forms. It is shown on the second flowchart in Figure 11.

– The existing machine for straightening will be used only for bar straightening. It is shown on the third flowchart in Figure 11.

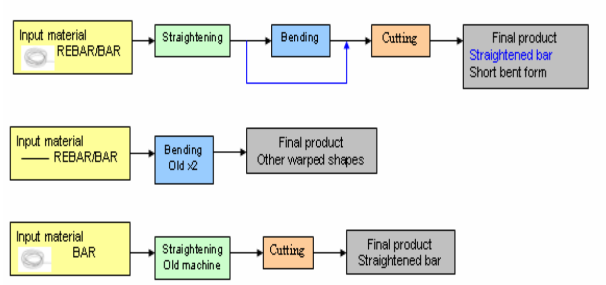


Fig. 11. Product profile 2

Product profile 3:

– Develop a highly productive automatic machine for straightening, bending and cutting of bar and rebar armature for all armature shapes. It is shown on the first flowchart in Figure 12.

– The existing machine for straightening will be used only for bar straightening. It is shown on the second flowchart in Figure 12.

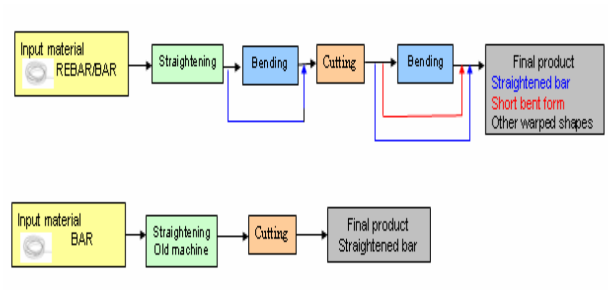


Fig. 12. Product profile 3

Product profile 4:

– Develop a highly productive automatic machine for straightening, bending and cutting of bar and rebar armature only for long bend forms. It is shown on the first flowchart in Figure 13.

– Using of the existing straightening machine and two manual bending machines for short bent forms. It is shown on the second flowchart in Figure 13.

– Develop a new machine only for bending of short bent forms with small capacity. It is shown on the third flowchart in Figure 13.

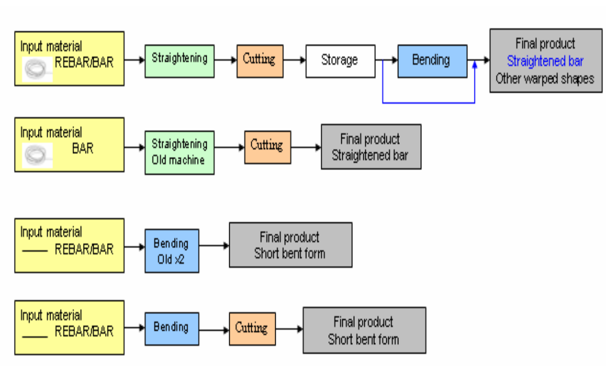


Fig. 13. Product profile 4.

Product profile 5:

– Develop a combined machine which will contain the old bar straightening machine and the additional new machine for bending of short forms, which needs to run 10 hours per day to fulfill its capacity. It is shown on the first flowchart in Figure 14.

– Develop a highly productive automatic machine for bar and rebar armature straightening.

– Two existing manual bending machines to be used for bending of long bend forms. It is shown on the third flowchart in Figure 14.

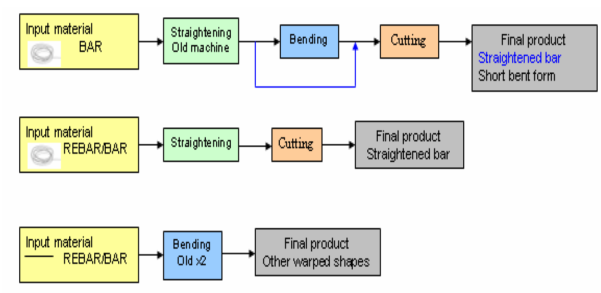


Fig. 14. Product profile 5

The presented profiles were further assessed based on five criteria such as: profile price, waste generated, net profit per year, maintenance cost and ergonomics. The results are presented at the Figure 15 with a spider diagram. These results were presented by the company management at the second meeting. Although the third profile was ranked as most effective, the company for which the profile is developed decided to give highest priority to the low cost which resulted in selection of the third product profile to further developing.

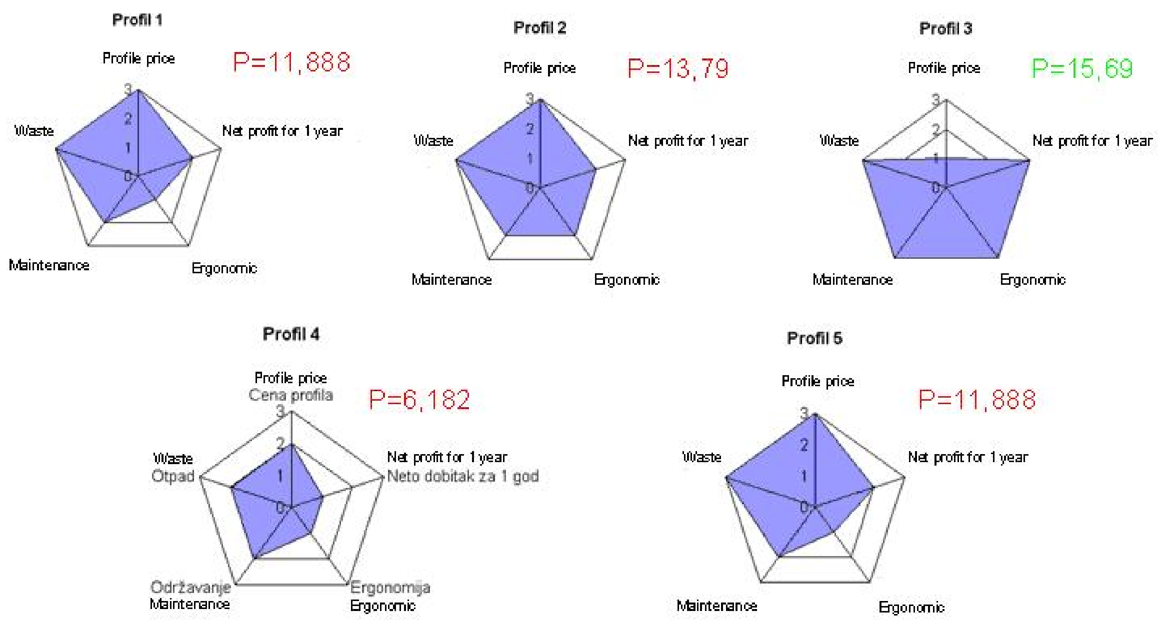


Fig 15. Assessment of the product profiles

4.4. Development of concept and selection of the best concept

In order to develop a concept of the new machine specialized for bending of short forms, we analyzed the existing solutions and also developed new innovative conceptual solutions.

Main sub functions of the system are determined to be the following: appointing of coil on the entry part, straightening, cutting, bending and storage. The conceptual solutions for sub functions are given in the morphological matrix shown in the figure 16. The used method of morphological matrix is elaborated in literature [2], page 166.

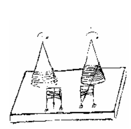
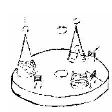
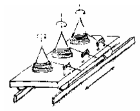
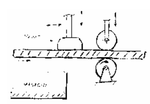
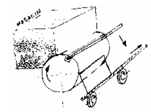
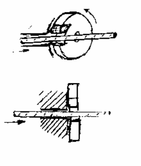
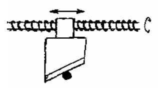
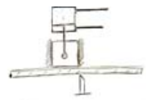
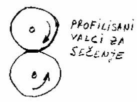
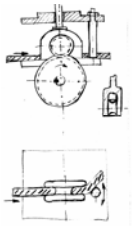
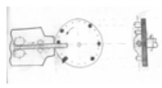
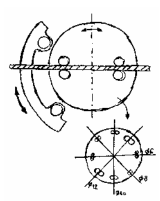
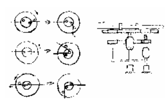
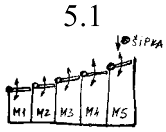
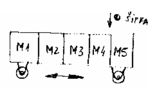
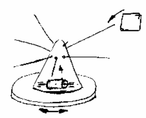
Sub function	Executors				
Appointing of coil on entry part	1.1 	1.2 	1.3 	1.4 	1.5 
Straightening	The straightening will be executed on the existing machine for armature straightening				
Cutting	3.1 	3.2 	3.3 	3.4 	
Bending	4.1 	4.2 	4.3 	4.4 	4.5 
Storage	5.1 	5.2 	5.3 		

Fig. 16. Morphological matrix

Combining the partial solutions given in the morphological matrix we come to four variant concepts for performing the main function of the system. The concepts of combining different fields of the morphological matrix for solving the sub functions are shown in the Figure 17.

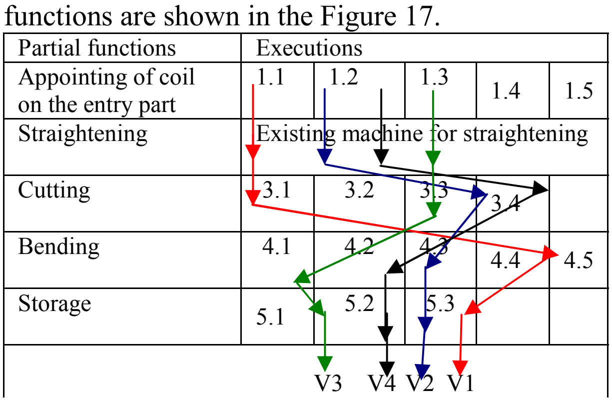


Fig 17. Various solutions - concepts

Based on technical and economical criteria (explained in detail in literature [2], page 225) the conceptual solution V4 was determined as the most promising solution for further development.

The conceptual solution V4 was proposed by the project team at the third meeting before the management of the company. In correlation between the team and management of the company, the following constraints were proposed:

The armature straightening will be performed on the existing machine,

The bending process will be for the range of dimensions from 100x100 mm to 400x400 mm rectangle forms and the armature diameter GA ø6 and GA ø8,

The number of workers for the machine is limited to one worker, The investment limit is up to 25 000 €

The operations will be performed in a linear process.

4.5 Detail product development and engineering

The structure of the linear system for production of straightened bars and short bend forms is given in figure 18.

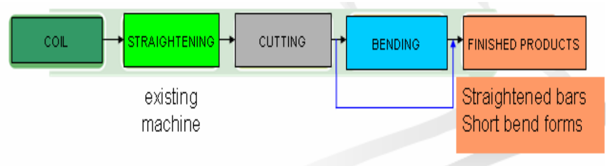


Fig 18. Linear production process

4.5.1. Armature uncoiler system

The input module consists of three uncoilers for holding armature coils. The three uncoilers rotate around the main axis and around their own axis which is the reason for having three uncoilers to reduce the delay for change of armature coils. When armature coil is spent, the next armature coil is ready for processing and thus the delay in respect to the system which has only one uncoiler. The system with three uncoilers has the advantage in respect to the system with one uncoiler, so there is no delay for changing coils.

The armature from the uncoiler goes in the system for straightening. This system already exists in the company.

The dimensioning of the uncoiler system is determined on the base of the axial force caused by the weight of the coils and their own weight and also the radial force caused by pulling the operational rolls performed by the straightening unit.

Fig 19. Armatureof the uncoiler system

4.5.2. Armature cutting system

From the straightening system, the armature goes to the cutting system.

The cutting system is composed from two units: mechanical units and control system unit for control cutting on the defined length.

The elements of this mechanical unit are given in expanded view in the figure 20 (left) and the complete system is shown in figure 20 (right).

Cutting is executed with the help of flying knives. The system is started by the electromotor (1). The power is transferred through the belt reducer (2), gear box (3) and electromagnetic clutch (4) to the gear couple (5) which consists of the same gears with ratio 1. The system has also electromagnetic brakes (6). Driven pulley at the same time is flywheel which accumulates kinetic energy which is used for fast starting of the system when the electromagnetic clutch is turned on. When electromagnetic clutch is turned off, the electromagnetic brake is turned on for stopping the system.

This cutting system has a few advantages: the cutting of armature without stopping of the rest units, cutting at the defined length, low energy consumption, the system is easy for maintenance.

The dimensioning of the cutting system is determined on the base of the force needed for armature cutting.

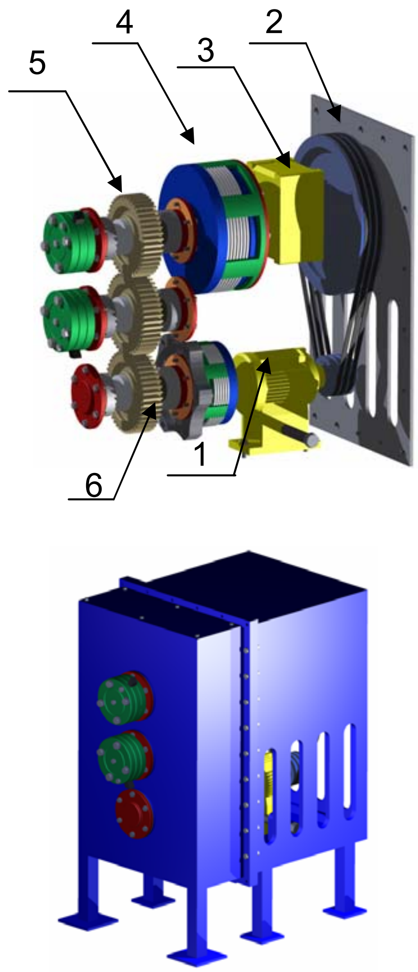


Fig. 20. Armature cutting system

4.5.3. Armature bending system

From the cutting system, the armature goes to the bending system.

The production unit system for short armature rectangle forms is shown in the Figure 21.

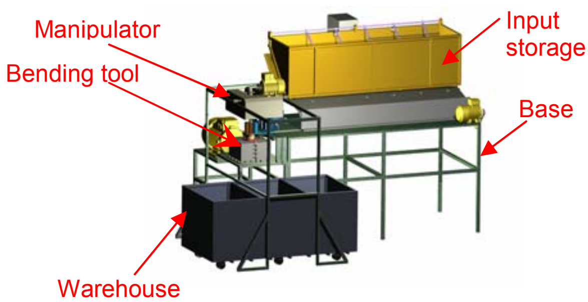


Fig. 21. Bending tool

The machine is composed of the entry storage for cut bars, automatic control system for counting the bars and their range in vertical direction bars introducing them in the directional unit, system for feeding with bars, bending system, output manipulator and storage for finished products.

From the entry storage, cut bars with proper length pass though the automatic control system which counts up to 10 bars with diameter of ø8 and range them in vertical directional unit. With help of the pusher which consists of the system thread/thread spindle and positional sensors, the bars come to the bending tool.

The bending tool bends the bars in four operations (Figure 22).

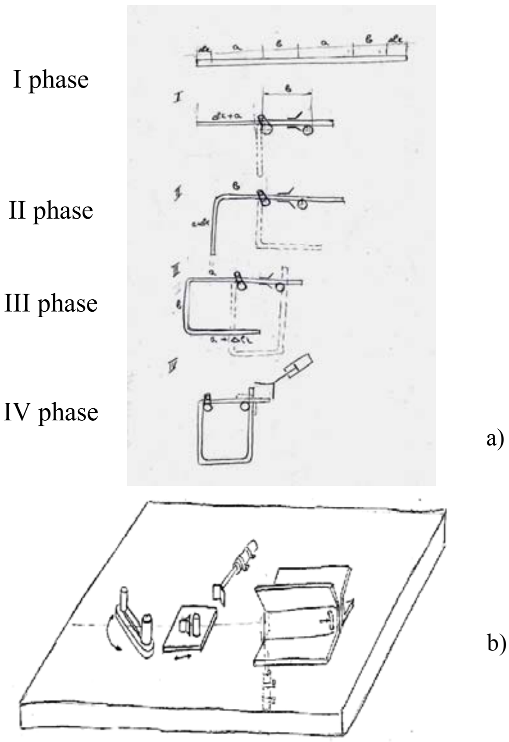


Fig 22. (a) Phases of short bent forming; (b) The first idea of dimensional 3D view of the bending module

This system differs from other systems on the market which usually makes five operations for the same bent form. Differences come from the possibility proposes of the system to make two bents in the last operation.

Typically for this tool is that it consists of a needle roller bearing an outside fat wall ring which is used to perform armature bending (see Figure 23). The design of this module is innovative and is not found at the other machines on the market. A system of channels provides lubrication for the needle roller bearings. The structure of the complete module for bending is shown in the Figure 24.

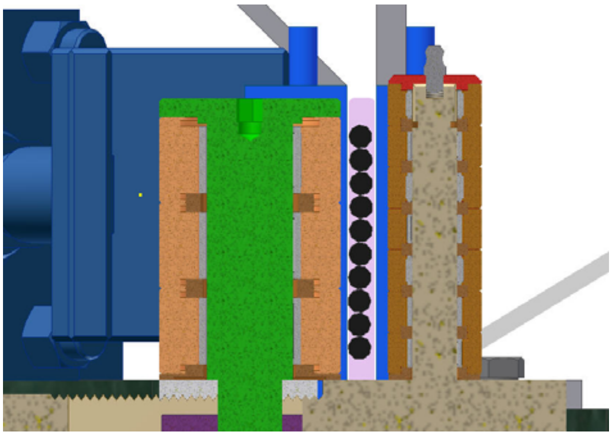


Fig. 23. Cross section of tool pins

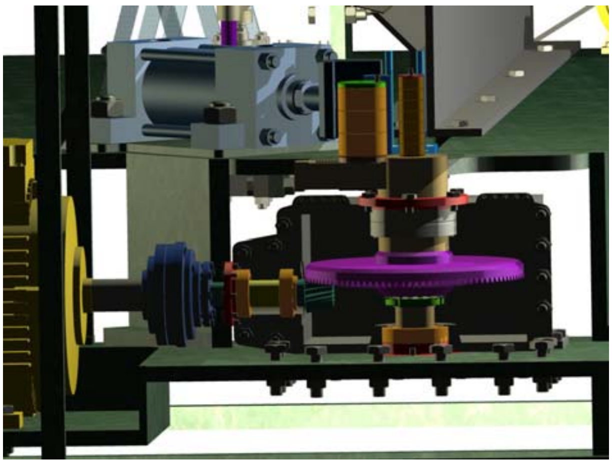


Fig. 24. Cross section of the bending module

To evaluate the performance of the system the structural analysis in ANSYS V11 Workbench was performed which proved that stress and deformation at structural parts are below the limits. The deformed situation of the bending tool is shown in the Figure 25.

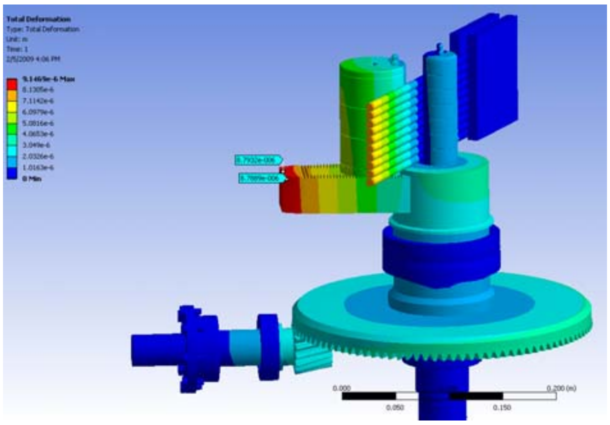


Fig 25. Deformation state of the bending tool

5. ECONOMIC ANALYSIS

Economical analysis was made to evaluate the profit at time span of three years. For this analysis in the calculation we get the total profit, costs and net profit (see Figure 26 and Table 1).

The price for overall system is also calculated.

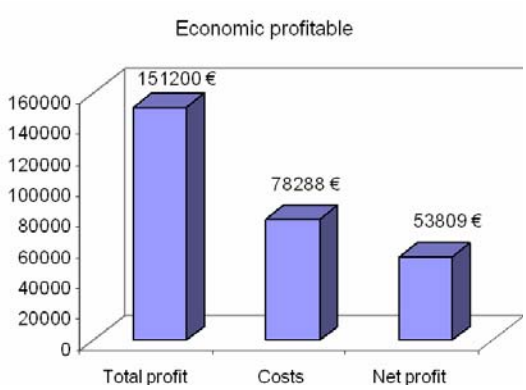


Fig. 26. Economic profit of the overall system

Table 1

Cost of the automatic machine (€)

Uncoiler	Cutting tool	Bending tool	Automation	Total
1900	3470	9100	10 000	24 470

By comparing the price for overall system of 24470 € and the net profit for three years of 53 800 €, we can conclude the production system for armature bending pay off for 1,5 years.

6. CONCLUSION

The overall analysis performed the first phase of the project indicated the need for a highly specialized machine for production of short bend forms with a rectangle shape. The product development process resulted in an innovative design of modules of the bending machine, integration of operations and increasing of the throughput. detecting the ability of reducing one the ability of reduced one working operation, because competition machines process execute in 5 working operations, where as with our machine it is executed with 4 operations. The developed machine specialized for bending short armature forms can bent simultaneously up to 10, and reduces the waste to the minimum (practically zero).

In this paper an application of the integrated product development process in accordance to the KaLeP model developed at the University in Karlsruhe, is presented. The practical example was defined in corporation with the Faculty of Mechanical Engineering in Nis and the regional industries in Serbia. The experience got from the use of the KaLeP educational model is of big importance for the young engineers of the development thing. The KaLeP educational model is proven as a valuable method for successful education and training of young engineers in the area of product development. The industry evaluated high the results of the project especially in the systematic improvement of capabilities of the engineers.

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Р е з и м е

ПРИМЕНА НА ОБРАЗОВНИОТ МОДЕЛ KaLeP ВО ИНТЕГРИРАН РАЗВОЈ НА ПРОИЗВОД

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Клучни зборови: KaLeP образовен модел; развој на производ.

Развојот на производ е една комплексна и важна фаза од целокупната креативна верига на создавањето на нов производ. Универзитетското образование има големи проблеми во создавањето на квалитетен и способен кадар кој ќе одговори на предизвиците кои се јавуваат во практичната работа. Индустријата се повеќе се соочува со недостиг на квалитетно способен кадар и бара од универзитетите да создадат кадар кој ќе одговори на денешните и идните предизвици.

Со цел за подобрување на оваа ситуација на младите инжинери во компаниите, главно барање за инжинерското образование е подобрување на клучните квалификации за времетраење на образованието.

Во овој труд опишан е KaLeP (Karlsruhe образовен модел за развој на производ) образовниот модел, примената на овој модел во високото образование, детално е објаснет интегралниот развој на производ (ИРП) преку пример кој се реализираше во рамките на Машинскиот факултет во Ниш, и големите успеси што ги имаат младите инженери при примената на KaLeP моделот за развој на производ во компаниите.

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Original scientific paper

DEVELOPMENT OF AIR SPRING DYNAMIC MODEL FOR VEHICLE SUSPENSION

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A b s t r a c t: This Air springs are well-known for their low transmissibility coefficients and their ability to vary load capacities easily by changing only the gas pressure within the springs. Air springs can be used for a mechatronic approach in suspension design because of their ability to provide a controlled variable spring rate and they offer simple and inexpensive automatic levelling. **A**ir spring dynamic model with frequency dependent characteristics has been developed for the purpose of this research. The mathematical model enables application of the model in simulation without many experimentally obtained parameters. Frequency dependence of the stiffness characteristic implemented in the new model is the main difference between the classical models and the new dynamic model. The verification of the dynamic air spring model is done by an experiment. The experimental results and results obtained by simulation in Matlab/Simulink are compared.

Key words: air spring, dynamic model, vehicle suspendsion system, mechatronic

1. INTRODUCTION

One of the basic and most important systems in a vehicle is the suspension system. The major purpose of any vehicle suspension system is to isolate the body from road unevenness disturbances and to maintain the contact between the road and the wheel. Therefore, the suspension system is responsible for the ride quality and driving stability. The design of a classical passive suspension system is a compromise between these conflict demands. However, the improvement in vertical vehicle dynamics is possible by developing an air spring suspension system.

The air spring is mainly used in commercial vehicles, but lately it is also used in higher classes of passenger vehicles. The main advantages of the air spring suspension system to the classical one are:

- Simple stiffness decreasing for obtaining soft suspension for increased comfort and decreased transfer of shocks;
- Constant natural frequencies of the system for the normal loading rank;
- Constant suspension space between the sprung and unsprung mass independent of load;
- Regulation opportunity of the stiffness and achieving an adaptive stiffness coefficient to the conditions.

The given advantages give the reason for the use of these systems in passenger vehicles. As main disadvantages are the higher price, the higher maintenance costs and the possibility of mechanical damages.

Despite the fact, that the air springs for passenger cars are commercially available, there are not enough researches devoted to their dynamic characteristics. Quaglia and Sorly [3] discuss the vehicular air suspensions from design aspects, but not from a control viewpoint. The researches in this area are mostly for commercial vehicles. In [2], a detailed overview of the constructive characteristics and the theoretical assumptions for the processes in the air springs are given. There are also some results from experimental analyses.

Presthus [3] develops few dynamic air spring models for rail vehicles. In his paper the nonlinear mathematical air spring model is developed and the results are compared with the experimental results. But this paper can not be used for air springs in passenger vehicles.

Therefore, a new dynamic model of an air spring was developed. The new dynamic model with frequency dependent characteristics was verified by experiment.

2. AIR SPRING MODELING

The air spring system, figure 1, consists of an air balloon (primary volume) connected to a reservoir (additional volume) by a pipeline system. Since the stiffness of the air spring depends on the total volume, with an electromagnetic valve the additional volume can be included or excluded from the system, and the stiffness can be changed. When the system is disposed to vibrations, the gas gets compressed or expanded, and the pressure becomes equal in the primary and the additional volume. Considering the dimensions and the construction of the pipeline there is a phase difference between the pressures in the two volumes.

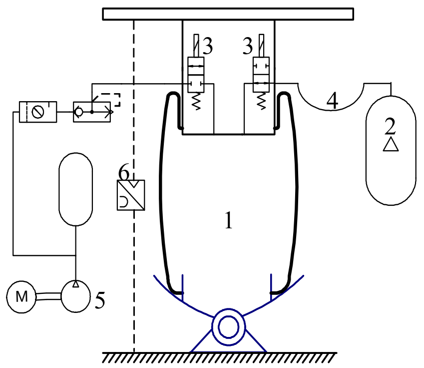

Fig. 1. Air spring system
1. Air balloon; 2. Additional volume; 3. Electromagnetic valve; 4. Pipeline; 5.Compressor; 6. Levelling sensor

Modelling of an air spring is based on the basics of thermodynamics and fluid dynamics. Although the process itself is quite complex, in the literature the air springs are usually presented with simplified equivalent mechanical models.

The modelling of an air spring, presented here, does not take in consideration the levelling system because these changes are very slow. Here the mathematical models incorporate the stiffness and the damping characteristics of the air spring.

Under the vibrations, the behaviour of the compressed air within the air spring system is polytrophic. The minimal stiffness is when there is an isothermal change of the gas state (for frequencies f < 0.1 Hz), and the maximal stiffness is with adiabatic state change (for frequencies f>3 Hz).

Analyses of the vehicle vertical dynamics show special interest around the frequency domain from 0 to 20 Hz. Classical dynamic models, as well as the manufacturer's technical data are for very low frequencies from 0 to 1 Hz. But the experimental analyses show nonlinear frequency dependence of the mechanical characteristics of the air spring. The change of the stiffness of the air spring is present when there is an additional volume and it depends on the size of the balloon, the volume of the additional reservoir and the length and the diameter of the pipeline connecting the two volumes.

The difference between the classical and the new dynamic model is presented on the following Figure 2. From the figure it can be concluded that the classical model is only valid for low frequencies.

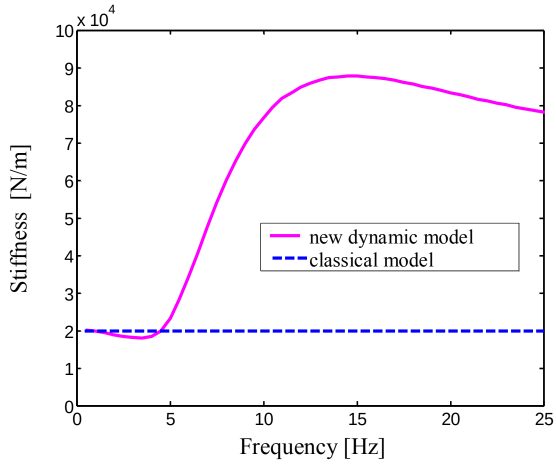

Fig.2. Comparison of classical and new dynamic model

2.1. *Classical model of an air spring*

The absolute pressure in the air spring and the force coming from the elastic element are:

$$p_0 = p_B + p_{at} \tag{1}$$

$$F_z = (p_0 - p_{at})A_{ef} = p_B A_{ef} \tag{2}$$

where p_0 is the absolute pressure in the air spring, p_{at} is the pressure of the atmosphere, p_B is the measured pressure in the air spring, A_{ef} is the effective area and F_z is the vertical force.

The stiffness characteristic of the pneumatic element can be determined from the equations above:

$$c_z = \frac{dF_z}{dz} = p_B \frac{dA_{ef}}{dz} + \frac{dp_B}{dz} A_{ef} = p_B \frac{dA_{ef}}{dz} + \frac{dp_0}{dz} A_{ef} \tag{3}$$

If the gas condition change is determined that it is polytrophic, the following equation is valid:

$$pV^n = const \tag{4}$$

where n is the polytrophic coefficient.

The equation (II.4) is differentiated:

$$\frac{d}{dz}\left(p_0 V^n\right) = p_0\, n\, V^{n-1}\frac{dV}{dz} + \frac{dp_0}{dz}V^n = 0 \tag{5}$$

From the equations above, follows that:

$$c_z = \frac{p_0\, n\, A_{ef}^{\,2}}{V} + p_B\frac{dA_{ef}}{dz} = c_{z1} + c_{z2} \tag{6}$$

The equivalent mechanical model according to the classical approach is presented in Figure 3, consisting of 2 springs with stiffness c_{z1} and c_{z2}.

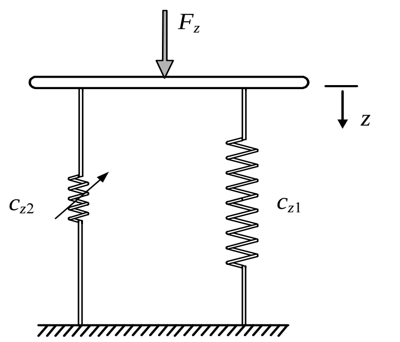

Fig.3. Classical model

2.2. *New dynamic model of an air spring*

To derive the new mathematical model of the air spring and to determine the needed parameters, a physical model of a simplified air spring is used. The model of an air spring is shown in Figure 4.

In order to take in consideration the change in the gas state in the two volumes, an approximation has been introduced by implementing a mechanical barrier (fictive piston) in the pipeline. The mechanical barrier is considered to be with neglected mass, and equivalent fluid mass that is moving through the pipeline is added to the barrier. This approximation is justified because small amount of fluid oscillates between the two volumes. The piston displacement is marked with the coordinate z, and the displacement of the fictive piston is marked with the coordinate z_p.

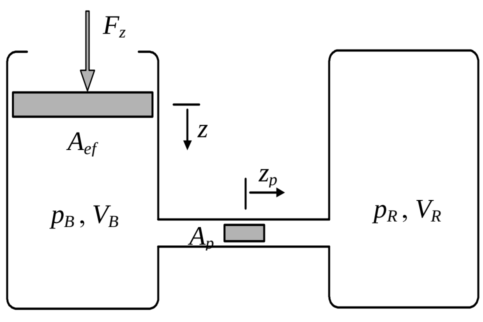

Fig.4. Air spring physical model

The piston displacement causes a pressure change in the cylinder (balloon) and the additional reservoir:

$$p_B = p_0 + \Delta p_B$$
$$p_R = p_0 + \Delta p_R \tag{7}$$

where: p_0 is the initial pressure, and Δp_B and Δp_R are the pressure difference in the balloon and the reservoir. After the displacement the new volumes of the balloon and the reservoir are defined with:

$$V_B = V_{B0} - zA_{ef} + z_p A_p$$
$$V_R = V_{R0} - z_p A_p \tag{8}$$

Where A_{ef} is the effective area of the piston, A_p is the cross section area of the pipeline, and V_{B0} and V_{R0} are the initial volumes of the balloon and the reservoir. Since the gas state change is polytrophic, the following equation is valid:

$$p_1 V_1^{\,n} = p_2 V_2^{\,n} = const \tag{9}$$

where n is the polytrophic coefficient.

Assumptions for small changes for the gas state are made by using the following linearization:

$$\left(V + \Delta V\right)^n \approx V^n + n\cdot\Delta V\cdot V^{n-1} \tag{10}$$

and the form of equations for the gas state change is:

$$p_0 V_{B0}^{\,n} = \left(p_0 + \Delta p_B\right)\cdot\left[V_{B0}^{\,n} + n\left(-zA_{ef} + z_p A_p\right)V_{B0}^{\,n-1}\right]$$
$$p_0 V_{R0}^{\,n} = \left(p_0 + \Delta p_R\right)\cdot\left[V_{R0}^{\,n} + n\left(-z_p A_p\right)V_{R0}^{\,n-1}\right] \tag{11}$$

After rearranging:

$$\frac{\Delta p_B}{p_0} + \left(\frac{\Delta p_B}{p_0} + 1\right)\cdot\left(\frac{n\left(-zA_{ef} + z_p A_p\right)}{V_{B0}}\right) = 0$$
$$\frac{\Delta p_R}{p_0} + \left(\frac{\Delta p_B}{p_0} + 1\right)\cdot\left(\frac{n\left(-z_p A_p\right)}{V_{R0}}\right) = 0 \tag{12}$$

Because of the relatively small growth of the pressures in the balloon and the additional reservoir, the following approximations have been made:

$$\frac{\Delta p_B}{p_0} << 1 \; ; \qquad \frac{\Delta p_R}{p_0} << 1$$

With implementation of these approximations in equation 12, the pressure change becomes:

$$\Delta p_B \approx p_0\frac{n\left(zA_{ef} - z_p A_p\right)}{V_{B0}}$$
$$\Delta p_R \approx p_0\frac{n\, z_p A_p}{V_{R0}} \tag{13}$$

From the force balance that acts on the piston from the cylinder and from the motion equation of the fiction piston, the following equations come out:

$$F_z = A_{ef}\, p_B - A_{ef}\, p_{at}$$
$$m\, \ddot{z}_p = (\Delta p_B - \Delta p_R) A_p - b_{pp}\, A_p\, \dot{z}_p^{\,2} \qquad (14)$$

where: p_{at} is the outside ambient pressure, b_{pp} is the coefficient for the pressure fall from the flow resistance in the pipeline, and the pressure fall is taken in consideration with the quadratic change. The b_{pp} reduced to the surface of the fictive piston A_p gives the damping coefficient $b_p = b_{pp} A_p$.

By rearranging the expressions the following equations are the result:

$$F_z = (p_0 - p_{at}) A_{ef} + \frac{p_0\, n\, A_{ef}^{\,2}}{V_{B0}} z - \frac{p_0\, n\, A_{ef}\, A_p}{V_{B0}} z_p$$
$$m\, \ddot{z}_p = \frac{p_0\, n\, A_{ef}\, A_p}{V_{B0}} z - \frac{p_0\, n\, A_p^{\,2}}{V_{B0}} z_p - \frac{p_0\, n\, A_p^{\,2}}{V_{R0}} z_p - b_p\, \dot{z}_p^{\,2} \qquad (15)$$

The equivalent mechanical model that is implemented is shown in Figure 5.

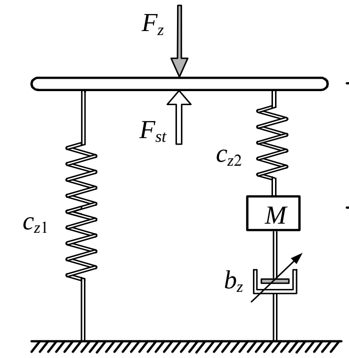

Fig.5. New dynamic model

To fit the equivalent model, equations (15) need to be scaled for the fiction piston displacement from the pipelines by scaling factor k_1:

$$\begin{cases} k_1 \dfrac{A_p}{A_{ef}} \left(\dfrac{V_{B0} + V_{R0}}{V_{R0}} \right) = 1 \\[2ex] \dfrac{k_2\, p_0\, n\, A_{ef}\, A_p}{V_{B0}} = \dfrac{k_1\, p_0\, n\, A_{ef}\, A_p}{V_{B0}} \end{cases} \qquad (16)$$

The solution of this linear system of equations is:

$$\begin{cases} k_1 = \dfrac{A_{ef}}{A_p} \dfrac{V_{R0}}{(V_{B0} + V_{R0})} \\[2ex] k_2 = k_1 \end{cases} \qquad (17)$$

By replacing for the constants k_1 and k_2:

$$F_z = F_{st} + z\, c_{z1} + (z - z_1) c_{z2}$$
$$M\, \ddot{z}_1 = (z - z_1) c_{z2} - b_z\, \dot{z}_1^{\,2} \qquad (18)$$

where:

$$F_{st} = (p_0 - p_{at}) A_{ef}\ ;$$

$$c_{z1} = \frac{p_0\, n\, A_{ef}^{\,2}}{V_{B0} + V_{R0}} \qquad c_{z2} = \frac{p_0\, n\, A_{ef}^{\,2}}{V_{B0} + V_{R0}} \frac{V_{R0}}{V_{B0}}\ ;$$

$$b_z = b_p \left(\frac{A_{ef}}{A_p} \frac{V_{R0}}{(V_{B0} + V_{R0})} \right)^3 ; \qquad M = m \left(\frac{A_{ef}}{A_p} \frac{V_{R0}}{(V_{B0} + V_{R0})} \right)^2$$

In the presented dynamical model, the change of the effective area is neglected, because for the air spring the experiments were made for, this change is very small. But for certain types of air springs, this change cannot be neglected, so in the new complete dynamic model a nonlinear spring was implemented with stiffness c_{z3}:

$$c_{z3} = p_B \frac{dA_{ef}}{dz} \qquad (19)$$

In the new full dynamic model, friction force, experimentally determined, could also be implemented to enable a more precise definition of the curve "force-displacement". The force is considered to grow slowly till it reaches the maximum value following the expression:

$$F_{fr} = \frac{z}{|z_s|} F_{fr\max} \qquad z_s = z\big|_{\dot{z}=0} \qquad (20)$$

The value z_s, changes every time the direction of the displacement changes, $\dot{z} = 0$.

The new dynamic model of an air spring with frequency dependent characteristics is shown in Figure 6. The new full dynamic model consists of: two linear springs c_{z1} and c_{z2} that represent the stiffness of the spring; a non linear spring c_{z3} that describes the change of area due to deflection; a mass M, a nonlinear viscous damper b_z and a friction damper F_{fr} which describe the inertia of the air in the pipe between the air bag and auxiliary volumes.

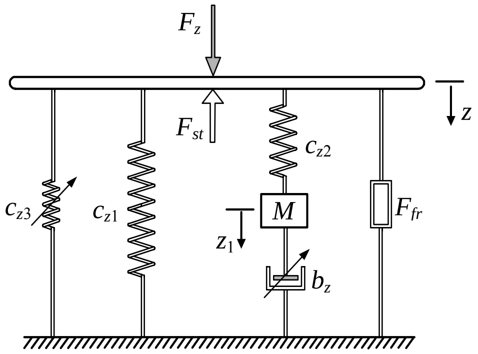

Fig. 6. New full dynamic model

3. EXPERIMENTAL VERIFICATION

The verification of the dynamic air spring model is done by an experiment. Experimental results and results obtained by simulation in Matlab/Simulink are compared, and a graphical representation of the results is given in Figure 7 and Figure 8.

Experimental results and simulation results in Matlab/Simulink are obtained for two different additional volumes and for two different pressures:

- V_{R0} = 0.00094 m^3, p_B=302 kPa (labelled as V1p1),
- V_{R0} = 0.00094 m^3, p_B=508 kPa (labelled as V1p2),
- V_{R0} = 0.0074 m^3, p_B=297 kPa (labelled as V2p1),
- V_{R0} = 0.0074 m^3, p_B=508 kPa (labelled as V2p2).

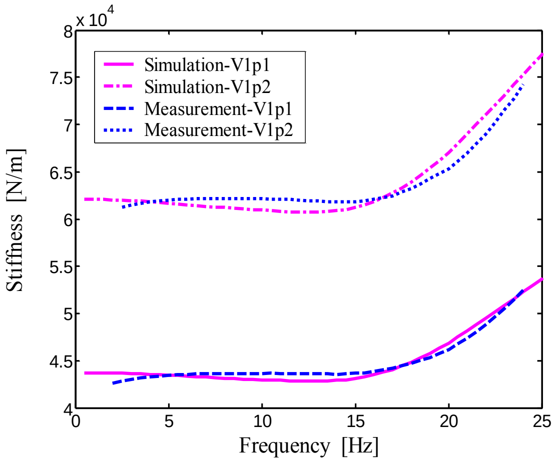

Fig. 7. Frequency dependent stiffness characteristics for additional volume 1

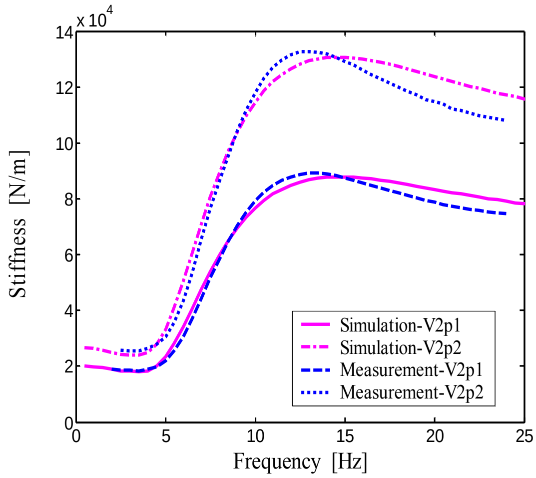

Fig. 8. Frequency dependent stiffness characteristics for additional volume 2

The diagrams show that the simulation results match the experimental results. This verifies the new dynamic model for the air spring suspension system.

4. CONCLUSIONS

Air springs are well-known for their low transmissibility coefficients and their ability to vary load capacities easily by changing only the gas pressure within the springs.

This paper has outlined improvements of the classical model with a new dynamic model of an air spring with frequency dependent characteristics.

It is shown that connecting an additional volume to the air spring gives two values of the stiffness property and the design parameters of the surge pipe that connects two volumes influence the frequency dependence of the stiffness properties. The stiffness frequency dependence could enable design of an air spring with lower stiffness for lower frequencies and higher stiffness for higher frequencies, which will improve road holding and riding comfort at the frequencies near the sprung mass natural frequency. The proposed air spring with additional volumes has two main benefits: possibility for the vehicle level control and possibility for suspension stiffness control. With the design of the surge pipe that connects the volumes a possibility is given to tune the frequency range where the additional volume is operating.

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Р е з и м е

РАЗВОЈ НА ДИНАМИЧКИ МОДЕЛ ЗА ПНЕВМАТСКИ ЕЛАСТИЧЕН ЕЛЕМЕНТ ОД СИСТЕМ ЗА ПОТПИРАЊЕ НА ВОЗИЛА

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Клучни зборови: пневматски еластичен елемент; динамички модел; систем за потпирање; мехатроника

Во овој труд развиен е динамички модел за пневматски еластичен елемент од систем за потпирање на возило со фрекфентна зависност на крутосна карактеристика. Пневматските еластични елементи може да се употребат за мехатронички простап во дизајн на систем на потпирање кај возила поради нивната способност да овозможат уравувачки коефициент на пригушување. Математичкито модел овозможува употреба на моделот во симулации без многу експериментално добиени параметри.

Фрекфентната зависност на крутосна карактеристика внесена во новиот модел е главната разлика меѓу класичниот и новиот динамички модел. Верификацијата на динамичкиот модел на пневматски еластичен елемент е направена со експеримент. Експерименталните резултати и резултатите добиени со симулација во Matlab/Simulink се споредени.

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Original scientific paper

NUMERICAL SIMULATION OF SLOSHING IN RECTANGULAR TANKS WITH OpenFOAM CFD PACKAGE

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A b s t r a c t: The aim of this paper is to simulate the sloshing phenomenon using OpenFOAM CFD software package. The present paper treats a 2D numerical simulation of a partially filled tank that is located on a LNG carrier. Experiments were done on a rectangular tank excited with different excitation periods and amplitudes and the pressure was measured at certain locations on the tank walls. The goal of this research is to compare the experimental data for the pressure with the pressure results obtained with the CFD software. It is shown that the obtained results match well with the experimental data.

Key words: Sloshing, rectangular tank, numerical calculation, OpenFOAM

1. INTRODUCTION

The sloshing phenomenon can be defined as a violent behavior of a fluid inside partially filled tanks. This phenomenon is of a great interest in marine, automobile and space industry. It is known that partially filled tanks are prone to violent sloshing under certain motions. The large liquid movement creates highly localized impact pressures on tank walls which may cause structural damage and affect the stability of the vehicle which carries the tank. The impact pressure, in general, depends on the nature, amplitude and frequency of the tank motion, liquid filling ratio, liquid properties and tank geometry. When the frequency of the tank motion is close to the natural frequency of the liquid inside the tank, large impact pressures can be expected.

The sloshing problem has been to a great extent investigated in the last 50 years. The first attempts were based on mechanical models of the phenomenon by adjusting terms in the harmonic equation of motion. These types of techniques are used when time-efficient and not very accurate results are needed.

The second series of investigations solves a potential flow problem with a very sophisticated treatment of the free-surface boundary conditions that extends the classical linear wave theory by performing a multimodal analysis of the free-surface behavior. This approach is very time efficient and accurate for specific applications but it cannot handle overturning waves and neither is it clear how it could resolve the flow for generic geometries and baffled tanks.

The third group of methods solves the nonlinear shallow water equations with the use of different techniques.

The fourth group of techniques used to deal with highly nonlinear free-surface problems is aimed at solving numerically the incompressible Navier–Stokes equations. One can solve the nonlinear potential flow problem with a finite difference method in a 2-D tank that is subjected to horizontal and vertical motion. The results are very good but this approach suffers from similar shortcomings to the multimodal method. Also, one can solve the complete problem by using a finite difference scheme and a VOF formulation for tracking the free-surface with very promising results. [1]

2. THEORETICAL BACKGROUND

Sloshing phenomena in moving rectangular tanks can usually be described by considering two-dimensionall fluid flow. The difficulty of describing and obtaining the exact solutions to the problem of liquid sloshing is simplified by making several assumptions concerning the nature of the fluid and the type of the flow:

- incompressible fluid

- irrotational flow
- no sources or sinks.

The above mentioned assumptions allow classical potential flow theory to be used. According to this theory, the velocity $\vec{V}$ can be expressed as a gradient of a velocity potential:

$$\nabla \phi = \vec{V} \tag{1}$$

The mass conservation law (the continuity of the fluid) is given by:

$$\nabla \vec{V} = 0 \tag{2}$$

The condition that must be satisfied in the fluid domain is represented by the equation:

$$\nabla^2 \varphi = 0 \tag{3}$$

The linearized form of the Bernoulli's energy equation for the free surface is given by the following expression:

$$\frac{\partial \phi}{\partial t} + \frac{p}{\rho} + gz = 0 \tag{4}$$

where only the gravitational force has been taken into account as important body force. From the last equation, the pressure can be expressed as:

$$p = -\rho \left(\frac{\partial \phi}{\partial t} + gz \right) \tag{5}$$

Boundary conditions

In order to solve the problem, two boundary conditions can be introduced: boundary condition on the free surface of the liquid and boundary condition on the tank walls. The free surface boundary condition is given by the following equation:

$$\frac{\partial^2 \varphi}{\partial t^2} + g \frac{\partial \varphi}{\partial z} = 0 \quad \text{for} \quad z = \frac{h}{2} \tag{6}$$

where $z = h/2$ represents the free surface of the liquid in the tank. This condition states that the pressure at the liquid free surface is equal to the static pressure of the gas above the liquid.

The boundary condition on the tank walls states that the liquid velocity, perpendicular to the tank walls, must be equal to the velocity of the tank. This condition is represented by:

$$\frac{\partial \phi}{\partial n} = \vec{V}_n \tag{7}$$

Equations (3), (6) and (7) represent the Boundary Value Problem which has to be solved based on the motion of the tank. [2]

The most violent behavior of the liquid can be expected when the natural frequency of the liquid and the frequency of the tank motion are equal. The natural frequency of the liquid can be calculated as follows:

$$\omega = \sqrt{\pi(2n-1)(g/a)\tanh[\pi(2n-1)(h/a)]} \tag{8}$$

3. EXPERIMENTS

The experiments have been performed on a rectangulars tank [1]. The dimensions of the tank are: length 900 mm, height 508 mm and breadth 62 mm which is actually quasi 3D. The tank is subjected to a harmonic rolling motion with amplitude of 4 degrees. The rotating axis, as shown on Fig.1, is located on the centerline at 184 mm from the bottom line of the tank (point O). Three different experiments have been performed, concerning the fluid height in the tank and the excitation frequencies of the tank (Tab. 1). For case A, the fluid height is 93 mm and the excitation period is 1.91 seconds which is equal to the natural frequency of the fluid (resonant period). For the second case, case B, the fluid height in the tank is 222 mm and the excitation period is 1.32 seconds, which again equals to the resonant period of the fluid in the tank. The fluid height for case C is the same as case B, 222 mm from the bottom line but the excitation period is 1.19 seconds which is 90 percents of the resonant period.

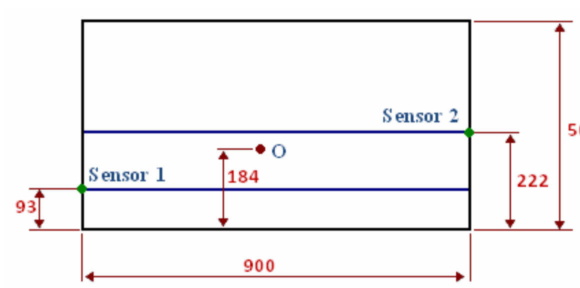

Fig. 1. Tank geometry and position of the sensors

Table 1

Water levels and frequencies considered

Case	Water Level (mm)	Excitation period (s)	Angle Amplitude
A	93	1.91	4
B	222	1.32	4
C	222	1.19	4

The pressure is measured at different locations which are also shown on Fig. 1. For the first case, the pressure is measured at the sensor location 1 and for the cases B and C the sensor location 2 is considered. The pressure sensors used in the experiments are BTE6000 – Flush Mount with a 500 mbar range.

4. OpenFOAM

OpenFOAM is free, open-source CFD code [3], developed for solving problems in the field of fluid mechanics. It has a wide range of predescribed solvers. For the purpose of this paper, *interDyMFoam* solver is selected. This is a special solver developed for solving sloshing problems. It is based on a Reynolds Averaged Navier Stokes (RANS) model with Volume of Fluid (VOF) surface capturing method.

For the simulations, the cell dimensions are 10 mm X 10 mm X 10 mm so the computing domain has 27000 cells (Fig. 2). The viscosity and the gravitational forces have been taken into account. The surface tension force has been neglected. The initial time step for the calculation is 0.05 seconds. For solving the first time derivative terms, Euler (first order, bounded, implicit) scheme is used. For the divergence terms Gaussian discretization is chosen with cubic interpolation of the values. All other terms are solved using Gaussian discretization with linear interpolation.

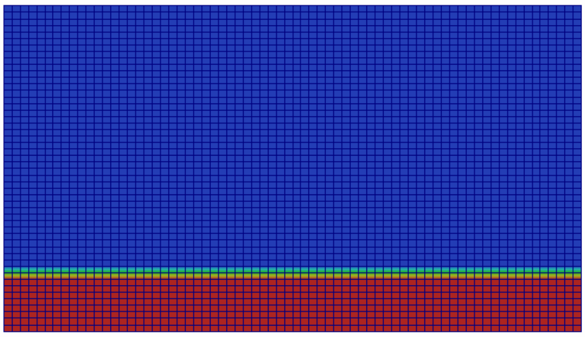

Fig. 2. The computational domain in OpenFOAM

For both the experiment and numerical calculation, the liquid in the tank is water with these properties:

– density 998.2 kg/m^3

– kinematic viscosity $1.004 \cdot 10^{-6}$ m^2/s

and the gas above the water in the tank is air with:

– density 1 kg/m^3

– kinematic viscosity $1.48 \cdot 10^{-5}$ m^2/s.

5. COMPARISON OF THE EXPERIMENTAL DATA AND CFD RESULTS

The obtained results and the comparison with the experimental data are shown on Fig. 3 to 5.

The experimental roll time history slightly differs from the perfect sinusoidal law (at least in the initial phase in which an infinite acceleration would be needed to represent the exact sinusoidal law). This is not considered during the numerical simulation and exact sinusoidal roll motion is applied to the numerical model.

The pressure time history for case A is given on Fig. 3. In general, the first and second peaks of the pressure are not captured correctly because the experimental roll time history is not applied to the numerical simulation. From the third peak and on, the order of magnitude is captured correctly. An example of kinematics capturing is presented on Fig. 6, showing a good qualitative capturing of the sloshing impact phenomena.

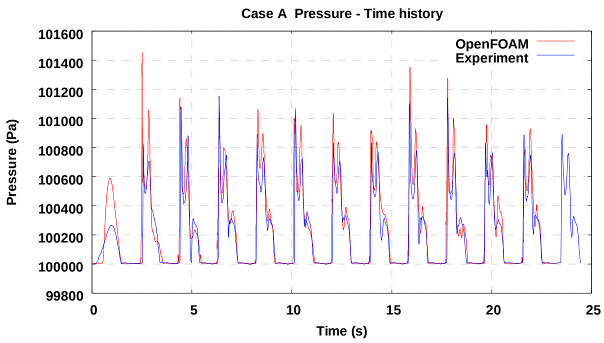

Fig. 3. Case A Pressure – Time history comparison

For case B, the pressure time history is shown on Fig. 4. Here, we can see that the pressure peaks are over predicted at the start of the simulation but later the pressure is captured more accurately, even still over predicted. The free surface capturing for this case is shown on Fig. 7.

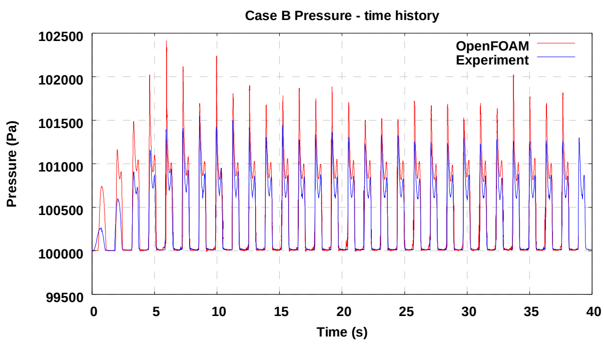

Fig.4. Case B Pressure – time history comparison

For the case C (Fig. 5) it is interesting the presence of beating type phenomenon with pressure peaks of oscillating amplitude and not periodic with the same value for each period. The beating type phenomenon is captured but the pressure peaks are overestimated during the whole time history mainly due to numerical diffusion. Pressure curve shapes are captured correctly with a sort of secondary peak during excitation phase and a more bell-shaped curve during the damping phase. The experimental results show under-pressure after each impact. This is because of the sensitivity of the measuring equipment. The free surface capturing is shown on Fig. 8.

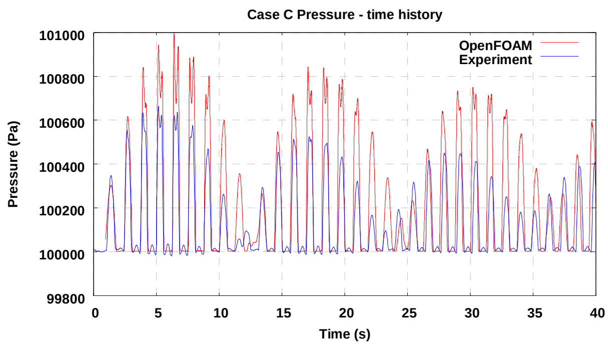

Fig. 5. Case C Pressure – time history comparison

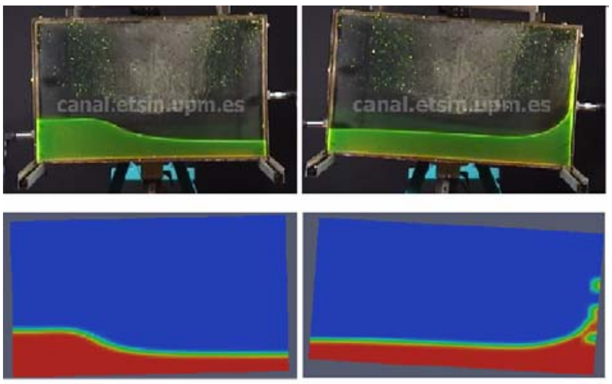

Fig. 6. Case A - free surface capturing

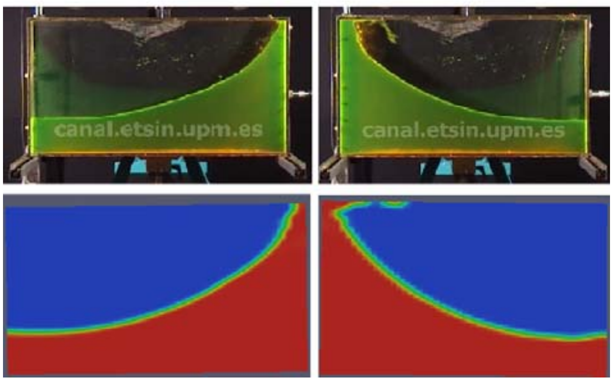

Fig. 7. Case B – free surface capturing

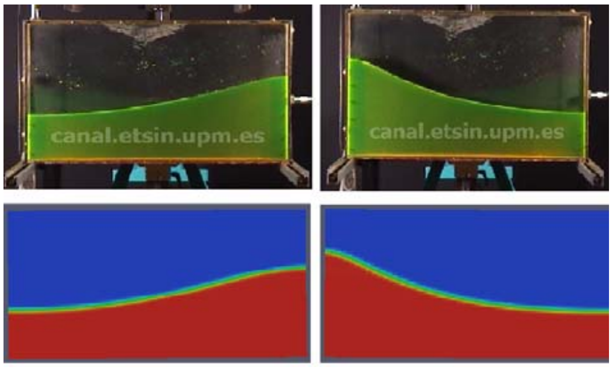

Fig. 8. Case C – free surface capturing

6. CONCLUSION

From the comparisons we can see that the pressures predicted by the numerical calculation are rather satisfactory in general, with a sufficient correspondence with the experiments. The most problematic case is the third case, where the beating phenomenon is captured but still the pressure peaks are over predicted.

Improvements can be made with refining the mesh and increasing the cell number. Here it is important to mention that increasing the cell number leads to rapid increasing of the computational time. Other remark we can mention, in order to improve the results, is using different numerical schemes and decreasing the time step of the simulation, which again leads to increased CPU time. In the foregoing cases, interDyMFoam solver was used. This solver solves two – phase flow.

In future, in order to decrease the CPU time, one – phase solver can be developed. Also, HPC (High Performance Computer environment) can be used (parallel processing) to decrease the computational efforts.

OpenFOAM is an ideal platform for further developments including automatic post-processing of the results, calibration of other potential codes and developing of coupled solver for seakeeping - sloshing calculations.

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Р е з и м е

НУМЕРИЧКА СИМУЛАЦИЈА НА ЗАПЛИСКУВАЊЕ ВО ПРАВОАГОЛНИ РЕЗЕРВОАРИ СО ПАКЕТОТ OpenFOAM CFD

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Целта на овој труд е да се симулира феноменот на заплискувањето користејќи го софтверскиот CFD пакет OpenFOAM. Притоа е изведена 2D нумеричка симулација на делумно наполнет резервоар кој што е лоциран на LNG носач. Експериментите се изведени на правоаголен резервоар кој што се побудува со различни периоди и амплитуди на побуда и при тоа е извршено мерење на притисокот на определени локации на ѕидовите на резервоарот. Целта на ова истражување е да се споредат експерименталните податоци за притисокот кој се јавува по резервоарот со резултатите добиени преку CFD симулациите. Се покажува дека добиените резултати добро кореспондираат со експерименталните мерења.