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C O N T E N T S

DOMINANT TECHNOLOGIES IN "INDUSTRY 4.0"

MONITORING AND CONTROL SYSTEM USING GPRS
Asst.Prof. M.Sc. Zhejnov Z. PhD., Assoc.Prof. Ivanov S. PhD. 101

DECISION-MAKING IN A MANUFACTURING SYSTEM BASED ON MADM METHODS
M.Sc. Rudnik K. PhD. 104

SIMPLIFIED ANALYTIC SOLUTION OF THE PROBLEM OF AUTOMATED MOTION CONTROL OF AN AUTONOMOUS RIGID BODY WITHOUT ITS OWN PROPULSION SYSTEM IN INCOMPRESSIBLE STRATIFIED VISCOUS FLUID
Postgraduate Kuznetcova L.V., Prof., Dr. Tech. Sci. Firsov A.N. 108

IEC-62264 BASED QUALITY OPERATIONS MANAGEMENT ACCORDING THE PRINCIPLES OF INDUSTRIAL INTERNET OF THINGS
Prof. Dr. Batchkova I. A., Assoc. Prof. Dr. Gocheva D. G., Eng. Georgiev D. 111

BUSINESS & "INDUSTRY 4.0"

VIBRATION POWER GENERATION WITH PIEZOELECTRIC ELEMENT USING MECHANICAL-ACOUSTIC COUPLING IN ACTUAL ENVIRONMENT
B.Eng. Ohba Y., and Prof. D.Eng. Moriyama H. 115

FEM 2D AND 3D DESIGN OF TRANSFORMER FOR CORE LOSSES COMPUTATION
Assoc. prof. Dr. Sarac Vasilija 119

VARIANCES OF THE DYNAMIC PROPERTIES OF FILLED POLYMER MATERIALS IN A VARIATION OF INJECTION MOULDING INPUT PARAMETERS
Ph.D. Eng. Contos V. 123

DELTA 3D WIRE PRINTER FOR BUILDING OBJECTS – THEORETICAL PREREQUISITES FOR PROTOTYPE DESIGN
Head Assist. Dr. Vasilev, T. 127

SOCIETY & „INDUSTRY 4.0"

NBIC TECHNOLOGIES FOR A SYSTEM OF INTELLECTUAL SUPPORT OF INNOVATIVE ACTIVITIES OF INDUSTRIAL ENTERPRISES
Senior lecturer Avdeychik O., Assoc. Prof. cand. eng. Avdeychik S., Senior lecturer Antonov A. 131

COMPETENCY PROFILE OF THE INNOVATIVE ENTERPRISES
M.Sc. Dimov D. PhD. 135

REUSE OF SOFTWARE ENGINEERING
M.Sc. Ivanova Milka 139

PRODUCTION SYSTEMS SAFETY, MODELLING, SIMULATION AND THE POSSIBILITY OF AUTOMATION OF A PRODUCTION WAREHOUSE AS A KEY COMPONENT IN CIM SYSTEMS
Prof.Asoc.Dr. Bruci M., Prof.Asoc.Dr. Likaj R. 143

LOGISTICS PERFORMANCE INDEX (LPI) AND INCENTIVES FOR LOGISTICS PERFORMANCE IMPROVEMENT IN BULGARIA
Senior Assistant Professor Varbanova A., PhD. 147

POSTAL MARKET DEVELOPMENTS IN SERBIA
PhD student MSc Eng. Nikolić B. Ivana, Prof. Dr. Eng. Dobrodolac J. Momčilo, Prof. Dr. Eng. Marković D. Dejan 151

MONITORING AND CONTROL SYSTEM USING GPRS

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Abstract: *A structure of a multifunctional hardware - software system for sensing and control of remote objects in the household and in the industry are considered. A version of data transferring between control center and controlled object using GPRS service is proposed. The monitoring and control are realized by a set of remote stations which control the objects and receive parameters from them. Every station has a microcontroller and GSM - GPRS modem with SIM card. The stations are linked to the switching server. Data received from remote stations are kept in the server. The server distributes information and sends control commands. Personal computers of the control center are connected in a local network. They receive data from WEB sites and send commands to the switching server. The design and the characteristics of two realized systems for remote monitoring and control are described.*

Keywords: REMOTE CONTROL, REMOTE SENSING, GPRS COMMUNICATION, SWITCHING SERVER, CONTROL CENTER, REMOTE STATION

1. Introduction

Management of remote objects in households and industry requires the use of channels for transmitting data to obtain the parameters of the object and to send commands to it. Depending on the information size transmitted per unit of time, the distance to the controlled object, the required speed of response to changing parameters and other characteristics can be realized a variety of control circuits and methods for data transmission, and the medium for transmitting the information may be different [1].

If the analyzed parameters are few and change slowly, the response time is not critical, the distance from the control center to the objects is big, or they are moving, then the management and monitoring can be carried out on the radio. Imposed restrictions related to the spreading of radio waves depend on the location of the managed object, spectrum and ensuring sufficient output power of the transmitter significally complicate the task, reduce reliability and increase the cost of implementation. Lately in connection with the development of the mobile network there are options for data transmission between the control center and the managed object using GSM network. The first services in GSM networks were asynchronous and related to schemes for switching circuits - Circuit Switched Data (CSD). They have been used analog telephone networks for a long remote data transmission. For dialing and transmission of data, only specific international standard protocols are used. Since all ordinary receivers provide support for these international standards of devices used in cellular telephone networks in the year 2000 additional services to exchange data with high speed were introduced. These are HSCSD (High Speed Circuit Switched Data) with speeds up to 38.4 kbit / s and packet switching in a data transmission GPRS (General Packed Radio Service) with speeds up to 53.6 kbit / s. Since the beginning of 2004 some cellular network operators have launched commercial UMTS (Universal Mobile Telecommunication Services) services, reaching speeds of 384 kbit / s. Ordinary CSD services are also available in UMTS networks [2].

2. Prerequisites and means for solving the problem

In CSD service one or more channels are occupied all the time. In GPRS data is broken into small packets and transmitted in one or more available radio channel between the mobile device and packet switched network (eg. Internet). These radio channels are occupied only temporarily and released immediately so that multiple devices have simultaneous virtual access to available wireless channel. Therefore, CSD (HSCSD) has an advantage for sending large amounts of data while mobile devices are on-line for a short time - for example, for transferring large files over the intranet within a company. GPRS service makes mobile communication faster, more convenient and cheaper. It provides high-speed operation of WAP and mobile Internet. The user can continuously remain on-line during transmission, because the price depends only on the amount of transferred data. GPRS is advantageous for small volume of transmitted data, for example text or commands and continuous state on-line. Moreover, GPRS provides a direct connection to the Internet without Internet Service Provider [3]. This makes GPRS preferred for data transmission via GSM networks in the systems for monitoring and control.

3. Solution of the examined problem

The block diagram of the described system is shown in Fig. 1.

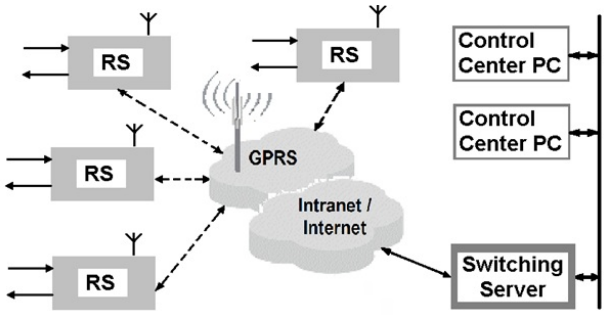


Fig. 1. *Block diagram of a system for monitoring and control*

System for monitoring and control is built by lot of remote stations (RS), which manage the objects and take the necessary parameters. Each station consists of managing microcontroller and GSM-GPRS modem with a SIM card. The stations are connected by the cellular network of a mobile service provider to a Switching Server, which stores the received data from remote stations, controlling the objects. It distributes and directs control commands. By controlling PC-s, connected in a local network the personnel in the control center receives data from objects and sends commands to the switching server.

Remote stations are powered by a 220V mains via an adapter 12V with the possibility of including a battery. A MPS430 microcontroller of company “Texas Instruments” with 400 KB RAM and 1.7 MB Flash memory is used. Two serial interfaces (RS-232 and USB), SIM card control and 4-band GSM modem, as well as five digital optical isolated inputs, 5 analog inputs, 4 relay outputs for control of the object are realized. In order to connect M2M between RS and the switching server in the microcontroller Java Virtual Machine and IMP-NG software are installed. The access to TCP / IP stack is done by a small number of AT commands. For example, the command to read data from ADC contains the following fields: one byte number of bytes sent, 4-byte number of radio, a byte read command and a byte number of input. The command to enable / disable input contains one byte number of bytes sent, 4-byte number of radio, one byte command activation (01) / disable (00) and a byte number of input. After sending a command to a radio, the server returns the byte 00 if there is no connection and byte 01 if the command is sent successfully.

ALOP (Advanced Light OSCAR Protocol) client, running on TCP / IP in real time is started to support GPRS communication on the control PC. The support of Advanced Encryption Standard (AES) ensures the security of information transferred through the system.

3. Results and discussion

To check the operation of the system a tester with 5 digital inputs, 5 analog inputs and 4 digital outputs was connected to a remote station / Fig. 2 /. The voltage on the analog inputs A1-A5 was changing by variable resistors and the levels of digital outputs were switched between 0/1 by the buttons S1-S5. The levels of the digital inputs and the relay outputs C1-C4 were indicated by the LEDs.

Correctness of input data and operation of the 4 relay outputs were checked by a little test app written in C ++ and running on the PC in the control center running under Windows OS.

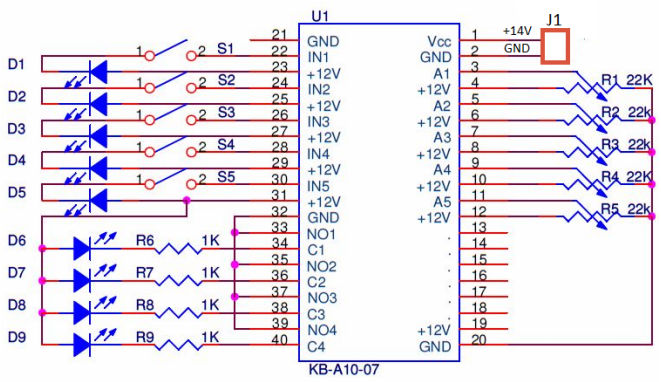


Fig. 2. *Connecting the tester of remote station*

Fig. 3 shows a screen-shot of the remote station system in test mode.

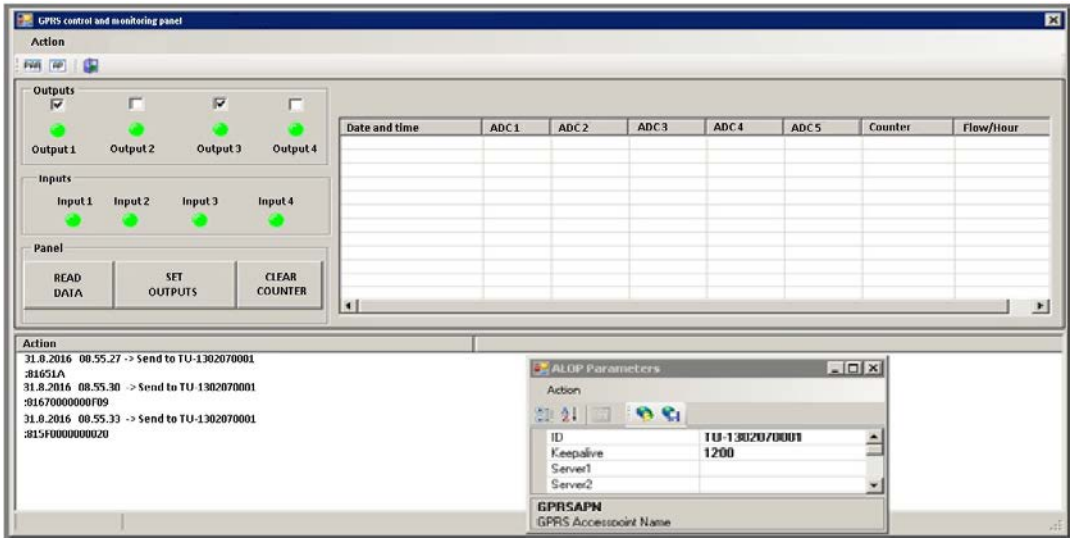


Fig. 3. *Working screen of the system in test mode*

Mobile automatic weather station is another example of application of the system for monitoring and control of remote objects. In classical ground stations the information is read from the devices and sent manually. The automatic weather station saves man labour and staff and can take measurements in hard to reach places [4]. Weather data transmitted over wires or radio for processing and for storage.

Automatic mobile weather station measures the temperature and humidity of air, atmospheric pressure, direction and speed of wind, and the brightness of the light at the location where it is. It has a block for data collection that makes these measurements automatically. It is cost-effective to use the national cellular networks to connect the device that collect data going to the server.

The collecting data device periodically reads data from various sensors through which information about the parameters of weather is received. Then it transforms their format into a format suitable for processing. Then it records the collected meteorological data in non-volatile memory to send it then to the WEB server via GPRS connection for storage and processing. The device interacts with sensors through its specialized interfaces and supports the necessary protocols to transmit information to sensors [5]. A block diagram of the device for the collection of meteorological data is shown in Fig. 4. The block of visualization and management of meteorological data is a device, by which the user can monitor the processed meteorological parameters and manage the block for collection of meteorological data.

This unit can be a mobile device or desktop computer with Internet access. It has a screen, suitable for displaying the results, the necessary memory for storing the software and the results. It has a module that communicates with other nodes of the system.

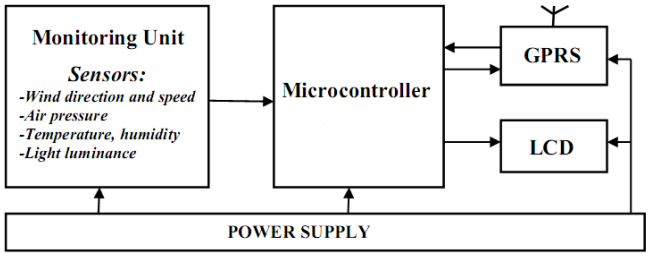


Fig. 4. *Block diagram of the device for collection of meteorological data*

Managing microcontroller CC430F5137 is a member of the family of microcontrollers of the company "Texas Instruments". Microcontrollers of this kind were widely used in digital devices, converters, heat measurement systems, wireless connection networks and systems for remote access [6]. The microcontroller includes integrated 1 GHz transceiver that can be used to connect the microcontroller with other remote peripherals. This controller has five modes of reduced consumption, and it is suitable for battery powering. It includes a powerful 16-bit MSP430 microprocessor, volatile memory 32KB, 4KB RAM, two 16-bit timers, a fast 12-bit ADC, a comparator, universal serial interface, real time clock and 44 lines for input / output. The control program is stored in the flash memory of the microcontroller. Programming can be made via standard JTAG interface.

A digital sensor for temperature and humidity on the type DHT22 is used. The sensor is controlled by the microcontroller using 1 signal line and a special protocol.

The digital sensor for measuring air pressure is of type BMP085. The sensor is connected to a microcontroller via I2C

serial interface. Data about the air pressure received by the sensor are recalculated using constants, stored in volatile memory.

The sensor for the wind direction is of the type NRG 1904. It is compact and resistant to the fluctuations of temperature, moisture and corrosion. This is an analog sensor and converts the angle from 0 to 3600 into voltage.

The wind speed sensor is of type 40C and is a standard analog sensor. It is widely used in industry. It generates a sinusoidal voltage with frequency 0-125 Hz, in proportion to the measured speed. To measure the frequency of the signal received by the sensor it passes through comparator and the frequency of rectangular pulses on the output of the comparator is measured. Light sensor is analog and it works using photo resistor.

For connection between WEB server and other nodes of the system for collection of meteorological data a GPRS module of type SIM800L (SIMCom) is selected. It is small, has low power consumption and is controlled simply by the microcontroller. It can exchange data through the network and auxiliary functions of GSM / GPRS. It can also call and send SMS. This module supports communication protocols HTTP, FTP, TCP / IP. Management of the GPRS module is realized by sending AT commands via asynchronous serial interface of the microcontroller UART.

LED display is used for local visualization of the measurement values, and also shows state of the microcontroller. It is a symbol display with 2 rows and 16 columns. It uses a parallel interface with 7 signal lines.

The sensors and the microcontroller are powered with different voltage. They are obtained from a 12V stabilizer. Several other stabilizers are attached to its output.

A block diagram of the system software for collection and transmission of meteorological data is shown in Fig. 5.

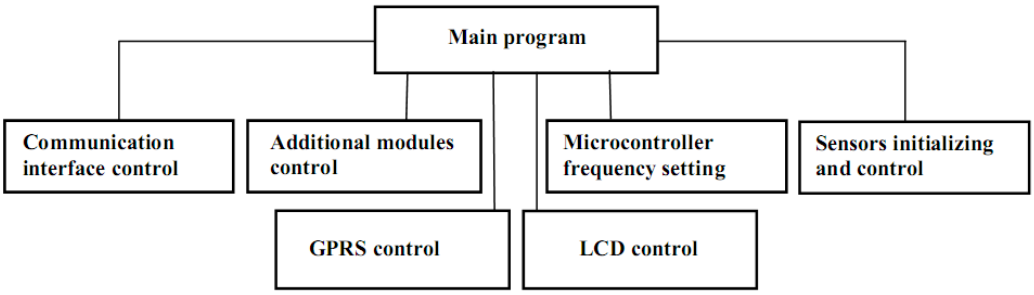


Fig. 5. *Flowchart of the software*

The communication between functional blocks is implemented differently. The connection between the block for collection and transmission of weather data and processing block is realized by a wireless network using GPRS - the device [7], which supports a stack protocol TCP / IP. The connection between the block for processing of weather data and display unit uses HTTP - protocol, such as GET and POST calls.

The realization of WEB system is done using two servers that work in parallel. The first server accepts HTTP - requests from the control unit of the weather station and display device, as well as some requests of the device for data collection. The server HTTP uses a free server Apache HTTP. The second server is TCP server. It implements connection with the data collection device and transmits the commands coming from the control unit.

The server TCP is realized using a library of programming language nodeJS - NET. The processing of HTTP - requests and receiving data is realized using programming language PHP. For storage of processed data and the data of different types associated with the system a database system MySQL is used.

To create templates, which are displayed on the device for visualization and control of metrological data, programming language AngularJS was used.

The proposed weather station was realized as a model using ready modules. It was used for research and to preparing students by studying its subsystems and their improvement.

4. Conclusion

The practical application of the proposed system for monitoring and control of remote objects includes a collection of measurement data for electricity, water or gas from vending machines or level sensors. Other applications can be remote service test equipment, transmission of messages in a signaling system, high-speed data transfer of electronic payments, monitoring the performance of machines, vending machines and weather in autonomous meteorological stations [8]. This system is suitable for M2M connection with programmable logic controllers.

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DECISION-MAKING IN A MANUFACTURING SYSTEM BASED ON MADM METHODS

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Abstract: *Nowadays, manufacturing systems are much larger with an increasing number of production lines and units. As a result, the decision-making of manufacturing system is a non-trivial problem and requires complex control subsystems. The use of Programmable Logic Controllers (PLCs) allows to program various and non-standard solutions. In the paper the application of Multi-Attribute Decision-Making (MADM) methods to a decision-making related to flow control in a manufacturing system with three production lines is described. For this purpose, the SAW (Simple Additive Method), WASPAS (Weighted Aggregated Sum Product ASsessment) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods are applied and simulated with using manufacturing system model in Matlab Simulink and SimEvents. In methods subjective weights defined by an expert are used. However, in order to move away from subjectivism, Shannon's entropy is used for determining weights of criteria. The used approaches have been compared.*

Keywords: MANUFACTURING SYSTEM, DECISION-MAKING, MADM METHOD, SAW METHOD, WASPAS METHOD, TOPSIS METHOD, FLEXIBLE MANUFACTURING SYSTEM, ENTROPY, SIMULATION

1. Introduction

Manufacturing system is a set of elements related to manufacturing processes. It consists of deliberately designed and organised material, energetic and information systems used for production of defined products to fulfil the needs of consumers [1]. As a result of manufacturing activity new use values appear. From technical and organisation perspective, the manufacturing process is adjustment and transformation of work into a product made with the use of the means of work (machines) with or without the participation of human workforce. Those factors are tightly connected and a change of one results in change of another element [1], which, subsequently, may cause a change in use values. From this perspective, information and decision-making processes are important elements in the manufacturing process. Their aim is to submit complete information to systems and later making decisions based on the choice of an optimal decision variant with an assumed decision criterion which is advantageous for the manufacturing system.

Decision-making processes may be considered in relation to manufacturing process management but not only. Decision-making process may be also considered as a control process in basic and supportive processes – technological operations in simple machine systems, transport operations, and storage operations, etc. Decision criterion which is advantageous for one subsystem may be disadvantageous for another subsystem or for superior control process. Hence, in this article multi-criteria approach to decision-making in production process was considered. A single decision-making process may than consist of criteria adjusted for a single subsystem but it may also consider general criteria adjusted do the management process. They may be simple criteria (e.g. machine activity, processing time on a machine) or complex criteria, which are a result of calculations based on information from different systems or being system/ subsystem productivity indicators.

Decision-making in multi-criteria approach is the aim of Multi-Criteria Decision-Making (MCDM) methods. In case of a finite number of alternatives (variants) Multi-Attribute Decision-Making (MADM) methods can be used. MADM methods determine procedures of processing information concerning alternative assessment in controlling in relations to a set of criteria. It is performed in order to establish a ranking of solutions and best choice. Within the above approach, a wide range of methods can be distinguished [2-6]. In the article three MADM methods are presented and compared while used to decision-making of particular subsystem in automated manufacturing system. This subsystem relates to controlling a trolley and particularly to define trolley's destination. Due to their popularity and minimization of needed expert knowledge the following methods have been chosen: SAW (Simple Additive Method) [7], WASPAS (Weighted Aggregated Sum Product ASsessment) [8] and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [6]. The above methods use weights in order to place preference of criteria during the choice of optimal alternative. As it was shown in [9] determination of criteria weights is a key task in decision-making process. In order to move away from subjectivism, in the article, apart from subjective weights Shannon's entropy [10] was used to determine criteria weights.

The remainder of the paper is organized as follows. In section 2 calculation procedure for SAW, WASPAS and TOPSIS methods is presented. Moreover, steps for establishing criteria weights with reference to Shannon's entropy are described. Section 3 refers to problems of decision-making in manufacturing system. The object of research and its simulative model are described as well as the structure of decision-making process are presented. Simulation results and discussion concerning the comparison of used methods can be found in section 4. Section 5 summarises the research done.

2. Chosen MADM methods

MADM methods relate to making preferential decisions concerning choice, assessment or ranking of decision alternatives in relation to chosen decision criteria. Assessments (values) of each alternative in relations to criteria are most often presented in the form of decision (evaluation) matrix $X = (x_{mn})_{MxN}$ (Table 1). In Table 1 x_{mn} is the evaluation of mth $(m = 1, \dots, M)$ alternative in relations to nth $(n = 1, \dots, N)$ criterion, however w_n is the weight of nth criterion. Criteria weights, following the requirement $\sum_{n=1}^{N} w_n = 1$, may be determined subjectively or using objective method (e.g. Shannon's entropy).

Table 1: *Structure of decision matrix*

	Criterion 1	Criterion 2	…	Criterion *N*
Alternative 1	x_{11}	x_{12}	⋯	x_{1N}
Alternative 2	x_{21}	x_{22}	⋯	x_{2N}
…	…	…	x_{mn}	…
Alternative *M*	x_{M1}	x_{M2}	⋯	x_{MN}
Weights	w_1	w_2	…	w_N

Subsequent steps of calculation procedure of final alternatives' ranking depend on the method used.

SAW method

The SAW method was used for the first time in [7] as a method for solving the portfolio selection problem. The main procedures to find the scores of the alternatives using SAW can be as follows.

1. Determine the normalized decision matrix $R = (r_{mn})_{MxN}$ in the following way:

$$r_{mn} = \begin{cases} \frac{x_{mn}}{\max_n x_{mn}} & if \quad n \in C_{ben} \\ 1 - \frac{x_{mn}}{\max_n x_{mn}} & if \quad n \in C_{cost} \end{cases}, \quad (1)$$

where C_{ben} is the set of benefit criteria, C_{cost} is the set of cost criteria. For benefit criterion the highest value of alternative evaluation is preferred whereas for cost criterion – contrary – the lowest value.

2. Calculate the weighted normalized decision matrix $V = (v_{mn})_{MxN}$ using the weights values (w_n, n = 1,…,N) as follows:

$$v_{mn} = w_n \cdot r_{mn}. \quad (2)$$

3. Aggregate the total relative importance of mth alternative as follows:

$$Q_m = \sum_{n=1}^{N} v_{mn}. \quad (3)$$

WASPAS method

WASPAS method was presented in [8] as an approach combining Weighted Sum and Weighted Product Models (WSM and WPM). Zavadskas et al. suggested that accuracy of WASPAS method is more advantageous than using only WPM or WSM. Stages of WASPAS method are presented below.

1. Determine the weighted sum model (WSM): aggregate the total relative importance of mth alternative in the following form:

$$Q_m^{(1)} = \sum_{n=1}^{N} w_n \cdot r_{mn}, \quad (4)$$

where r_{mn} is calculate using the formula (1).

2. Determine the weighted product model (WPM): aggregate the total relative importance of mth alternative as follows:

$$Q_m^{(2)} = \prod_{n=1}^{N} (v_{mn})^{w_n}. \quad (5)$$

3. Calculate the total importance of mth alternative in the following form [8,11]:

$$Q_m = \lambda \cdot Q_m^{(1)} + (1-\lambda) \cdot Q_m^{(2)}, \ \lambda \in [0,1], \quad (6)$$

where

$$\lambda = \frac{\sum_{m=1}^{M} Q_m^{(2)}}{\sum_{m=1}^{M} Q_m^{(1)} + \sum_{m=1}^{M} Q_m^{(2)}}. \quad (7)$$

TOPSIS method

TOPSIS method, proposed by Hwang and Yoon [6], is one of the most popular methods. It consists in comparison of weighted reference solutions: the positive ideal solution and the negative ideal solution. The total importance of alternatives is calculated by measuring simultaneously their distances from the positive ideal solution and the negative ideal solution. The steps of TOPSIS are as follows.

1. Calculate the weighted normalized decision matrix $V = (v_{mn})_{MxN}$ using the formula (2).

2. Determine the positive ideal solution S^+:

$$S^+ = (v_1^+, v_2^+, \dots, v_N^+) = \{(\max_m v_{mn} \mid n \in C_{ben}), (\min_m v_{mn} \mid n \in C_{cost})\}, \quad (9)$$

where C_{ben} is the set of benefit criteria, C_{cost} is the set of cost criteria.

3. Determine the negative ideal solution S^-:

$$S^- = (v_1^-, v_2^-, \dots, v_N^-) = \{(min_m v_{mn} \mid n \in C_{ben}), (\max_m v_{mn} \mid n \in C_{cost})\}. \quad (10)$$

4. Calculate the distances of each alternative from the positive ideal solution S^+ (d_m^+) and from the negative ideal solution S^- (d_m^-):

$$d_m^+ = \sqrt{\sum_{n=1}^{N} (v_{mn} - v_n^+)^2} \text{ and } d_m^- = \sqrt{\sum_{n=1}^{N} (v_{mn} - v_n^-)^2}. \quad (11)$$

5. Determine the relative closeness of mth alternative to the ideal solutions $S^+$and S^- in the following way:

$$Q_m = \frac{d_m^-}{d_m^+ + d_m^-}. \quad (12)$$

The last stage of these methods is the ranking of the alternatives according to their calculated value Q_m. The best alternative is the alternative with the largest value Q_m.

Determination of criteria weights with the use of Shannon entropy

From the perspective of information and decision-making processes in manufacturing systems as well as any other decision-making process, assessment criteria may have different meanings, hence criteria weights are not equal. Determining proper weights is the main and at the same time difficult stage in decision-making process. In literature, there can be found a division into two groups of methods of weights determining: subjective and objective methods. In case of large amount of data and automated objects the use of subjective methods is difficult or undesirable. In this case the use of subjective methods such as: entropy method, multiple objective programming [12], etc can be considered.

In the article, in order to determine the importance of criteria the concept of Shannon's entropy [10] was used. It plays an important role in information theory and is used for determining general uncertainty measures [13]. Original procedure of calculating weights on the basis of Shannon's entropy is as follows.

1. Calculate the normalized decision matrix $P = (p_{mn})_{MxN}$, where:

$$p_{mn} = \frac{x_{mn}}{\sum_{m=1}^{M} x_{mn}}. \quad (13)$$

2. Determine the entropy h_n $(n = 1, \dots, N)$ as follows:

$$h_n = -h_0 \sum_{m=1}^{M} p_{mn} \cdot ln(p_{mn}), \quad (14)$$

where h_0 as the entropy constant is equal to

$$h_0 = 1/(\ln M). \quad (15)$$

3. Determine the objective weights w_n $(n = 1, \dots, N)$ based on the Shannon's entropy concept:

$$w_n = \frac{1-h_n}{\sum_{n=1}^{N}(1-h_n)}. \quad (13)$$

3. Problem of decision-making in the flow of manufacturing system

The problem of decision-making in production process may be considered on different hierarchy levels. First level consists of machines: programmable controllers, controllers for CNC machines, robots, means of transport, etc. It is the operative control. Second level consists of decision-making in work cell and production line. These are: inspections and statistical process control, materials handling, part sequencing etc. Third level concerns factory floor, that is management process: materials management, maintenance management, quality management etc. Higher levels of decision-making consist of planning strategic controlling processes on the plant and distribution level.

In this article the issue of decision-making on the first level of hierarchy is considered. It concerns the control of the flow of work pieces in PVC (Poly(Vinyl Chloride)) windows manufacturing system with the use of a transport trolley. The details of the problem are presented below.

Problem formulation

The manufacturing system contains three concurrent and independent welding and cleaning lines (WCLs) and three assembly and treating lines (ATLs). The trolley, located between WCLs and ATLs, transports work pieces from one of the production lines

(WCLs) to the appropriate ATL. The problem in question consists in the development of a flow control algorithm for the trolley, which specifies the trolley's destination (the appropriate ATL) [9].

Structure of decision-making process

Flow control algorithm may be considered in the form of structure of decision-making process, where three ATLs (ATL1-ATL3), which are trolley's destination, are alternatives in MADM methods. Criteria for decision-making process are shown in Fig.1.

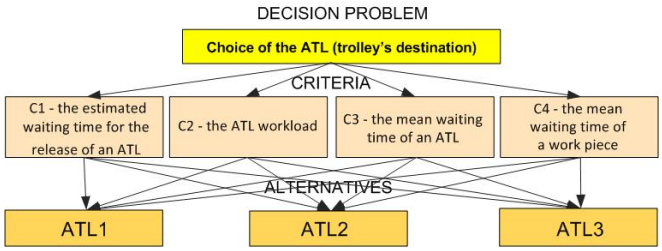


Fig. 1 *The structure of decision problem for trolley in the manufacturing system (cf. [14])*

Simulation model

To verify methods' efficiency a model of analysed manufacturing system has been created with the use of Matlab Simulink with SimEvents (see Fig. 2). Model consists of the following: workstations (units) within WCLs i ATLs (U1-U3), supporting buffers before ATLs, trolley and a trolley's controller. In order to make comparative analysis, the controller bases subsequently on three methods: SAW, WASPAS and TOPSIS. Controller at the input uses signals (information) coming from buffers and units U1-U3 and generates output concerning the destination of a work piece in the trolley (appropriate ATL). Signals from units are saved during the whole simulation and on its basis complex, average parameters are calculated. They are used as criteria in control process.

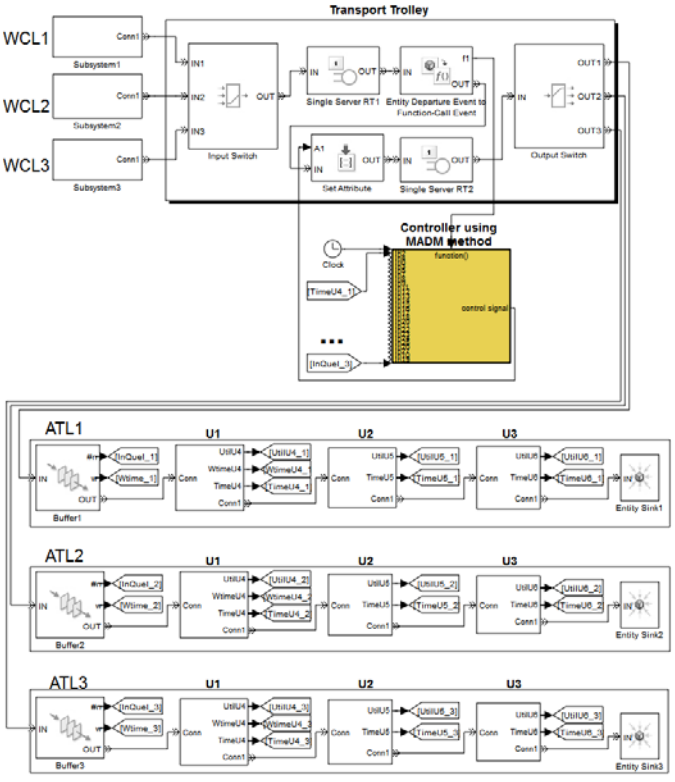


Fig. 2 *Model of manufacturing system in the Matlab Simulink (cf. [9])*

4. Results and discussion

MADM method with subjective weights of criteria

In the simulation, the parameters are calculated according to criteria C1-C4. These parameters can be used at the same time as criteria for the evaluation of the MADM method. The results of the simulation depend on the values of weight vector $w = \{w_n, n = 1, \dots, n\}$ for production line evaluation criteria. In this paper we present three different subjective weight vectors: $w = \{0.1, 0.4, 0.4, 0.1\}$, which indicates that balancing the workloads of a production line is more important than minimizing the waiting time on a production line; $w = \{0.25, 0.25, 0.25, 0.25\}$, which indicates that all the criteria are equivalent; $w = \{0.4, 0.1, 0.1, 0.4\}$, which indicates that balancing the workloads of a production line is less important than minimizing the waiting time on a production line.

Figure 3 present the results of the simulation using the three weight vectors, on the example of the SAW method. In the simulation we calculate both the workloads of the ATLs and the standard deviation of the workloads, taking into account all three ATLs. Fig. 3 shows that higher weights for criterion C2 (the ATL workload) and criterion C3 (the arithmetic mean waiting time of an ATL) result, in fact, in a better balancing of ATL workloads, but they also increase the mean waiting times of a work piece in the buffer just before the ATLs. Therefore, the application of MADM methods together with criteria weights allows for the individual adjustment of the control. The importance of the criteria can differ depending on the investor.

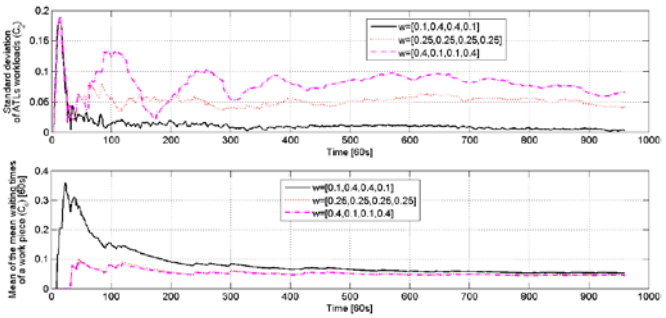


Fig. 3 *The comparison of SAW method with the various vectors of subjective weights*

The SAW, WASPAS and TOPSIS methods have been compared also with other dispatching rule, such as a simple method in which the first non-blocked ATL is used. In the analysis, $w = \{0.1, 0.4, 0.4, 0.1\}$ is used as the vector of criteria weights. Fig. 4 shows a comparison of the parameter values which are the aggregations of ATL parameters.

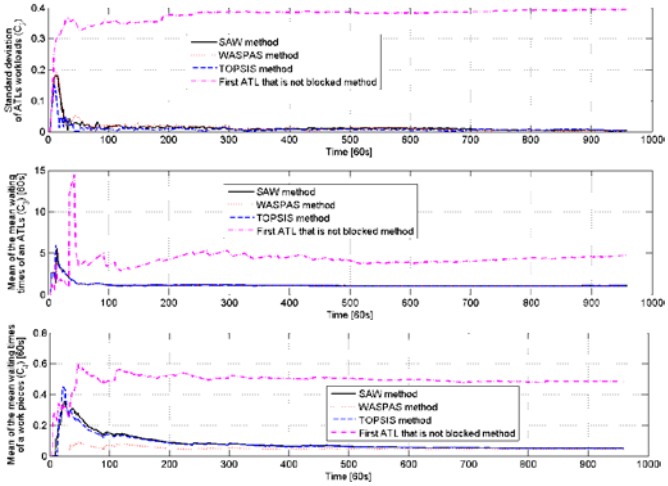


Fig. 4 *The comparison of MADM methods and a method in which the first non-blocked ATL is used*

Simulations using these methods indicate that the best production parameters are those obtained with WASPAS. In this method, the standard deviations of the line workloads are similar to those in the other MADM methods, but the means of mean waiting times of a work piece in ATLs are the lowest. One can also consider the application of TOPSIS; its results are comparable with those of WASPAS for some criteria weights. In this case of flow control, one should not apply the rule of using the first non-blocked ATL.

MADM method with weights based on Shannon entropy

In order to move away from subjective decisions in automated system, analysis considers using also weights basing on Shannon's entropy. Fig.5 presents the comparison of SAW, WASPAS and TOPSIS methods, which use the objective weight vector. On the basis of diagrams it can be stated that due to the mean waiting times of a work piece in the buffer just before the ATLs, SAW and WASPAS methods are more effective, especially at the beginning of manufacturing system operation. From the perspective of two subsequent criteria (the standard deviation of the workloads, the arithmetic mean waiting time of an ATL), it is difficult to say about visible advantage of any of the methods.

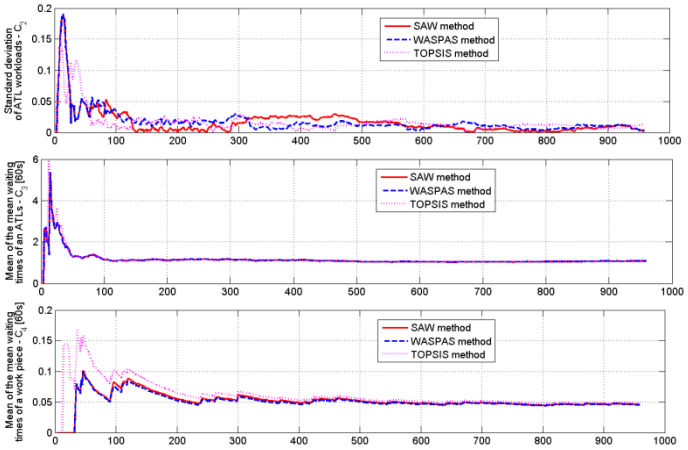


Fig. 5 *The comparison of MADM methods with weights based on Shannon entropy*

Analysed average parameters for manufacturing system (analyses results) for methods with weights based on Shannon entropy are better that in the case of using methods with subjective weights. In a particular case of preference of any of the criteria the value of this parameter (criterion) is advantageous for manufacturing system, however, the remaining parameters are less advantageous. In case of equality of criteria ($w = \{0.25, 0.25, 0.25, 0.25\}$), all analysed parameters are on average level whereas for objective weights the values of analysed parameters are comparable or more advantageous than in case of subjective equivalent criteria.

5. Conclusion

The case study shows that the older MADM methods (SAW, TOPSIS), as well as the new WASPAS method can be used with success as decision-making methods for a transport trolley. The methods presented here are not computationally complex, hence they can be readily used in PLC programming. The application of the multi-criteria approach allows to take into account criteria for machines (units) and all manufacturing system simultaneously. It is more flexible approach, because a change of production parameters has no large effects in lowering the effectiveness of control.

Additionally, the use of subjective criteria weights allows for simple adjustment of control to the investor's requirements. It is advantageous in case of particular preference of any of the criteria. However, in case of lack of particular preference of any of the criteria it is more advantageous to use objective weights basing on Shannon entropy.

The analyzed methods have been compared. The WASPAS method turns out to be the best in the analyzed case: the flow of the manufacturing system is optimal for the presented criteria. The results obtained are close to those of the round robin method but WASPAS can be effectively used in diversified production, which requires adapting to changing conditions and production requirements.

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SIMPLIFIED ANALYTIC SOLUTION OF THE PROBLEM OF AUTOMATED MOTION CONTROL OF AN AUTONOMOUS RIGID BODY WITHOUT ITS OWN PROPULSION SYSTEM IN INCOMPRESSIBLE STRATIFIED VISCOUS FLUID

УПРОЩЕННОЕ АНАЛИТИЧЕСКОЕ РЕШЕНИЕ ЗАДАЧИ АВТОМАТИЗИРОВАННОГО УПРАВЛЕНИЯ ДВИЖЕНИЕМ АВТОНОМНОГО ТВЕРДОГО ТЕЛА БЕЗ СИЛОВОЙ УСТАНОВКИ В СТРАТИФИЦИРОВАННОЙ ВЯЗКОЙ НЕСЖИМАЕМОЙ ЖИДКОСТИ

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Резюме: *This paper results are based on the mathematical model of the motion control of an autonomous solid body moving in incompressible stratified viscous fluid which was presented by the authors at and XIII MTM Congress held in March 2016 and XIII MTM Congress held in September 2016. It is assumed that the body does not have its own propulsion system, but is equipped with controlled rudders - wings of finite span. It is moved by the influence of the buoyancy force and wings lift effect. The control is produced by the angle of attack of the wing change for reaching to a neighborhood of the given point by this solid body. This body motion is considered to be plane-parallel motion. At this paper authors present a simplification of this mathematical model in order to find an analytical solution of the differential equation describing the object motion and a necessity and acceptability analysis of the simplification.*

КЛЮЧЕВЫЕ СЛОВА: MATHEMATICAL MODEL, MOTION OF SOLIDS IN A FLUID, MOTION COTROL, BUOYANCY FORCE, ENSURING ACCESS TO THE GIVEN POINT, WINGS OF FINITE SPAN, WINGS LIFT

1. *Introduction*

The effectiveness of observations and measurements obtained in the study of the underwater world via underwater vehicles, in particular, unmanned, depends on minimizing the impact of these submersible crafts to surrounding underwater environment. First of all, it refers to a moving apparatus, which movement is carried out by various power plants (screw propeller or other propulsion). Therefore, the reduction or elimination of such effects is an important application. The ideal situation would obviously be the complete lack of engine. This means that movement control of the body can be carried out only by natural hydrodynamic forces, for instance, the Archimedes buoyancy or an wing lift effect (the body can be equipped with wing). Basic terminology and classical results for the body's motion in continuum can be found in the books [1, 2].

2. *Mathematical model*

As an autonomous rigid body, the authors propose to consider a research submersible – a uniform sphere-shaped rigid body with two similar symmetrically located around the ball centre wings (fig. 1). Actually other modifications of mutual bracing of the sphere-shaped body and wings are possible. However, the proposed mathematical model can be taken as a basis for whole these alternatives.

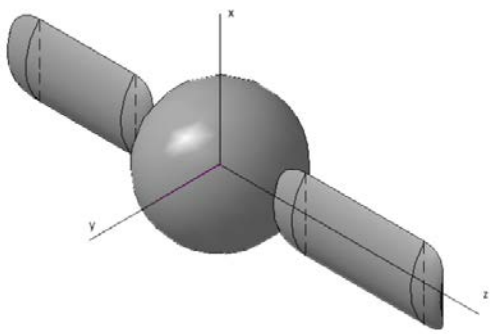


Fig. 1. Schematic submersible craft image.

The motion of submersible craft is assumed to happen in a limitless borehole bottom reservoir with an ideal incompressible non-conducting stratified liquid with viscosity effect. The viscosity is taken into account as a Stokes' drag force. It is also assumed that each layer has own density, which is known. Furthermore, liquid in each layer can move rectilinearly and uniformly with known velocity along the horizontal axis, which is perpendicular to a wingspread.

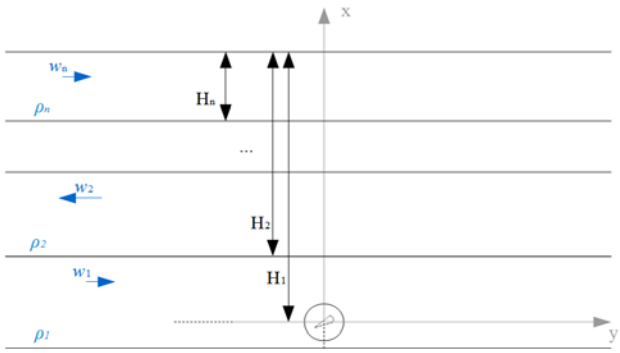


Fig. 2. Stratified continuous medium figure.

In this paper the authors consider plane-parallel motion of submersible craft case. At the initial time this body is located in stationary state at a predetermined depth (fig. 2). It is necessary to define the obtaining solution algorithm in a one-layer liquid for building a similar solution in stratified liquid..

At the previous authors paper [3,4] mathematical model of the submersible craft plane-parallel motion was constructed. It allows controlling the body through wings angle of attack α modifications:

$$\begin{cases} \left(m+\frac{2}{3}\rho\pi R^3\right)\frac{d^2x}{dt^2} = F_{arch} - 2F_i\cos\delta - \left(F_{drag}^{(1)} + 2F_{drag}^{(2)}\right)\cos\delta - 2F_{lift}\sin\delta - F_g; \\ \left(m+\frac{2}{3}\rho\pi R^3\right)\frac{d^2y}{dt^2} = -2F_i\sin\delta - \left(F_{drag}^{(1)} + 2F_{drag}^{(2)}\right)\sin\delta - 2F_{lift}\cos\delta. \end{cases}$$

Here F_{arch} – is the buoyancy force, $F_{drag}^{(j)} = C_X^{(j)} S^{(j)} \frac{\rho v^2}{2}$ – the head resistance force for a sphere (j=1) and wings (j=2), $F_{lift} =$

$\rho v^2 S \frac{k\alpha}{1+\mu_0}$ – the wing lift, $F_i = \frac{\rho}{2} v^2 S \frac{\mu_0}{2k} \left(\frac{2k\alpha}{1+\mu_0}\right)^2$ – the induced drag force (details can be found in [3]).

Using the standard change of variables:

$$x = z_1 \qquad y = z_3$$
$$\dot{x} = \dot{z_1} = z_2 \quad \dot{y} = \dot{z_3} = z_4,$$

initial mathematical model is reduced to the nonlinear differential equation system:

$$(1) \quad \begin{cases} \dot{z_1} = z_2, \\ \dot{z_2} \cdot b_0 = b_1 - (b_2 \cdot \alpha^2 + b_3 + 2b_4) \cdot z_2 \cdot \sqrt{{z_2}^2 + {z_4}^2} - \\ \quad -2b_5 \cdot \alpha \cdot z_4 \cdot \sqrt{{z_2}^2 + {z_4}^2} \\ \dot{z_3} = z_4, \\ \dot{z_4} \cdot b_0 = -(b_2 \cdot \alpha^2 + b_3 + 2b_4) \cdot z_4 \cdot \sqrt{{z_2}^2 + {z_4}^2} + \\ \quad +2b_5 \cdot \alpha \cdot z_2 \cdot \sqrt{{z_2}^2 + {z_4}^2} \end{cases}$$

Here coefficients are defined as:

$b_0 = m + \frac{2}{3}\rho\pi R^3$, $b_1 = \rho g V - mg$, $b_2 = \rho S_{kp} \frac{2k\mu_0}{(1+\mu_0)^2}$, $b_3 = c_{0_sph} \frac{\rho\pi R^2}{2}$, $b_4 = c_{0_w} \frac{\rho S_w}{2}$, $b_5 = \rho S_{kp} \frac{k}{1+\mu_0}$.

From a practical standpoint, it is presented that the system (1) is too lengthy for operational applications. The authors show below, that this system can be simplified without the loss of required accuracy in significant cases from the applied point of view.

3. *Simplified mathematical model*

By analyzing numerical solution of differential equation system (1) in homogeneous liquid with zero initial conditions [4], it can be noted that $z_2 \gg z_4$. Therefore $\sqrt{{z_2}^2 + {z_4}^2}$ can be expand this function in a Taylor series near the point $z_4/z_2 = 0$:

$$\sqrt{{z_2}^2 + {z_4}^2} = z_2 \sqrt{1 + \frac{{z_4}^2}{{z_2}^2}} \approx z_2 \left(1 + \frac{z_4}{2z_2} - \frac{1}{8}\left(\frac{z_4}{z_2}\right)^3 + \cdots\right).$$

It is assume that $\sqrt{{z_2}^2 + {z_4}^2} \approx z_2$. By excluding a term $-2b_5 \cdot \alpha \cdot z_2 \cdot z_4$ from the second equation of (1) under the assumption of $z_2 \gg z_4$, differential equation system is transformed into

$$(2) \quad \begin{cases} \dot{z_1} = z_2, \\ \dot{z_2} \cdot b_0 = b_1 - (b_2 \cdot \alpha^2 + b_3 + 2b_4) \cdot {z_2}^2 \\ \dot{z_3} = z_4, \\ \dot{z_4} \cdot b_0 = -(b_2 \cdot \alpha^2 + b_3 + 2b_4) \cdot z_2 \cdot z_4 + 2b_5 \cdot \alpha \cdot {z_2}^2 \end{cases}$$

If the function of attack angle is time-invariant (constant value), the system (2) can be solved [5] with zero initial conditions:

$$(3) \begin{cases} z_1 = -\sqrt{\frac{k_1}{k_2}} + \frac{1}{k_2} \ln\left(\frac{exp\{2\sqrt{k_1 k_2}t\}+1}{2}\right), \\ z_2 = \sqrt{\frac{k_1}{k_2}} \cdot \frac{exp\{2\sqrt{k_1 k_2}t\}-1}{exp\{2\sqrt{k_1 k_2}t\}+1} \\ \dot{z_3} = z_4, \\ z_4 = \frac{2exp\{\sqrt{k_1 k_2}t\}}{1+exp\{2\sqrt{k_1 k_2}t\}} \cdot \frac{k_1 k_3}{k_2} \int_0^t \left(\frac{exp\{2\sqrt{k_1 k_2}t\}-1}{exp\{2\sqrt{k_1 k_2}t\}+1}\right)^2 \cosh\sqrt{k_1 k_2}t\, dt \end{cases}$$

Here coefficients are defined as:

$k_1 = \frac{b_1}{b_0}$, $k_2 = \frac{(b_2 \cdot \alpha^2 + b_3 + 2b_4)}{b_0}$, $k_3 = \frac{2b_5 \cdot \alpha}{b_0}$.

Below it is shown that original and simplified system numerical solutions coincide virtually.

4. *Numerical examples*

Software called MATLAB 7.10.0 (R2010A) is used for numerical solution.

Motion of the submersible craft in homogeneous (single-layer) ideal incompressible viscous fluid with shear flow in the line of horizontal axis is considered. Authors examine three cases of the variation law of attack angle:

1) $\alpha = 0.3$;
2) $\alpha = 0$;
3) $\alpha = -0.3$.

4.1. *Original system numerical solution*

Fourth-order of accuracy Runge-Kutta method was applied for numerical solution of the differential equation system (1).

Motion trajectories of the submarine craft corresponding to the angle of attack can be calculated by solving the system (1) with zero-initial condition (fig. 3).

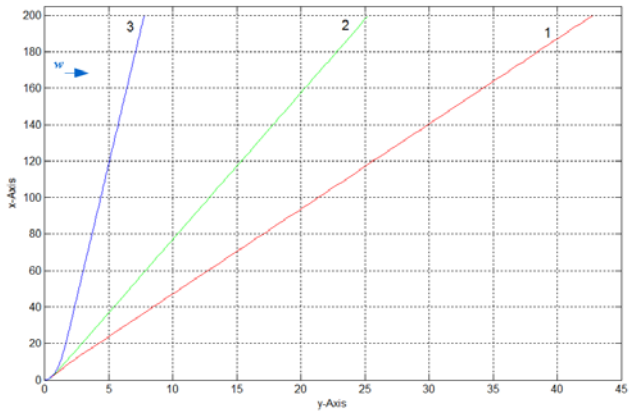


Fig. 3. Motion trajectories of the submarine craft in accordance with system (1).

4.2. *Simplified system solution*

In the system (3) the first two equations represent in an explicit form dependence of the first (z_1) and the second (z_2) components on time. In order to solve the third and the fourth equations, the authors use the method of numerical integration of single variable function – trapezium method.

Motion trajectories of the submarine craft corresponding to the angle of attack can be calculated by solving the system (3) with zero-initial condition (fig. 4).

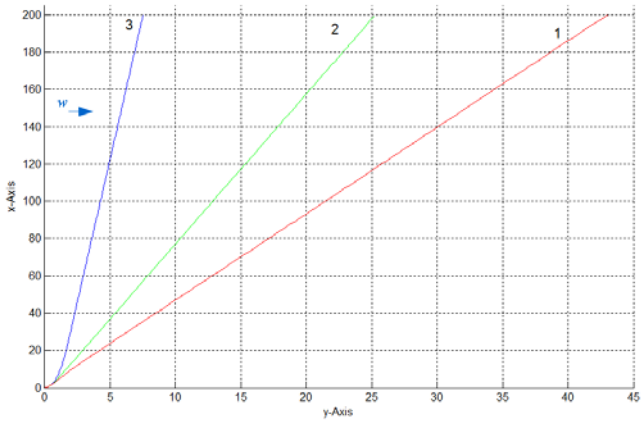


Fig. 4. Motion trajectories of the submarine craft in accordance with system (3).

From figure 3 and 4 it can be noted that the nature of the trajectories of the submersible craft motion does not change during the transformation from system (1) to the system (3). Component-wise divergences of the system (1) and (3) solutions are presented in a figure 5.

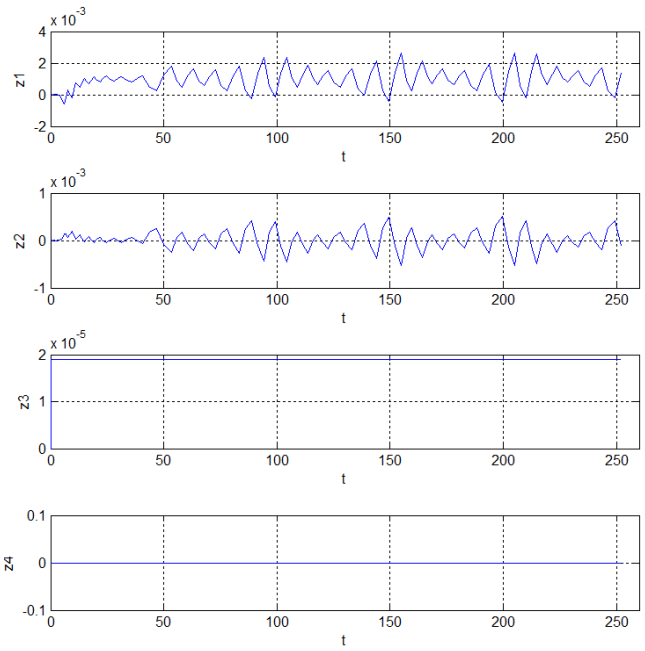


Fig. 5. Component-wise divergencse of the system (1) and (3) solutions.

In the figure 5 the largest variances are obtained for the first (z_1) and the second (z_2) components. This is explained by the fact that for the system (1) these components are calculated numerically while for the system (3) they are defined analytically. The third (z_3) and the fourth (z_4) components have the least differences due to the use of numerical methods in both cases.

At these examples, the following values of quantities are offered. The diameter of the surfaced body (ball) is 1 meter; its mass is calculated like $m = 0.98\rho V$, where ρ is averaged body density. It is assumption to consider rectangular wings with wingspan 1 meter, aspect ratio of the wing 5 and relative maximum thickness 16 %. An initial immersion depth H_1 equals 200 meters. In case of homogeneous liquid its density is supposed to be 1038 kg/m^3, shear flow velocity – $|\vec{w}| = 0.1$ m/s.

5. *Conclusion*

At this paper analysis of the possibility of simplifying the original system which describes the motion of the submersible craft without its own propulsion system in homogeneous (single-layer) incompressible viscous fluid with shear flow in the line of horizontal axis is presented. In the transformation to stratified (layered) liquid it is necessary to solve the corresponding differential equation system sequentially for each layer starting with the bottom layer. Its initial conditions are supposed zero conditions. For other layers initial conditions are recalculated depending on coordinates of inertia center of the submarine craft at the transitional point from layer to layer.

Thus, the authors solved 2 problems:

1. The transformation to the simplified equation system allowing analyzing the behavior of the system by analytical methods is justified.
2. Development algorithm of numerical solution of the system is simplified. It has substantial practical value.

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IEC-62264 BASED QUALITY OPERATIONS MANAGEMENT ACCORDING THE PRINCIPLES OF INDUSTRIAL INTERNET OF THINGS

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Abstract: *Manufacturing Operations Management (MOM) systems as central information and data hub play a very important role for an easy and seamless transition to Industrial Internet of Things (IIoT) applications. IIoT is mainly used in the context of Industry 4.0, that pursues the organization and management of value-added processes in the manufacturing industry with means of digitalization. The main aim of the proposed paper is to suggest some modifications to the IEC 62264 based models and architectures using RAMI 4.0 reference architecture in order to follow the basic principles of IoT and achieving the main advantages of IIoT.*

Keywords: INTERNET OF THINGS, OPERATIONS MANAGEMENT, QUALITY, REFERENCE ARCHITECTURE, ISO/IEC 62264

1. Introduction

Achievements in industry are closely related to the use of the latest developments in information and communication technology. Regardless of the progress made in using ICT, modern enterprises are characterized by a relatively static IT architecture that cannot cope with the changes and uncertainties, lack of flexibility of hardware and software systems as well as rigid boundaries between cooperating companies. It has been found that the advanced Internet of Things (IoT) paradigm can address these issues by ensuring reliable data collection and sharing, ubiquitous computing, and computing clouds using powerful resources to solve a variety of decision-making tasks that abound in production systems.

IoT is an Internet extension that provides immediate access to information about physical objects and leads to innovative services with high efficiency and productivity [1]. IoT is also known as ubiquitous computing, ambient intelligence, and distributed electronics. The core concept is that everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective.[2]

The Industrial Internet of Things (IIoT) is the industrial application of IoT paradigm and is mainly used in the context of Industry 4.0. Industry 4.0 describes a new industrial revolution with a focus on automation, innovation, data, cyber-physical systems, processes and people. Considering a faster adoption of the new concept by industry, it is desirable to ensure a smooth transition to new technologies through the use of transition technologies and standards to achieve the IIoT objectives without major investment. For this reason, there are plenty of prerequisites in the industry: embedded devices and controllers, wireless sensor networks, RFID technologies and more. While hardware industry is relatively prepared for a transition to IIoT, there are serious challenges to software and architectures. An important step in the right direction is to use reference architecture that aims to achieve interoperability, simplify development, and facilitate implementation. Some of the most popular reference architectures are: RAMI4.0 [3], IIRA [4], IoT-A [5]. While IoT-A focuses on the functional and informational aspects of the architecture, RAMI4.0 of the Working Group for Industry 4.0 and IIRA of the Industrial Internet Consortium are industry-focused. Between the last two reference architectures exist some similarities and intersections, and there is an agreement between organizations to precisely identify the interoperability features between the two architectural paradigms and try to align them, as well for defining standardization requirements and using common test beds. The approach, proposed in this paper is based on RAMI 4.0 model, because it is built upon existing standards and functional descriptions and only some modifications are needed to achieve an IIoT application.

Manufacturing Operations Management (MOM) systems are key element in achieving IIoT applications, or also known smart factories. They are increasingly used for real-time control and visualization of production sequences, linking the manufacturing facilities with the business information systems and staying in the middle of automation pyramid. IEC 62264 standard supports the development and use of MOM, providing standard models and terminology for describing the activity models of manufacturing operations management and interfaces between the business systems of an enterprise and its manufacturing operations and control systems, in order to integrate them [6, 7]. Quality operations management is an important set of activities in the frame of MOM and is very suitable for a transition to IioT application.

The main aim of the proposed paper is to suggest some modifications to IEC 62264 based models and architectures in respect to the Quality operations management using RAMI 4.0 reference architecture in order to follow the basic principles of IoT and achieving the main advantages of IIoT.

The paper is organized in 4 parts. After the introduction, in part 2 the basic principle of IIoT are proposed. Part 3 discusses the ISO/IEC 62264 standard as a part in the IIoT architecture with a special attention on the quality operations management. In Part 4 of the paper the suggested approach is described. Finally some conclusions are made.

2. Basic Principles of Industrial Internet of Things

Tom Bradicich [8] defines 7 basic principles of IoT, as shown in Fig.1:

①*"Big Analog Data"* - The IoT will include vast numbers of heterogeneous predominately analog devices and sensors, generating enormous quantities of variable analog data that is the oldest, fastest, and biggest of all big data. Analog data needs to be treated differently than digital data, and the unresolved problem is the extraction of business value from big analog data.

②*"Perpetual Connectivity"* - the IoT presents perpetual connectivity to the product and user, supporting 3 main functionalities:

- Monitor - continuous observing and checking the progress or quality of products, users on the market or industrial settings, allowing their systematic review;
- Maintain – to keep equipment in a good condition trough convenient push of upgrades, fixes patches and management;
- Motivate – the ongoing connection to users or workers shows the way to force or motivate others to take some actions, purchase a product, accessories, etc.

③ *"Really Real Time"*- IoT blends the world of Operational Technology with the world of Information Technology, following a 4 tier generalized solutions architecture for the IoT, and its related data flows:

- Tier 1: Sensor/actuator (wired, wireless);
- Tier 2: Internet gateways, Data acquisition systems (data aggregation, A/D, measurement, control actuation);
- Tier 3: Edge IT (analytics, pre-processing);
- Tier 4: Data center/Cloud (Analytics, management, archive).

④ *"The Spectrum of Insight"(Спектър на прозрение)* - Data analytics will be executed at 4 main domains

- At the sensor in the I/O channel;
- At the gateway or DAQ device;
- At the edge server or PC;
- At the data center or cloud.

⑤ *"Immediacy Versus Depth"* - Using advanced computer techniques and depending on the type of tasks solved, a compromise between speed and depth has to be found (so known "immediacy of insight vs. depth of insight"). Some tasks require immediate access to data and results from simple calculations, while others require more time to extract deep knowledge.

⑥ *"Shift Left"* - computation and data analytics will migrate to the lower tiers in the 4 Tier generalized solutions architecture of the IoT, enabling components and machines to gain self-awareness and self-predictiveness.

⑦ *"The Next 'V'"* - The IoT eliminates time and place constraints allowing access from disparate geographic locations and representing the "Visibility" of Big Data. Such a way IoT adds a next "V" to the traditional "V's" of Big Data, which are: variety (mix of structures), volume (large amounts), velocity (high speed, high sample rates), value (importance of analysis, which was previously limited by technology).

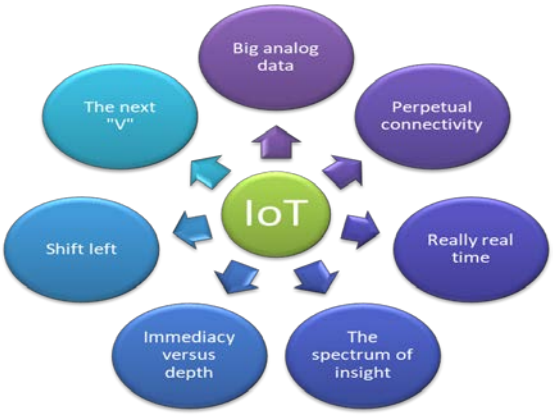


Fig.1: Basic principles of IoT

3. IEC-62264 standard as a part of IIoT

3.1. Short review and analysis of ISO/IEC-62264 Standard

ISO/IEC 62264 (ANSI/ISA-S95) series of standards [6, 7] offer the technology and a vendor independent way to exchange data and information. These standards are an agreement between leading companies (SAP AG, Eli Lilly, The Foxboro Co., Hewlett-Packard, Honeywell, Rockwell Automation, IBM Corp., Oracle Corp., ABB etc.) to create a common framework and guidelines for design and integration of systems. The standard ISO/IEC 62264 facilitate to separate business process from production processes and to separate the exchanged information from specific implementation of manufacturing systems and specific implementations of the business systems. The standard provides standard models and terminology for describing the interfaces between the business systems of an enterprise and its manufacturing-control systems (Fig.2). Activities related to manufacturing operations management (Level 3) integrate planning and logistics (level 4) and control functions defined on Level 2.

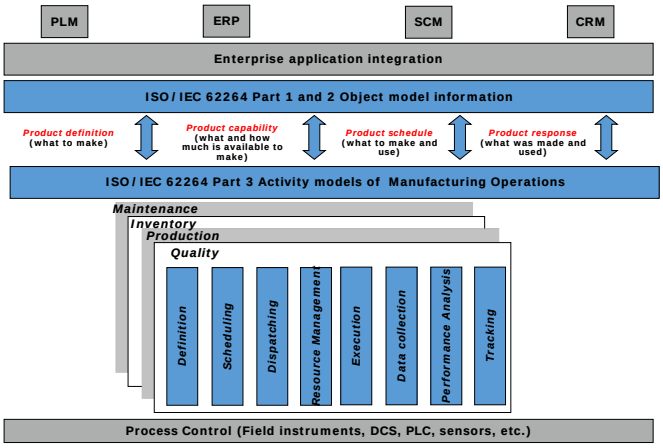


Fig.2: ISO/IEC 62264 Manufacturing Architecture [9]

According ISO/IEC 62264 the activities in manufacturing operations management are divided into four main areas: Production operation management, Maintenance operations management, Quality operations management and Inventory operations management. For all areas a common activity model of 8 activities (definition, planning, dispatching, resource provision, implementation, data collection, tracking and analysis) is suggested. The interrelationships between the four areas of MOM and the links with the main categories of information exchange defined in the standard are presented in Fig.3.

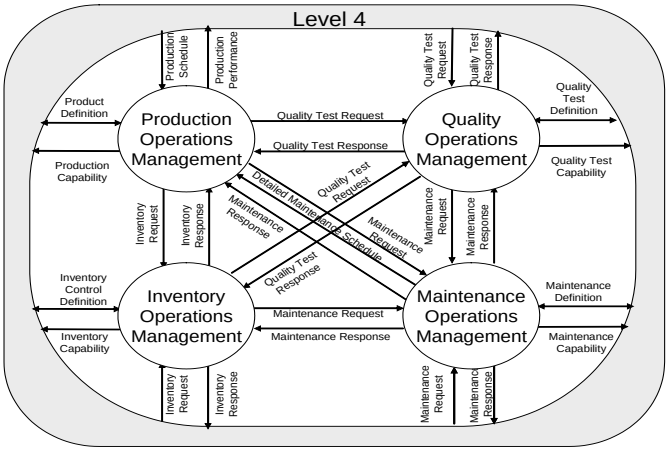


Fig.3: Interrelations between the areas of manufacturing operations management [7]

3.2. Quality operations management according ISO/IEC 62264

Quality operations management in the ISO/IEC 62264 standard is defined as a set of activities, which coordinate, manage and track the functions that measure and report quality. Quality operations management activities include: assessment of raw materials, intermediate and finished products, collection and maintenance of data records, use of analysis, real-time decision making, classification and certification tests, validation of measurements, maintenance of statistics for quality management.

The activity model for quality operations management, presented in Fig.4, defines what quality verification activities should be performed and the relative sequence of activities without specifying the way they are to be performed. The information related to the quality operations management according to the activity model is associated with the level 2 functions in the following categories: parameters and procedures, automatic commands for performing tests and obtaining results from them. Information flows from and to level 3 are classified as test definitions, resources, queries, and quality test results. The standard defines 8 types of activities related to the functions of the operations

management systems for quality testing (Fig.3): Quality test definition, Quality test resource, Detailed quality test scheduling, Quality test dispatching, Quality test execution, Quality test data collection, Quality test performance analysis and Quality test tracking.

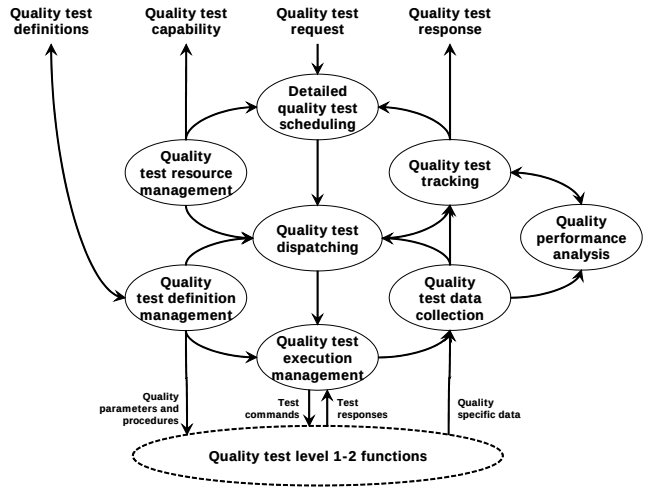


Fig.4: Activity model of quality operations management [7]

3.3. ISO/IEC 62264 as a part of RAMI4.0

The reference architectural model RAMI 4.0, proposed for Industry 4.0 and shown in Fig.5, is three-dimensional and describes the crucial aspects of Industry 4.0 [3]. The "Hierarchy level" axis includes the hierarchy levels defined in the ISO/IEC 62264 standard, including all different functionalities in the factory. In the RAMI 4.0 the functionalities are extended to the "product" according IEC 61512 standard and to "connected world". The left horizontal axis represents the life cycle of the facilities and products, based on the IEC 62890 standard and the vertical axis represents the six layers for decomposing into its properties. The reference model allows a step-by-step migration from present into the world of Industry 4.0. RAMI 4.0 integrates different user perspectives and provides a common understanding of Industry 4.0 technologies. It is a foundation for the following next steps towards Industry 4.0: thing identification, unified semantics and common syntax for data, defining of QoS components, communication connections and protocols.

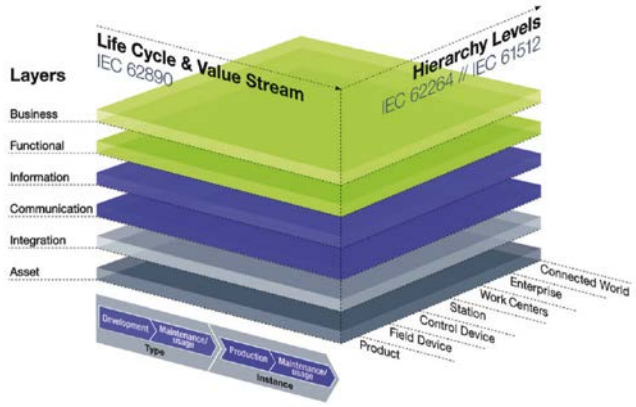


Fig.5: Activity model of quality operations management [3]

4. Quality operations management as IIoT application

For achieving an IIoT application of quality operations management system, a smooth migration path from existing deployments to emerging future internet technologies is needed. There is a consensus on the main steps to be taken [9], namely:

- Transparent (visible) factory - In his role as a central information and data hub, the MOM systems connect the business level in the form of the ERP system to the shop floor, thus ensuring mutual understanding and ultimately more transparency.
- Reactive factory (decentralization and autonomy) – based on identification of disturbances, detailed scheduling and reactive control
- Self-regulating factory - achieve more control loops and decentralization of tasks, control and the corresponding responsibilities. However, central synchronization is essential.
- Functional networking factory – based on interface between product development and production that is between PLM (product lifecycle management system) and MOM system, as well integrated quality assurance, a production-oriented energy management as well as the broadening of the viewing space to suppliers and customers - that is, to the complete supply chain.

The analysis of the above steps shows that paramount in building IIoT applications is the implementation of IEC 62264 based MOM system that supports the realization of three from all four steps. However, in order to achieve Step 3, it is necessary to solve the task of decentralizing the hierarchical model proposed in IEC 62264 standard according to the idea, presented in Fig.6. There are different approaches to successful decentralization in order to enhance integration and collaboration between decentralized components and to achieve self-X features of the system. The most successful and reliable approaches are those of Service Oriented Architecture (SOA) [10] and multi-agent systems (MAS) [11], as well the emerging infrastructures for fog or edge computing [12, 13]. MAS are widely used in the design of distributed manufacturing control systems with the purpose to enhance the horizontal and vertical integration of the enterprise systems. A short survey of the applied approaches is given in [14]. The fog computing extends the cloud computing closer to the enterprises network and is a horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum [12]. Very often the fog and edge computing are used interchangeably, but between them there is a difference in respect to the involved pushing intelligence and processing capabilities [13]. While the fog computing pushes intelligence down to the local area network level of network architecture, processing data in a fog node or IoT gateway, the edge computing uses for this purpose edge gateway or appliance directly into devices like programmable automation controllers.

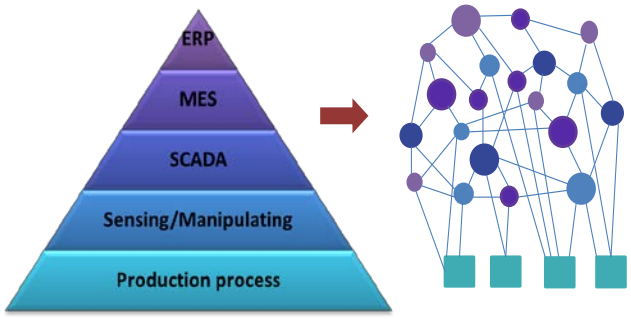


Fig.6: Transformation of automation pyramid

The IT structure of an IIoT components according RAMI 4.0 is represented on the vertical axis and consists of six layers. This layers help to visualize business processes, functional descriptions, data mappers, the communication behavior including Quality of Service (QoS), and the linking of assets via an integration layer. The data generated during production and in some cases customer-specific data for a specific instance is also considered as an asset.

The structure and sequence of operations at the functional level for Work Centers follows the proposed IEC 62264 based activity model, and in Fig.7a the activities and operations realized at this stage of development are presented. These are mainly related to

checking and evaluating the quality of intermediate and final products, collecting and maintaining records, reporting on classification results, using "at-time" analysis for decision-making in real time in terms of technology mode and specific technology map. According to the information from the business level for the quality of raw materials and product requirements, an intermediate quality assurance procedure for intermediates has been established with the help of the resource database. The information stored in the database can be analyzed using various means of information processing and decision making. Tracking the change of information is essential for the future implementation of the detailed scheduling of quality assurance procedures.

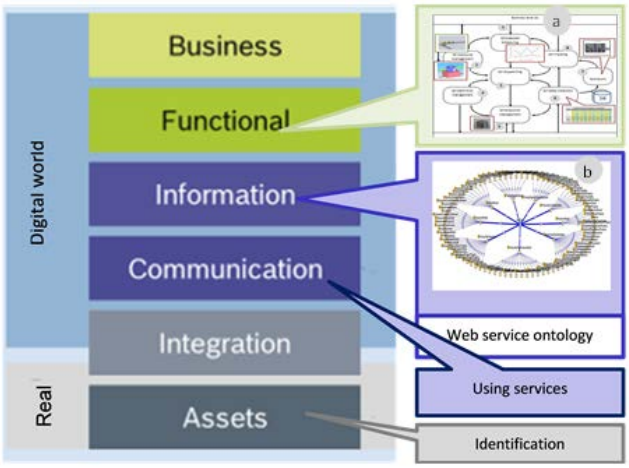


Fig.7: IT structure of quality operations management system based on RAMI 4.0

The quality operations management systems use a large amount of data from different data models. These models address different problems, have different users, may have been designed at different times, or may have come from different plant areas. In order to integrate and use these models, semantic technologies are used, based on the development of IEC 62264 based meta-ontology (Fig.7b) and different domain ontologies, as well an ontology for quality operations management, according to the standard model in ISO/IEC 62264 Part 4: Object Models and Attributes of Manufacturing Operations Management [16] and integrate it with the meta-ontology. In this way the quality management information, structured by the basic classes in the meta-ontology: "Material", "Equipment", "ProcessSegment" is connected with the five main interface classes, defining the relations Production-Process-Product: "ProductDefinition", "ProductionCapability", "ProductionSchedule", "ProcessSegmentCapability" and "ProductionPerformance" ensuring the main tasks in quality operation management: Quality test definition management. Quality test resource management, Detailed quality test scheduling, Quality test dispatching, Quality test execution management, Quality test data collection, Quality test tracking, Quality performance analysis. The ontological approach allows the creation of a knowledge-based system able to identify changes in the quality and to support decision-making through the integration of domain ontology and semi-structured data, including data from laboratory analyzes of raw materials and end products. Integration of different models and data ensures flexible communication between enterprise information systems by ensuring interoperability and mutual exchange of information. The aggregate model provides data sharing capabilities and the ability to retrieve information from distributed heterogeneous sources for decision making, Key Performance Indicators (KPIs) calculations, and optimization of manufacturing and business processes.

5. Conclusions

The transformation of MOM systems and especially quality operations management systems according to the basic principles and reference architecture of IIoT for their integration into the structure of IIoT applications is an important step in achieving high quality of end products and efficiency of manufacturing system. The use of IEC 62264 based models and terminology shorten the development time and reusability of models and architectures. The transition from object-oriented models to semantic models enhances the interoperability of IIoT components at the different levels of RAMI 4.0 reference architecture. The use of reasoning mechanisms and the creation of rules based on the formalism of descriptive logic support the creation of a knowledge-based system capable of responding to changes in the product quality and quality assurance procedures. In addition the quality operations management systems comprise quality analysis functionalities and are a source for new information; they can assist with optimizing the quality parameters. The systems offer a rational functional supplement for detailed scheduling of quality assurance procedures and controlling all quality parameters in real time for ensuring process and product quality transparency.

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VIBRATION POWER GENERATION WITH PIEZOELECTRIC ELEMENT USING MECHANICAL-ACOUSTIC COUPLING IN ACTUAL ENVIRONMENT

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Abstract: *This paper describes electricity generation characteristics of the vibration power generator with piezoelectric elements. In general, it is well-known that the above generator has low generation efficiency, having so simple structure. Moreover, vibrations of broad frequency band, which exist in actual environment, bring the characteristics to lower efficiency in comparison with the particular situation in which the host structure is excited by the vibration of the natural frequency. In this study, the vibrations of broad frequency band, i.e. random vibration, attracts attention and mechanical-acoustic coupling with an internal sound field enclosed by the host structures, on which the piezoelectric element is installed, is adopted to improve the electricity generation efficiency. The behavior of mechanical-acoustic coupling is determined by the relationship between the respective characteristics of the host structure vibrations and the internal sound field, so that the electricity generation efficiency depends strongly on those dimensions. Here, the electric power and the electricity generation efficiency are regarded as the representative characteristics of the electricity generation, then the characteristics are considered based on them with changing the dimensions to find the condition in which the efficiency can be improved. As a result, the applicability of such a power generation system in actual environments is mentioned.*

Keywords: MECHANICAL-ACOUSTIC COUPLING, CYLINDRICAL STRUCTURE, THIN END PLATE, INTERNAL SOUND FIELD, PLATE VIBRATION, NATURAL FREQENCY, RANDOM EXCITATION, PIEZOELECTRIC ELEMENT

1. Introduction

Scavenging untapped vibration energy and converting it into usable electric energy via piezoelectric materials has attracted considerable attention and has been regarded as one of new energy sources[1]. The authors have also been interested in a mechanical-acoustic coupling problem. The representative example was investigated as an architectural acoustic problem via a coupled panel-cavity system consisting of a rectangular box with slightly absorbing walls and a simply supported panel. The effect of the panel characteristics on the decay behavior of the sound field in the cavity was considered both theoretically and experimentally[1,2].

To develop a new electricity generation system, we adopt a cylindrical structure with plates at both ends as an analytical model, because the vibration area of the model on which piezoelectric elements can be installed is twice as large as that in the case of a single plate. The plate vibration induces electricity generation via electro-mechanical coupling with the piezoelectric effect of the surface-mounted piezoelectric element, while the plate vibration of the excitation side oscillates the other plate via mechanical-acoustic coupling. Consequently, the electro-mechanical-acoustic coupling problem must be considered and not only the natural frequency of the plate is adopted as the excitation frequency, but also the excitation of broad frequency band, i.e. random excitation, is attempted to assume an actual environment.

2. Analytical method

2.1 Analytical model

The analytical model consists of a cavity with two circular end plates, as shown in Fig. 1. Plates 1 and 2 are supported by translational and rotational springs distributed at constant intervals and the support conditions are determined by the translational spring stiffnesses T_1, T_2 and the rotational spring stiffnesses R_1, R_2, and then the suffixes 1 and 2 indicate plates 1 and 2, respectively. The plates of radius r_c have a Young's modulus E_c and a Poisson's ratio ν_c, however, the plate thickness is denoted by h_{c1} and h_{c2}, because it's possible the plates are different in the thickness. On the surfaces of both plates, piezoelectric elements are installed at the centers of the plates and have radius r_p, thickness h_p, Young's modulus E_p, and Poisson's ratio ν_p. Then an electrode plate is sandwiched between the above plate and piezoelectric element and has radius r_b, thickness h_b, Young's modulus E_b, and Poisson's ratio ν_b. The suffixes *c*, *p*, and *b* herein indicate the circular plate, piezoelectric element and electrode plate. On the other hand, the sound field, which is assumed to be cylindrical, has the same radius as that of the plates and varying length L because the resonance frequency depends on the length. The boundary conditions are considered structurally and acoustically rigid at the lateral wall between the structure and sound field. The coordinates used are radius r, angle ϕ between the planes of the plates and the cross-sectional plane of the cavity and distance z along the cylinder axis. The periodic point force F is applied to plate 1 at distance r_1 and angle ϕ_1. The natural frequency of the plates is employed as the excitation frequency.

w_{c1} and w_{c2} are the flexural displacements of plates 1 and 2, and w_{p1} and w_{p2} are those of the piezoelectric elements installed on the plates. They are found by substituting X^{s}_{cnm} of Equation (2) for the plate modes into Equation (1) as suitable trial functions. The flexural displacements of the piezoelectric elements are identical to those of the plates, respectively, because it is assumed that the piezoelectric elements adhere completely to each circular plate through the electrode plate.

$$w_{c1} = w_{p1} = \sum_{s=0}^{1}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty} X^{s}_{nm} A^{s}_{1nm} \mathrm{e}^{\mathrm{j}(\omega t+\alpha_1)} , \quad (1)$$

$$w_{c2} = w_{p2} = \sum_{s=0}^{1}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty} X^{s}_{nm} A^{s}_{2nm} \mathrm{e}^{\mathrm{j}(\omega t+\alpha_2)},$$

$$X^{s}_{nm} = \sin(n\phi + s\pi/2)(r/r_c)^m , \quad (2)$$

Where n, m, and s are, respectively, the circumferential order, radial order, and symmetry index with respect to the plate vibration. A^{s}_{1nm} and A^{s}_{2nm} are coefficients to be determined, ω is the angular frequency of the harmonic point force acting on the plate, and t is the elapsed time. α_1 and α_2 are the phases of the respective plate vibrations. In this analysis, α_1 is set to 0°, and α_2 ranges from 0° to 180°.

2.2 Modelling of Piezoelectric Part

Only the piezoelectric part of plate 1 is used to explain its modelling in this section. The relationships of stress σ_{p1}, strain ε_{p1}, electric displacement D_1, and electric field E_1 are as follows:

$$\begin{Bmatrix}\sigma_{p1}\\ D_1\end{Bmatrix} = \begin{bmatrix}E^{E}_{p} & -e^{T}\\ e & \gamma^{\varepsilon}\end{bmatrix}\begin{Bmatrix}\varepsilon_{p1}\\ E_1\end{Bmatrix}. \quad (3)$$

E^{E}_{p} signifies Young's modulus that was measured at a constant electric field, and γ^{ε} indicates the dielectric constant that was measured at a constant strain. The above equation expresses

relationships between electrical and mechanical characteristics of a piezoelectric element, and the stress is concretely related to the electric field by the piezoelectric coupling coefficient *e*. The piezoelectric coupling coefficient is expressed as

$$e = d_{31} E_p^E, \tag{4}$$

where d_{31} is the piezoelectric strain constant, in which the electric field occurs in the normal direction of the in-plane strain.

Then the electric field E_1, which occurs between both sides of the piezoelectric element, is expressed as follows:

$$E_1 = Y_{nm} v_1 = -R_p \dot{q}_1 = \mathrm{j}\omega B_{1nm}^s \mathrm{e}^{\mathrm{j}(\omega t+\alpha_1)}. \tag{5}$$

v_1 is the voltage that occurs in the electric field. We assume that the electric potential across the piezoelectric element is constant, since it is in the field that is not applied to the plate. Thus, Y_{nm} is defined as described above. R_p is the overall resistance value in an electricity generation circuit. The magnitude of the electric charge q_1 depends on the coefficient B_{1nm}^s that is determined in this analysis as well as A_{1nm}^s.

$$Y_{nm} = \begin{cases} -1/h_p & h_c/2 + h_b < z < h_c/2 + h_b + h_p, \\ 0 & -h_c/2 < z < h_c/2 + h_b, \end{cases} \tag{6}$$

$$q_1 = B_{1nm}^s \mathrm{e}^{\mathrm{j}(\omega t+\alpha_1)}. \tag{7}$$

In order to easily express the electro-mechanical equation, the elements $M_{p1nmm'}^s$ and $K_{p1nmm'}^s$ of the mass and stiffness matrices can be denoted as

$$M_{p1nmm'}^s = \int_{V_{p1}} \rho_p X_{nm}^s X_{nm'}^s \mathrm{d}V_{p1}, \tag{8}$$

$$K_{p1nmm'}^s = \int_{V_{p1}} z^2 X_{nm}^{s\,\prime\prime} E_p^E X_{nm'}^{s\,\prime\prime} \mathrm{d}V_{p1}. \tag{9}$$

The index *m'* is also of a radial order and has a transposed relation to *m*. The elements θ_1 and C_{p1} of the electro-mechanical coupling and capacitance matrices are defined as

$$\theta_1 = -\int_{V_{p1}} z \rho_p X_{nm}^s e Y_{nm'} \mathrm{d}V_{p1}, \tag{10}$$

$$C_{p1} = \int_{V_{p1}} Y_{nm} \gamma^{\varepsilon} Y_{nm'} \mathrm{d}V_{p1}. \tag{11}$$

2.3 Governing equations of electro-mechanical-acoustic coupling

Here, electro-mechanical coupling is considered from the above several relationships, and then mechanical-acoustic coupling is also taken based on the relationships between the vibrations of both plates and the sound field into the cylindrical enclosure. As a result, this electricity generation phenomenon depends strongly on electro-mechanical-acoustic coupling, so that the motions of both plates having a piezoelectric part are governed by the following Eqs. (12) and (13), respectively:

$$\sum_{m=0}^{\infty} \Big[\Big\{ K_{c1nmm'}^s (1+\mathrm{j}\eta_c) + K_{p1nmm'}^s (1+\mathrm{j}\eta_p) + K_{b1nmm'}^s (1+\mathrm{j}\eta_b) - \omega^2 \left(M_{c1nmm'}^s + M_{p1nmm'}^s + M_{b1nmm'}^s \right) \Big\} + r_c F_{sn} \left\{ T + \left(\frac{m}{r_c} \right) \times \left(\frac{m'}{r_c} \right) R \right\} \Big] A_{1nm'}^s \mathrm{e}^{\mathrm{j}\alpha_1} - \sum_{m'=0}^{\infty} \theta_1 v B_{1nm'}^s \mathrm{e}^{\mathrm{j}\alpha_1} = \mathbf{F}_{nm}^s \mathrm{e}^{\mathrm{j}\alpha_1} - \mathbf{S}_{1nm}^s \tag{12}$$

$$\sum_{m=0}^{\infty} \Big[\Big\{ K_{c2nmm'}^s (1+\mathrm{j}\eta_c) + K_{p2nmm'}^s (1+\mathrm{j}\eta_p) + K_{b2nmm'}^s (1+\mathrm{j}\eta_b) - \omega^2 \left(M_{c2nmm'}^s + M_{p2nmm'}^s + M_{b2nmm'}^s \right) \Big\} + r_c F_{sn} \left\{ T + \left(\frac{m}{r_c} \right) \times \left(\frac{m'}{r_c} \right) R \right\} \Big] A_{2nm'}^s \mathrm{e}^{\mathrm{j}\alpha_2} - \sum_{m'=0}^{\infty} \theta_2 v B_{2nm'}^s \mathrm{e}^{\mathrm{j}\alpha_2} = \mathbf{S}_{2nm}^s \tag{13}$$

$K_{c1nmm'}^s$, $K_{b1nmm'}^s$ and $K_{c2nmm'}^s$, $K_{b2nmm'}^s$ are stiffness matrix elements and $M_{c1nmm'}^s$, $M_{b1nmm'}^s$ and $M_{c2nmm'}^s$, $M_{b2nmm'}^s$ are mass matrix elements with respect to the circular and electrode plates, respectively. These are elements of the symmetrical matrices, because the index *m'* has a transposed relation to *m*, as well as $M_{p1nmm'}^s$ and $K_{p1nmm'}^s$. η_c, η_p, and η_b are the structural damping factors of the circular plate, piezoelectric element and electrode plate, respectively. Moreover, F_{sn} is a coefficient that is determined by the indices *n* and *s*, $\mathbf{F}_{nm}^s$ is a load vector that expresses the point force on plate 1, and $\mathbf{S}_{nm1}^s$ and $\mathbf{S}_{nm2}^s$ are the acoustic excitation vectors that express the acoustic excitations of both plates. The details of F_{sn} and the elements F_{nm}^s, S_{nm1}^s, and S_{nm2}^s of the respective vectors are as follows:

$$F_{sn} = \begin{cases} \pi, \text{ at } n \neq 0, \\ 0, \text{ at } n = 0 \text{ and } s = 0, \\ 2\pi, \text{ at } n = 0 \text{ and } s = 1, \end{cases} \tag{14}$$

$$F_{nm}^s = \int_{A_1} F \delta(r - r_1) \delta(\phi - \phi_1) X_{nm}^s \mathrm{d}A_1, \tag{15}$$

$$S_{1nm}^s = \int_{A_1} P_s X_{nm}^s \mathrm{d}A_1, \quad S_{2nm}^s = \int_{A_2} P_s X_{nm}^s \mathrm{d}A_2. \tag{16}$$

Here, δ is the delta function associated with the point force on plate 1, whose area is denoted by A_1. P_s is the sound pressure at an arbitrary point on the boundary surface of the plates, and A_2 signifies the area of plate 2.

On the other hand, the electricity generation behaviors of these piezoelectric elements are governed by the following Eqs. (17) and (18), respectively:

$$\sum_{m'=0}^{\infty} C_{p1}^{-1} \theta_1 A_{1nm'}^s = \sum_{m'=0}^{\infty} \left(\mathrm{j}\omega R_p + C_{p1}^{-1} \right) B_{1nm'}^s, \tag{17}$$

$$\sum_{m'=0}^{\infty} C_{p2}^{-1} \theta_2 A_{2nm'}^s = \sum_{m'=0}^{\infty} \left(\mathrm{j}\omega R_p + C_{p2}^{-1} \right) B_{2nm'}^s. \tag{18}$$

3. Experimental apparatus and method

Figures 2 shows the configuration of the experimental apparatus used in this study. The structure consists of a steel cylinder with circular aluminum end plates whose radius r_c and thickness h_c are 153 mm and 3.0 mm, respectively. The cylinder has the same inner radius as the radius of the end plate and the length *L* can range from 500 to 2000 mm to emulate the analytical model. Plate 1 is subjected to the point force excited by a small vibrator.

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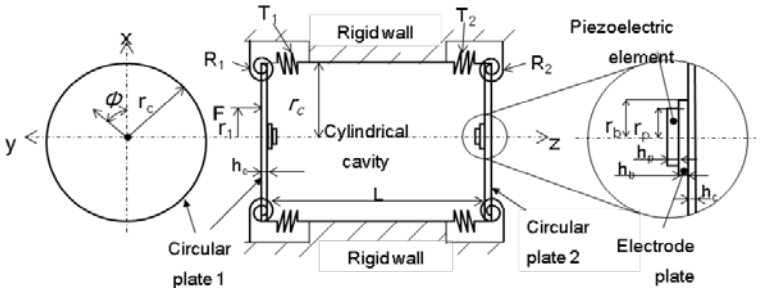


Fig. 1 *Configuration of analytical model.*

Plate 1 is subjected to the point force excited by a small vibrator. The cylinder has the same inner radius as the radius of the end plate and the length L can range from 500 to 2000 mm to emulate the analytical model. Plate 1 is subjected to the point force excited by a small vibrator. The excitation is carried out near the natural frequency of the (0,0) mode, otherwise it covers the wide frequency range due to assuming actual situations and signifies the random excitation. The position of the point force r_1 is normalized by radius r_c and is set to $r_1/r_c = 0.4$.

To estimate the mechanical power P_m supplied to plate 1 by the small vibrator, an acceleration sensor is installed near the position of the point force on plate 1, and P_m is predicted from the point force and acceleration a_1. The phase difference between the plate vibrations is also measured owing to the installation of the acceleration sensor at the same position on plate 2, resulting in significant effects on the mechanical-acoustic coupling. To estimate the internal acoustic characteristics, the sound pressure level in the cavity is measured using condenser microphones with a probe tube. The tips of the probe tubes are located near the plates and the cylinder wall, which are the approximate locations of the maximum sound pressure level when the sound field becomes resonant.

The piezoelectric elements are installed at the centers of both plates. The electric power P_{e1} and P_{e2} generated by the expansion and contraction of the piezoelectric elements on plates 1 and 2 are discharged through the resistance circuit, which consists of three resistors having resistances R_v, R_i, and R_c, as shown in Figure 2. To grasp the effect of mechanical-acoustic coupling on energy harvesting, the electric power and other data are also measured without the cylinder (i.e. in the electricity generation under the vibration of only plate 1) and are estimated in comparison with those with cylinder. In such an estimation, electricity generation efficiency is used and is derived from the electric power normalized by the mechanical power P_m supplied to plate 1 by the vibrator. However, the electricity generation efficiencies, which are obtained from P_{e1}, P_{e2}, and their total electric power P_e, are denoted by P_{em1}, P_{em2}, and P_{em}, respectively, when electro-mechanical coupling is taken into consideration.

3. Results and discussion

3.1 Electricity generation characteristics in natural frequency excitation

Here, the thickness of plates is set to $h_c = 3$ mm in Figs. 1and 2. The support condition of plates, which have flexural rigidity D [$= E_c h_c^3/\{12(1-\nu_c^2)\}$], is expressed by the nondimensional stiffness parameters T_{n1} ($= T_{c1} r_c^3/D$) , T_{n2}, R_{n1} ($= R_{c1} r_c/D$), and R_{n2}. If R_{n1} and R_{n2} range from 0 to 10^8 when T_{n1} and T_{n2} are 10^8, the support condition can be assumed, from a simple support to a clamped support.

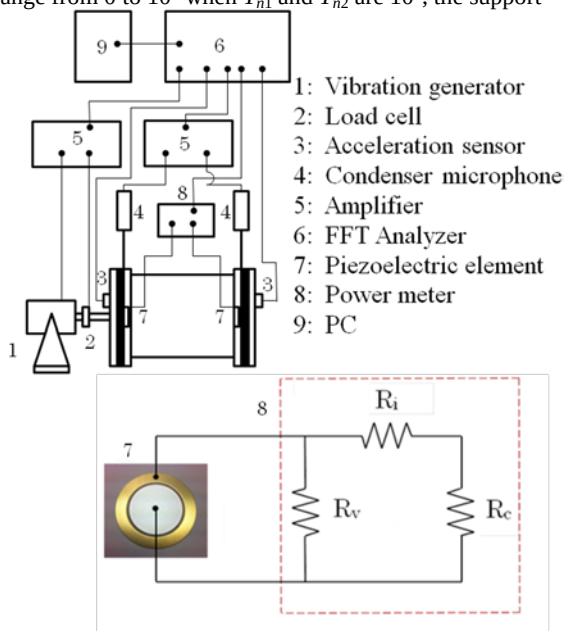


Fig. 2 *Experimental apparatus.*

Figure 3 shows the sound pressure level L_{pv}, which is averaged over the entire volume of the cavity and is maximized at each L when the phase α_2 ranges from 0 to 180°, as functions of L.

The excitation frequency f is 280 Hz, because both plates have the $h_c = 3$ mm and are supported by $T_{n1} = T_{n2} = 10^8$ and $R_{n1} = R_{n2} = 10$ to get closer to the apparatus. The theoretical level L_{pv} peaks at 610, 1230, and 1840 mm.

The peaks are caused by the promotion of mechanical-acoustic coupling between the plate vibration and acoustic modes. Then the acoustic modes are the (0,0,1), (0,0,2), and (0,0,3) modes whose plane modal shape is similar to that of plate vibration mode (0,0). To validate these theoretical results, the sound pressure levels L_{p1} and L_{p2}, which are measured near plates 1 and 2, are also indicated. The experimental peaks occur around the lengths where L_{pv} peaks, whereas L_{p1} decreases remarkably around $L = 950$ and 1600 mm in the process of shifting acoustic modes because of a changing L.

Figure 4 shows the electricity generation efficiency P_{em} as functions of f under the vibration of only plate and the vibrations of plates 1 and 2 with mechanical-acoustic coupling. However, P_{em} with coupling corresponds to the maximum electric power P_e at each f where L and α_2 are changed. Although both values of P_{em} have peaks in the vicinity of 280 Hz and exceed 7 %, P_{em} with coupling is somewhat improved in comparison with that without coupling. With respect to the electricity generation with coupling, $R_{n1} = 10^{0.78}$ is also adopted instead of $R_{n1} = 10$ to make the support condition approximate to the actual situation. Because plate 1 receives the additional mass of the stick exciting it, its natural frequency is shifted to a lower frequency region than the above cases. As a result, P_{em} peaks in the vicinity of 270 Hz and is suppressed until around 6%.

Figure 5 shows variations in the experimental P_{em} with changing L. Since the natural frequency of plate 1 is shifted in the lower region by the effect of the additional mass, as described above, the excitation frequencies $f = 256$ and 270 Hz are adopted and are close to the respective natural frequencies of plates 1 and 2. P_{em} at $f = 270$ Hz peaks at approximately L = 600, 1220, and 1870 mm and is similar to L_{p1} and L_{p2} in Fig. 3 in the length where the peaks appear.

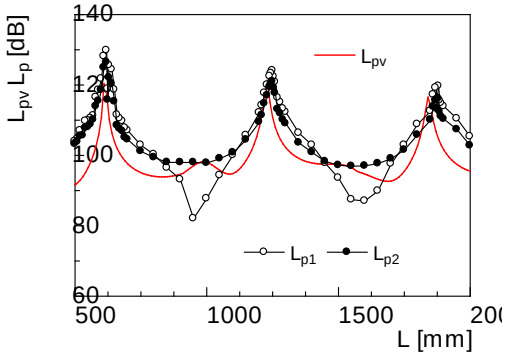


Fig. 3 *Sound pressure level inside cavity as function of cylinder length.*

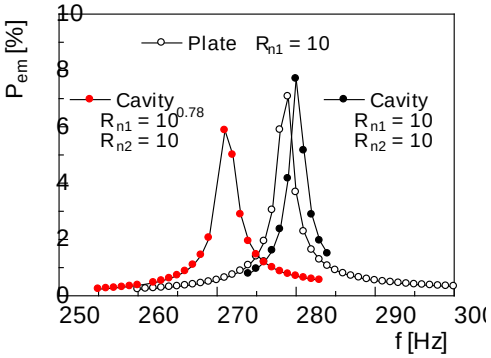


Fig. 4 *Electricity generation efficiency as function of excitation frequency.*

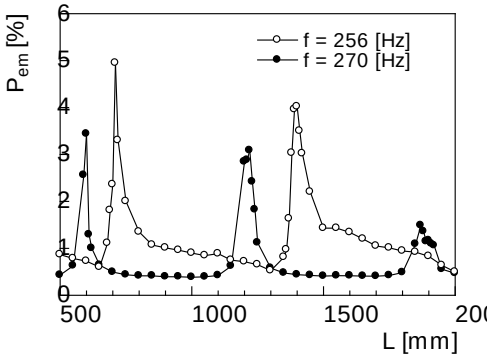


Fig. 5 *Electricity generation efficiency as function of cylinder length.*

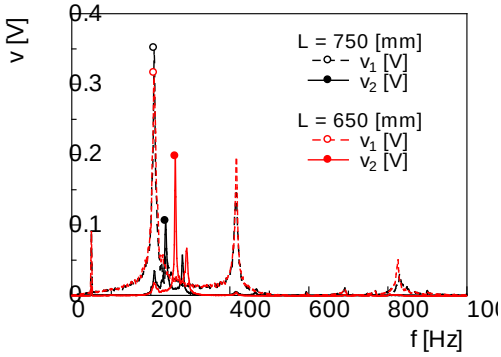


Fig. 6 *Voltage characteristics in random excitation.*

This excitation frequency is adjusted to be close to the natural frequency of plate 2 and is different from that of plate 1, so that the vibration of plate 1, which is subjected to the point force, is suppressed. However, because plate 2 is excited acoustically by the internal sound field via mechanical-acoustic coupling, P_{em} increases rapidly at the above lengths where the coupling is promoted. The electric power P_{e2} of plate 2 contributes almost to P_{em}, hence this is regarded as the electricity generation controlled by the vibration of plate 2.

In the case of f = 256 Hz, since the excitation frequency is close to the natural frequency of plate 1, the coupling is promoted between the vibration of plate 1 and the sound field, weakened between the vibration of plate 2. As described above, under a constraint of the experimental apparatus, the load cell cannot be directly installed on plate 1, so that the point force is applied to plate 1 via a stick from the vibration generator.

Therefore, an additional mass derived from the stick contributes to shift the natural frequency to the lower frequency region, not avoided in this experiment. Then such a tendency lowering the natural frequency brings the appearance of P_{em} peaks to the longer lengths. P_{em} peaks at both excitation frequencies are caused by the promotion of coupling with the (0,0,1), (0,0,2), and (0,0,3) modes, being different in those derivations.

P_{em} values decrease with increasing L and are maximized at the respective first peaks, i.e. by the coupling with the (0,0,1) mode. Those values are smaller than the theoretical results, as shown in Fig. 4. In the actual situation, the reverse sides of the plate surfaces facing to the internal sound field are bounded with atmosphere and the acoustic radiations should also take place on them. In the theoretical procedure, because the interaction between the plate and the medium is not taken into account on such a reverse surface, it is assumed as if the surface is exposed to a vacuum. In other words, it may be considered that the theoretical P_{em} is slightly overestimated. On the other hand, it is confirmed that the experimental P_{em} is suppressed until around 1.7 % without the coupling, i.e. only the plate vibration, in this electricity generation experiment and is much less than the theoretical P_{em} , as shown in Fig. 4. The above interaction is no longer taken into account in this theoretical procedure, so that it is considered that the effect becomes remarkable.

3.2 Electricity generation characteristics in random excitation

Figure 6 shows the voltages v_1 and v_2 based on the respective electricity generations of plates 1 and 2 as functions of the excitation frequency f, which is in the range of 0 Hz to 1000 Hz as the random excitation. Then the cylinder length is set to L = 650 and 750 mm. The variations in v_1 are characterized by the specific peaks, complicated by the random excitation, and are hardly different in changing L. The maximum peaks have the possibility deriving from the (0,0) mode, because of taking place in the vicinity of the natural frequency, as described in the previous section. However, the (0,0) mode cannot be confirm at the peak frequency from the experimental modal analysis and the difference from the natural frequency not affected by the additional mass is expanded in comparison with the difference shown in the previous section. Therefore, the coupling between the plate vibration and the internal sound field is weakened extremely and cannot transfer enough energy to plate 2. However, although v_1 decreases with shifting f to a higher frequency region, the modal shape is formed with shifting f. Consequently, v_2 increases due to the promotion of the coupling with getting closer to the natural frequency of plate 2.

In this case, the resonance frequency of the sound field at L = 650 mm is closer to the natural frequency of plate 2 than that at L = 750 mm, so that v_2 at L = 650 mm exceeds greatly that at L = 750 mm.

In the case of the random excitation, P_{em} slightly exceeds 0.1 % with the coupling, being much less than it without the coupling. Although it is hard to apply practically this system for now, we expect that the performance of energy harvesting is improved by controlling and adjusting plate vibration characteristics.

4. Conclusion

In this study, a new electricity generation system, which consisted of a cylinder with circular end plates on which a piezoelectric element was installed at the center, was proposed. One end plate was excited by the point force, and then not only the natural frequency of the plate was adopted as the excitation frequency, but also the excitation of broad frequency band, i.e. random excitation, was attempted to assume an actual environment.

The mechanical-acoustic coupling between the plate vibrations and the internal sound field is promoted by exciting at the natural frequency of the plate and by setting the cylinder to a specific length. It is verified that the electricity generation efficiency is considerably improved by using the promoted coupling in comparison with that of only the plate vibration without the coupling. Moreover, with respect to the random excitation, the prospect for the improvement of electricity generation characteristics is exhibited by applying the coupling effect to this system.

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FEM 2D AND 3D DESIGN OF TRANSFORMER FOR CORE LOSSES COMPUTATION

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Abstract: *Accurate simulation and prediction of losses in power transformer is important during transformer lifetime but also during the design stage. Paper presents the simulation model of transformer based of Finite Element Method that allows calculation of core losses and magnetic flux density in transformer cross-section. Two different models are constructed for 2D and 3D simulation. Obtained results are compared with experiments. Finally, flux density in both models is calculated and obtained results are presented for different time steps.*

Keywords: CORE LOSSES, POWER TRANSFORMER, FEM MODELS, MAGNETIC FLUX DENSITY

1. Introduction

Modeling of power transformers and their accurate simulation has been always a challenging task for engineers worldwide. Power transformers are the most expensive element in energy distribution networks therefore accurate prediction of transformer operation as well as possible malfunctioning has been always an issue among engineers. Heindl *et al*. propose high frequency models of large power transformers required for analysis of transient interaction between the transformers and the power system [1]. Ozgonenel and Kilic propose an algorithm and transformer model for identification of different internal faults, which lead to transformer outage [2]. During recent years Finite Element Method (FEM) gained a popularity for modeling various nonlinear materials and permanent magnets under the variety of conditions, employing sinusoidal waveforms and practically any other pulsed wave form of excitation [3] –[5]. FEM has been used for calculating transformer parameters in cases when partial discharge in transformer winding occurs [6]. In recent years, various powerful softwares have been developed for calculation of transformer parameters, operating modes and different type of losses [7]. Paper presents 2D and 3D model of power transformer for calculating core losses and magnetic flux density at transformer cross-section. Core losses are calculated at no-load for 50 Hz voltage supply, therefore only the low voltage winding is energized with rated voltage. Calculations are based on data of three phase transformer 115/13.8 kV, 60 Hz and 30 MVA with tested core losses of 23.7 kW.

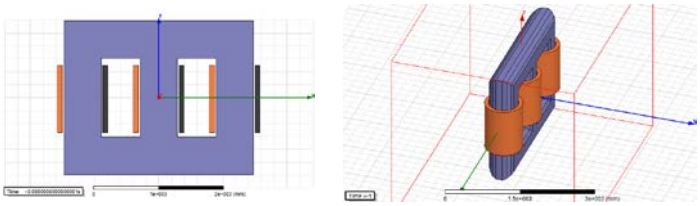


Fig. 1 Transformer 2D and 3D model

Computer animation has been used for presenting the magnetic flux density in core cross section. Flux density is calculated for different time intervals. Knowledge of flux density allows parts of transformer core close to the point of saturation to be detected and transformer construction to be modified in terms of avoiding saturation of core, high losses and low efficiency factor.

2. FEM models

Based on real transformer dimensions and geometry the FEM models have been constructed for 2D and 3D simulation of low frequency transient electromagnetic fields. The basic procedure of transient simulation includes spatial and temporal discretization of the physical equations. There are several approaches to do spatial discretization: finite differences, finite elements and finite volumes. The finite element method is widely used in engineering practice because it can model complex inhomgeneous, anisotropic materials and represent complicated geometry using irregular grids [8]-[9]. FEM solves the set of Maxwell equations for a given excitation and frequency. Transient simulation is performed by domain decomposition along time-axis (TDM-time decomposition method) to solve all time steps simultaneously, instead solving a transient problem time step by time step [7]. In both transformer models, boundary conditions are defined on object outer geometry as well as properties of all materials. Magnetic core is characterized with B-H curve of magnetization and thin laminations. They are input in both transformer models (Fig. 2). Specific core losses P are input as well, and core losses are calculated for one specific frequency, in this case 50 Hz (Fig. 3).

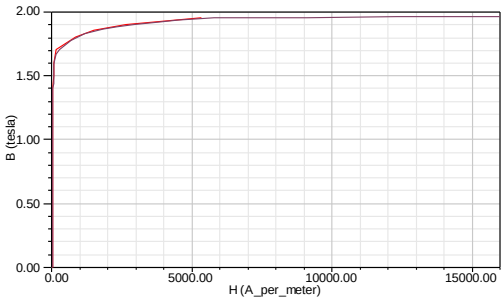


Fig. 2 B-H curve of core laminations

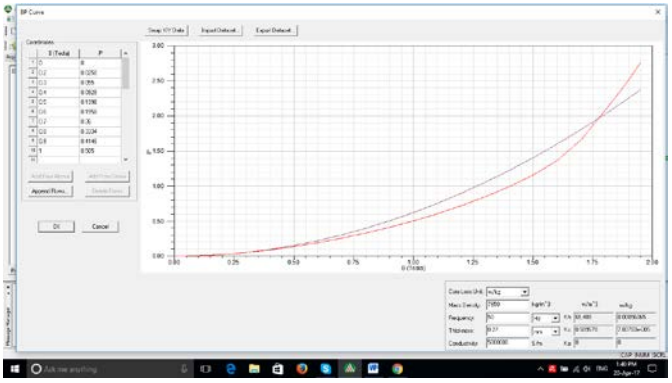


Fig. 3 P-B curve of core losses versus flux density

Traditionally, core loss P_c has been divided into two components: hysteresis losses P_h and eddy current losses P_e. According to the Steinmetz equation, measurement and calculation of core losses are normally made with sinusoidal flux density of varying magnitude-B and frequency-f. These measurements and calculations are based on the standard coil and frequently are modeled by a two-term function of the form:

$$P_c = P_h + P_e = k_h f B^n + k_c f^2 B^2 \quad (1)$$

k_h, k_c and n are the coefficients which depend on the lamination, material thickness, conductivity as well as other factors [10]. This formula is applicable up to the maximum flux density of B of 1 T, which is not the case in electrical machines and transformers.

In this paper, calculation of core losses is done according to:

$$P_c = P_h + P_e + P_{excess} = K_1 B_m^2 + K_2 B_m^{1,5} \quad (2)$$

Where the eddy current losses are:

$$P_e = k_c \left(f B_m \right)^2 \quad (3)$$

The hystersis losses are:

$$P_h = k_h f B_m{}^2 \quad (4)$$

and the excessive losses are:

$$P_{excess} = k_e \left(f B_m \right)^{1.5} \quad (5)$$

Therefore:

$$K_1 = k_h f + k_c f^2 \quad (6)$$

$$K_2 = k_e f^{1.5} \quad (7)$$

The eddy-current loss coefficient is calculated as:

$$k_c = \pi^2 \sigma \frac{d^2}{6} \quad (8)$$

Where σ is the conductivity and d is is is the thickness of one lamination sheet. Coefficients K_1 and K_2 are obtained from minimization of function:

$$f\left(K_1 K_2\right) = \sum \left[P_{vi} - \left(K_1 B_{mi}^2 + K_2 B_{mi}^{1.5} \right) \right]^2 = \min \quad (9)$$

Where P_{vi}, B_{mi}- the i-th point of the data on the measured loss characteristic curve. The other two loss coefficients are:

$$k_h = \left(K_1 - k_c f_0{}^2 \right) / f_0$$
$$k_e = K_2 / f_0^{1.5} \quad (10)$$

where f_0 is the testing frequency for loss curve.

In this case, core losses are input in transformer models as total losses for one specific frequency 50 Hz or 60 Hz (P-B curve). Since the starting transformer model is for 60 Hz, besides changing the model frequency to 50 Hz, the amplitude of input phase voltage ($13.8 \cdot \sqrt{2} / \sqrt{3}$ kV) is reduced for factor 5/6, as well as power rating of the transformer. This keeps the same currents in windings and avoids transformer overheating when 60 Hz transformer is run with 50 Hz voltage supply. For both frequencies, power losses are calculated. For core losses, only a single energized winding needs to be considered. An exponentially increasing voltage source is applied in order to eliminate inrush current and the needs for an unreasonably long simulation time (Fig. 4).

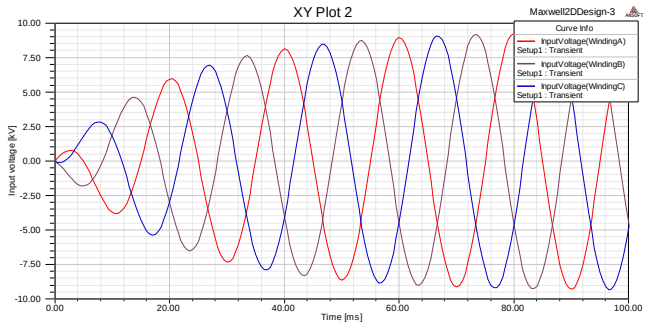
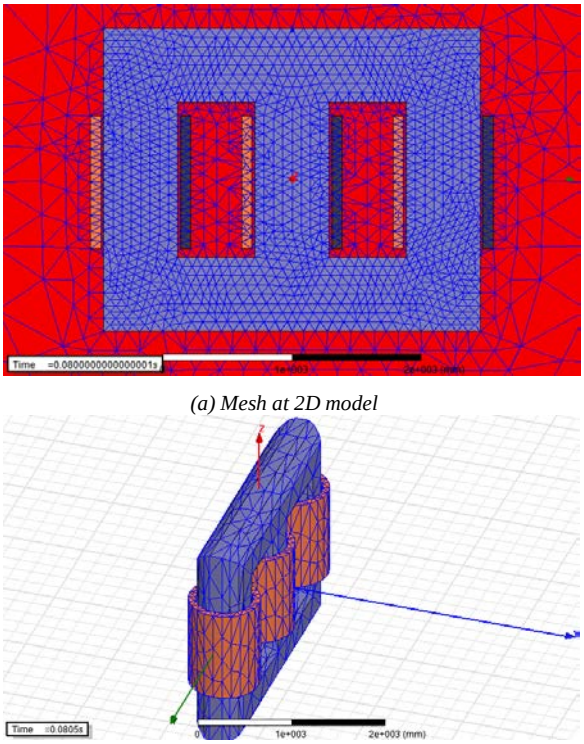


Fig. 4 Input voltage at 50 Hz

In order magnetic flux density **B** to be calculated, magnetic vector potential **A** must be found. For that purpose, the whole object geometry is divided into numerous elements, usually triangles, where **A** is approximated by a simple function. Created mesh of finite elements in 2D and 3D model is presented in Fig. 5.



(a) Mesh at 2D model

(b) Mesh at 3D model

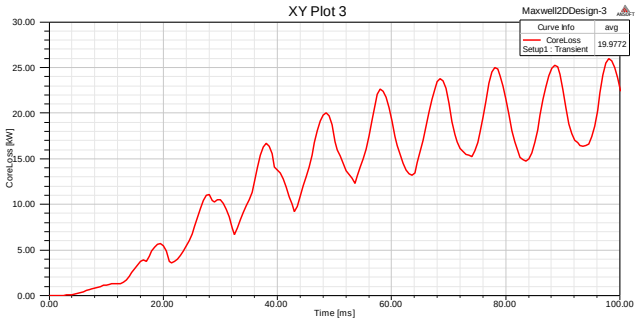
Fig. 5 Mesh at transformer models

The 3-D magnetic transient solver can calculate [7]:

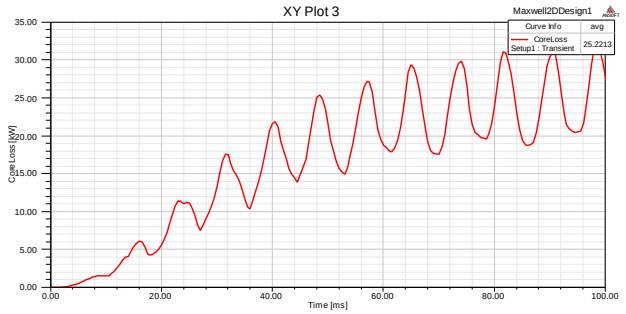
- the end-field effect as end-winding field effect and/or the influence of different stack lengths on the overall losses.
- core loss prediction due to a magnetic field component normal to the lamination stack.
- effect of time-controlled current/voltage wave forms on operating point conditions.
- eddy-current effects induced into conductive materials.

3. Results and discussions

Transient simulation is run for predefined time and time step. Simulation results of core losses are obtained for two different frequencies 50 Hz and 60 Hz and for 2D and 3D model. Core losses are averaged over the time. For all above-mentioned variants, they are presented in Figs. 6. and 7.

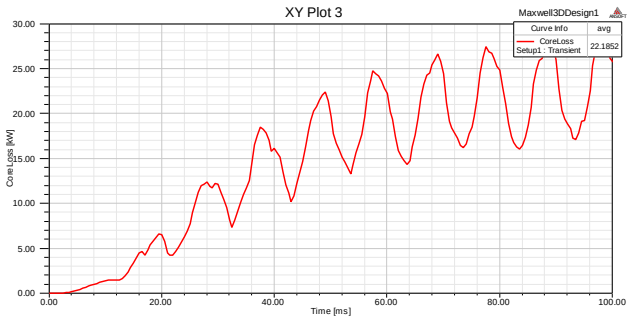


(a) core losses at 50 Hz

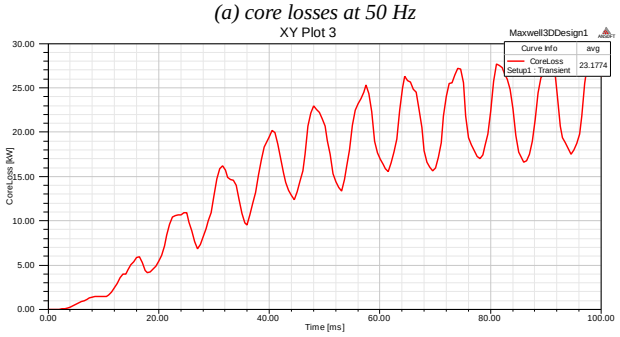


(b) core losses at 60 Hz

Fig. 6 Core loses at 2D model



(a) core losses at 50 Hz



(b) core losses at 60 Hz

Fig. 7 Core losses at 3D model

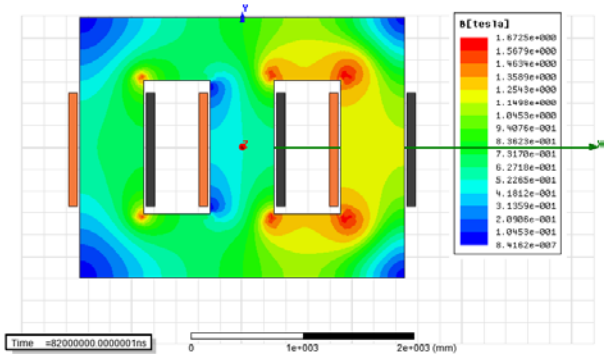
Core losses are averaged over the time interval from 80 to 100 ms. Their values in different models and frequencies are presented in Table 1.

Table 1: *Core losses at different models and frequencies*

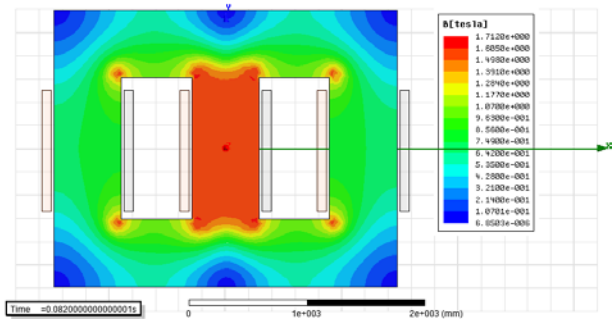
	2D model		3D model	
	50 Hz	50 Hz	50 Hz	60 Hz
Core losses [kW]	19.9	25.2	22.1	23.1

Comparison of results from Table 1 shows that there is a slight difference between the obtained values of core losses in 2D and 3D model of the transformer. The tested core losses at 60 Hz are 23.7 kW. Obtained results in both transformer models are close to the measured value of losses, which confirms the accuracy of presented models. Models are simulated for both frequencies of supply voltage 50 Hz and 60 Hz. As expected core losses are lower at frequency 50 Hz i.e. they should decrease approximately by factor 5/6. FEM model cannot consider all of the physical and manufacturing core loss effects in laminated core. These effects include mechanical stress on laminations, edge burr losses, step gap fringing flux, circulating currents, and variations in sheet loss values [7].

Over the years, FEM proved to be a useful tool toll in numerical calculation of different electromagnetic quantities. It is especially useful in calculation of magnetic flux density in machines cross-section. Calculation of the magnetic flux density, based on empirical formulas, gives only approximate values of the flux density at different parts of the machine. Accurate predication of the flux density at different parts of the machines is important in the design process for predicting so-called week parts of the machine where core material is close to the point of saturation (knee of the B-H curve). Operation of the machine near to the point of core saturation increases the losses, heat dissipation and reduces the efficiency. Therefore, flux density is analyzed at different time intervals for both models and both frequencies. Fig. 8 presents the results for 2D model and Fig. 9 for 3D model respectively.

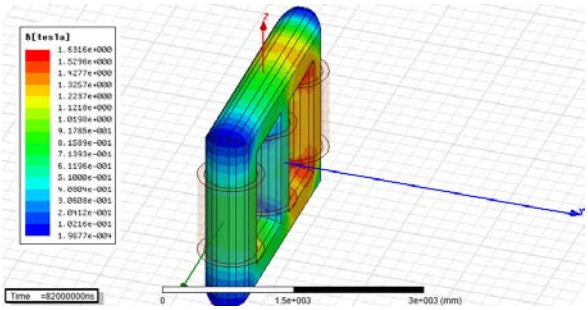


(a) flux density at 50 Hz

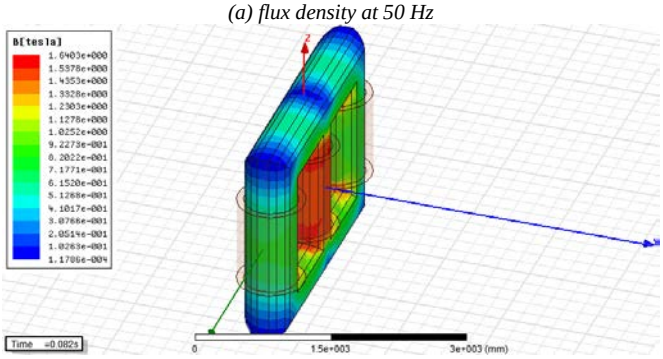


(b) flux density at 60 Hz

Fig.8. Flux density distribution at 2D transformer model



(a) flux density at 50 Hz



(a) flux density at 60 Hz

Fig. 9. Flux density distribution at 3D transformer model

From presented results in Figs. 8 and 9 it is evident that for both frequencies and in both models, transformer operates at no –load,

with flux density distribution in core cross-section well bellow the saturation point (approximately 2 T- Fig. 2). As expected due to the bigger core losses at 60 Hz, the flux density is higher at 60 Hz than at 50 Hz power supply.

4. Conclusion

Knowing the losses in electrical devices is important in terms of the exploitation of the device but also in terms of its design. Therefore, accurate simulation models for anticipating the losses are helping the designers in their task to design energy efficient devices. Simulation model of transformer based on FEM is presented. Obtained 2D and 3D models allow calculation of core losses for three-phase symmetrical power supply. Models are powered with 50 and 60 Hz power supply. Due to lower frequency losses are reduced at 50 Hz , compared to 60 Hz power supply. Flux density distribution in transformer cross-section is calculated as well. Obtained results in all models have proved that transformer at no-load is operating well beyond the point of core saturation. Further research will be focused on calculating the core and copper losses for all operating modes and obtaining the efficiency factor of the transformer, based on simulation models and analysis.

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VARIANCES OF THE DYNAMIC PROPERTIES OF FILLED POLYMER MATERIALS IN A VARIATION OF INJECTION MOULDING INPUT PARAMETERS

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Abstract: *A Continuum (filled polymer) is inhomogeneous and anisotropic. The Continuum is used in an injection moulding simulation at first (generally unnewton type of fluid). Then the continuum is solid (after cooling) and it is possible to carry out ordinary dynamics structural analysis with it. The solid continuum has different mechanical properties for each of discrete element. A consequent dynamics properties (natural frequencies) will generally have different values when influence of injection moulding is taken into account for analyses.*
KEYWORDS: FIBER ORIENTATION, INJECTION MOULDING, RHEOLOGY, NATURAL FREQUENCY, STRUCTURAL ANALYSIS, FEM, MESH

1. Introduction

The essence of the analysis was multiphysics task that combines structural dynamics analysis (FEM) and analysis of injection moulding for filled polymer (glass fiber). For the analysis of injection moulding technology parameters are changed according to the statistical distribution. The results of this multiphysics analysis were investigated.

2. Preconditions and means for resolving the problem

See the figure 1.

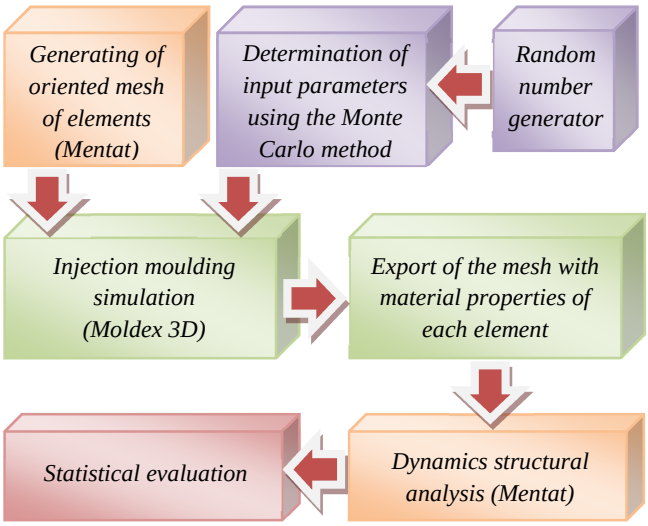


Figure 1. Multidisciplinary model assembling

2.1. Generating of oriented mesh of elements

The analysis was performed on a cover – see the figure 2. The picture shows fixing of the part for a structural analysis and an injection inlet (for an injection moulding analysis) is also shown, the range where a mould cavity is filled. The material chosen for the analysis was PP-GF30, especially TABOREN.

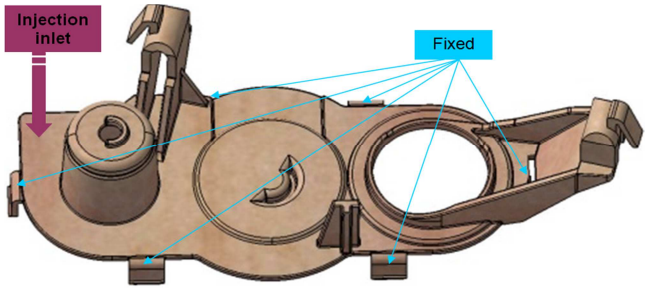


Figure 2. The cover

2.2. Determination of input parameters using the Monte Carlo method

They were set variables that are subjected to variation. In our case it was the injection time, melt temperature and mould temperature, in which the melt (filled polymer) is injected. It is appropriate to analyze the influence of individual variables using tools DoE (Design of Experiments). It was found that any of the factors is negligible. These factors are subsequently changed (due to the Monte Carlo method) according to a given distribution.

2.3. A random number generator

The change of the input parameters was performed through random number generator.

2.4. An injection moulding simulation

The oriented mesh was generated first in Mentat (see the figure 3). This mesh was (orientation included) imported into Moldex3D (see the figure 4) where the mesh for injection inlet was also modeled. After performing the initialization simulation, the mesh and material characteristics with a reduction were re-imported into Mentat again.

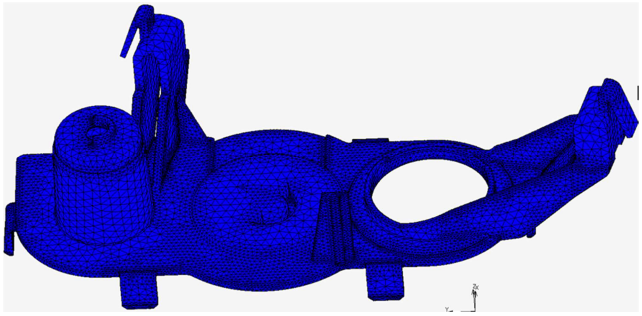


Figure 3. Oriented mesh

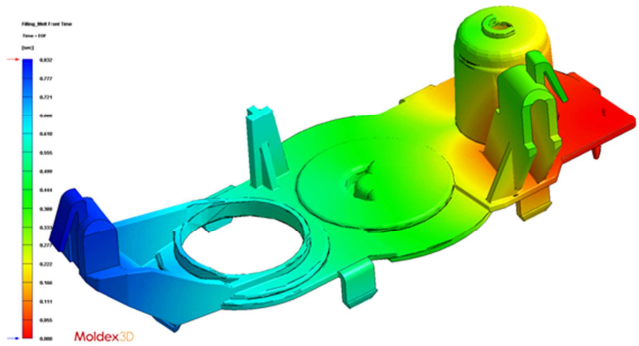


Figure 4. Model with the injection inlet

2.5. Export of the mesh with material properties of each element

Mentat loaded 225799 elements and 30418 material groups (material properties). The number of materials was therefore reduced to about one seventh. That means that roughly every 7th element has its unique material properties. Let us point out the reasons why we reduced the number of materials and why we did not create a full export of material properties for each element. Full conversion was performed but it turned out that the mesh export

from Moldex lasted for about 1 hours and the import into Mentat took incredible 7 hours! If we add a time for the analysis of injection moulding process and for the structural analysis we get to number about 8 hours per test. These are significant time costs. This time has to be multiplied by the number of performed iterations (the number of analyses with different technological parameters). This leads to a number from 1000 to 2000 hours of computing time! To be able to make our desired summary analysis (hundreds) a reduction of material groups is required. Time per analysis is thus shortened from about 7 hours to 40 minutes. So we have reduced the required processing time about 10 times.

3. Solution of the examined problem

As we know, the results should have a statistic character. In order to make the results of a statistical sample relevant, 256 experimental analyses were performed. Note that the input parameters were changed in the range of ± 7% of the nominal value (the nominal value of injection time = 0.8s, the nominal value of melt temperature = 230°C, the nominal value of mould temperature = 30°C). Histograms of generated input parameters are showed on the figure 5.

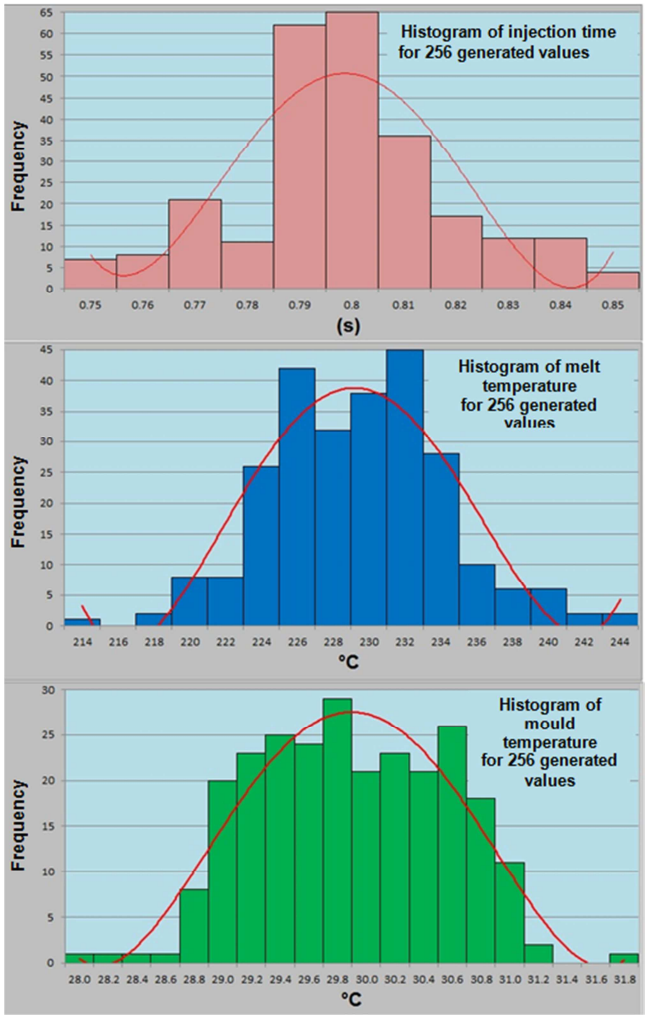


Figure 5. Histograms of input parameters

4. Results and disscussion

The resulting data are processed into graphs in figures 6 to 9, which are actually the output of our previous efforts.

From the frequency distribution it can be estimated that for an increasing number of analyses the trend of frequencies would probably converge to a curve of normal distribution. This trend is evident in all ten monitored graphs and it is even shown by the red curve of approximation, which is connected to the charts (see the figures 7 to 9) The polynomial regression of the 4th order was used for this trend curve. This frequency distribution could be expected

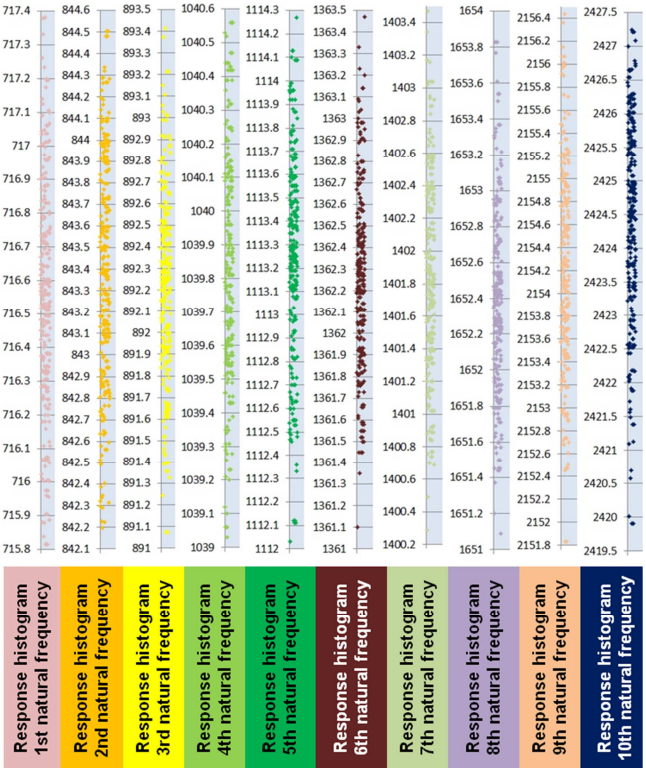


Figure 6. Histograms of output parameters – frequency responses of natural frequencies

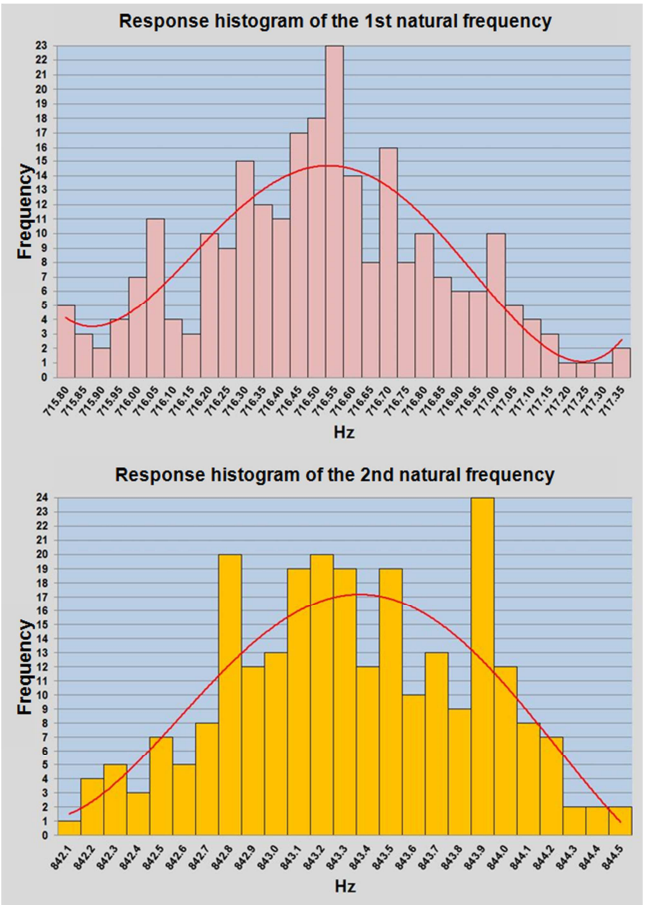


Figure 7. Histograms of output parameters – frequency responses of natural frequencies (1st – 2nd)

because input technological parameters were also selected along the pattern of the normal distribution, and this assumption was indeed confirmed. Each "overlaps" and "teeth" from "ideal" approximation functions are evidently caused by a relatively small

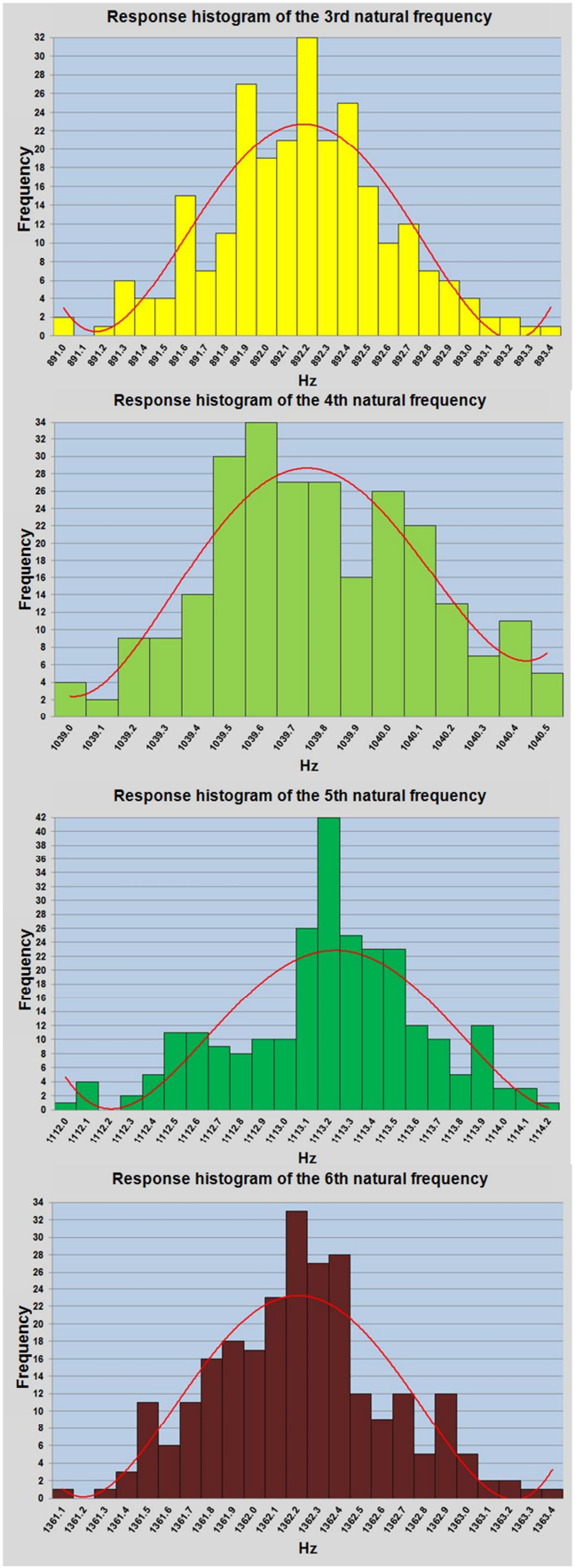


Figure 8. Histograms of output parameters – frequency responses of natural frequencies (3rd – 6th)

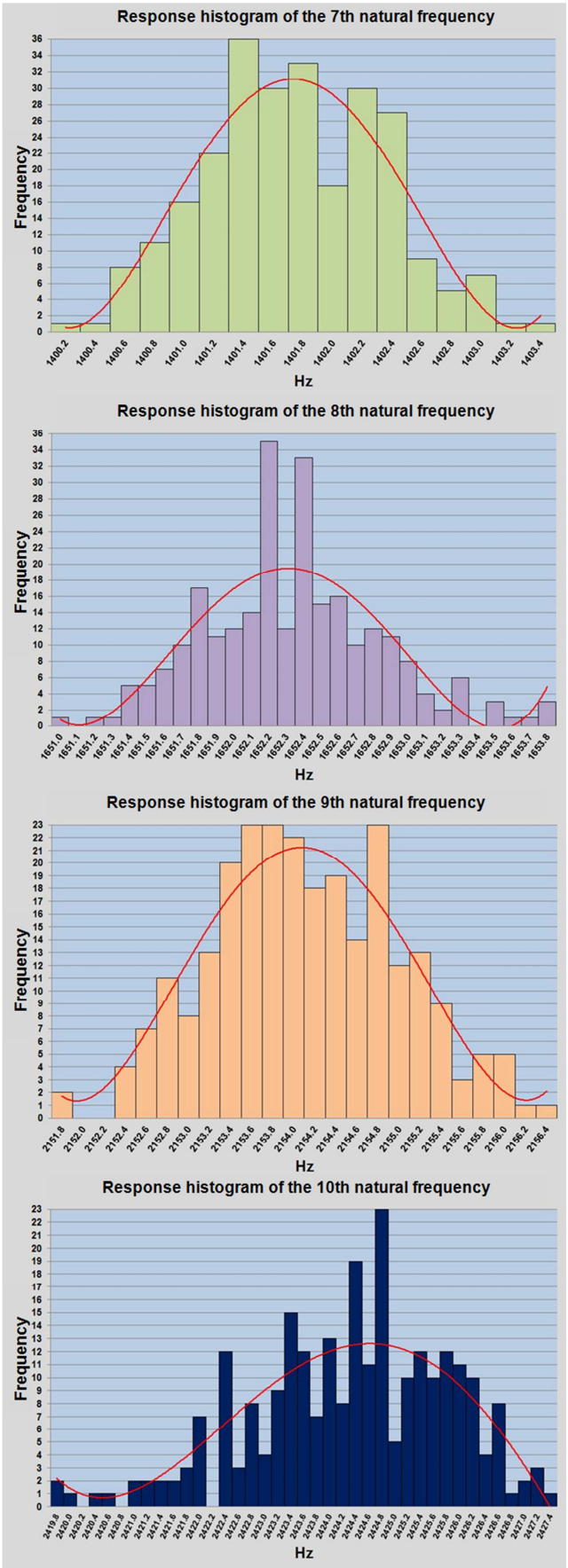


Figure 9. Histograms of output parameters – frequency responses of natural frequencies (7th – 10th)

number of experiments - even if it seems that number of 256 experiments is relatively high, it is estimated that the for extermination of these deviations would be required experimentation by one order more. Another factor that may distort the frequency distribution is the choice of the width of the intervals (classes). Inappropriate choice can lead to underexposure or overexposure of frequencies. While the frequency distributions along the lines of the normal distribution were expected,

considerable low variability in range of natural frequencies of continuum definitely surprises. Note that the input parameters are changed in the range of ± 7% of the nominal value (the injection time, melt temperature and mould temperature). But an output response varies in much thinner bands. When the middle value of each histogram is taken as a nominal value then we get a range of bandwidths responses:

- The response range for the 1st natural frequency is 716,575 Hz ± 0,775 Hz ≈ 716,575 Hz ± 0,1%.

- The response range for the 2nd natural frequency is 843,3 Hz ± 1,2 Hz ≈ 843,3 Hz ± 0,14%.

- The response range for the 3rd natural frequency is 892,2 Hz ± 1,2 Hz ≈ 892,2 Hz ± 0,13%.

- The response range for the 4th natural frequency is 1039,75 Hz ± 0,75 Hz ≈ 1039,75 Hz ± 0,07%.

- The response range for the 5th natural frequency is 1113,1 Hz ± 1,1 Hz ≈ 1113,1 Hz ± 0,1%.

- The response range for the 6th natural frequency is 1362,25 Hz ± 1,15 Hz ≈ 1362,25 Hz ± 0,08%.

- The response range for the 7th natural frequency is 1401,8 Hz ± 1,6 Hz ≈ 1401,8 Hz ± 0,1%.

- The response range for the 8th natural frequency is 1652,4 Hz ± 1,4 Hz ≈ 716,575 Hz ± 0,08%.

- The response range for the 9th natural frequency is 2154,1 Hz ± 2,3 Hz ≈ 2154,1 Hz ± 0,11%.

- The response range for the 10th natural frequency is 2423,6 Hz ± 3,8 Hz ≈ 2423,6 Hz ± 0,16%.

5. Conclusion

It follows that the variation of the input process parameters of injection moulding (the injection time, melt temperature and mould temperature) of 7% brings a variation of the output response (natural frequencies) in average range about 0.1%! It certainly was not an expected result. These results suggest that the effect of fiber orientation (caused by input parameters of injection moulding) has practically no influence on the dynamic behaviour of the continuum.

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DELTA 3D WIRE PRINTER FOR BUILDING OBJECTS – THEORETICAL PREREQUISITES FOR PROTOTYPE DESIGN

ВЪЖЕН ДЕЛТА 3Д ПРИНТЕР ЗА СТРОИТЕЛНИ ОБЕКТИ – ТЕОРЕТИЧНИ ПРЕДПОСТАВКИ ЗА ПРОЕКТИРАНЕ НА ПРОТОТИП

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Abstract: *With the use of 3D printing technology, layer by layer extrusion is possible printing of construction objects, but printers represent a large size and mobility limited metal construction. The main reason for the large size of constructions for existing structures of 3D printers for building objects are large strains of bending moments that construction must take. In a new scheme of 3D printer called "Delta Wired 3D Printer", the large stress created from bending moments are transformed in normal stress from tension. At this time, the printer has been developed as a conceptual project is therefore theoretically necessary to identify efforts in wires which is to be suspended extruders (load). For creating a large scale working 3D printer model is necessary to create a prototype. Through a theoretical study of the basic design parameters can be made a real printer prototype project. By using the theory of similarity can be define a unit of prototype error as to how much it will respond to the real model. This is also the main purpose of this publication.*

Keywords: *DELTA WIRED 3D PRINTER, PRINTING CONCRETE MIXTURES, PRINTING PROTOTYPE DESIGN*

1. Introduction

Creating the delta wired 3D printer prototype is a first step towards designing a real working model. In previous publications [8, 9, 10] relationships have been established by which the structural elements and the deformation of the extruder can be determined. In order to create a prototype of 3D printer, it is necessary to examine its relation to the real model in terms of structural elements and dimensions [1, 2]. The creation of a prototype, as well as the adequate connection between it and the real model, will allow for a preliminary analysis of the possibility of making such a printer used for printing of construction.

The advantages of the delta wired 3D printer are listed in [8], one of the most important advantages being the unloading of the bending tension construction by using three load-bearing wires loaded with normal stresses only.

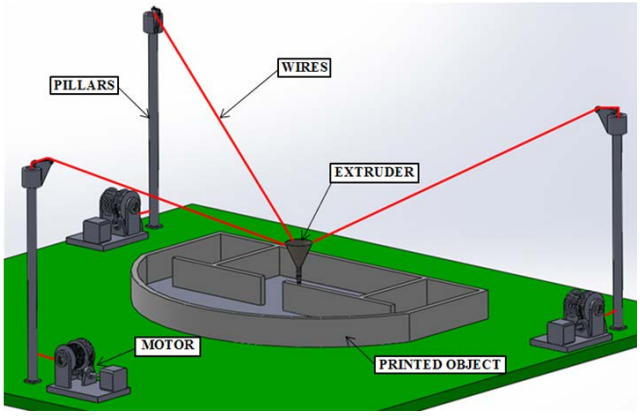


Fig.1 *Conceptual design of "delta 3D wired printer" [9]*

The main drawbacks of the construction that [8] are mentioned as potential problems are:

- Low stability of the structure - expressed as an unacceptably large extruder deflection;
- Motion synchronization problems;
- Problems with the acceleration of the load (extruder);
- A slip between the wire and the drum.

The ability to check whether the listed shortcomings will hinder the creation of a real model is a task to be solved by creating the prototype [3]. For this purpose, it is necessary to establish a connection between the real object and the prototype, by which it is possible to transform a unit of error from a printed model to the prototype to an error unit from the printed model to the real object.

2. Prerequisites and means for solving the problem

In order to achieve mathematical connectivity between parameters from the real object and the prototype, it is necessary to determine the basic strength and geometric parameters of the structure. In determining the load distribution [9], the dependencies were used in the supporting clones:

$$F_A = Q.K_{Fa}; F_B = Q.K_{Fb}; F_C = Q.K_{Fc}; \quad (1)$$

Where, F_A, F_B and F_C represented force in supporting clones, Q – weight of loads (extruder) and K_{Fa}, K_{Fb}, K_{Fc} – load factors for the respective clone.

The dependencies on load factors are as follows [9]:

(2)

$$K_{Fa} = \frac{\cos(\beta_Z).\cos(\gamma_Z).\cos(\varphi_{2\beta}).\sin(\varphi_{2\gamma}) + \cos(\beta_Z).\cos(\gamma_Z).\cos(\varphi_{2\gamma}).\sin(\varphi_{2\beta})}{C}$$

$$K_{Fb} = \frac{\cos(\alpha_Z).\cos(\gamma_Z).\cos(\varphi_{1\alpha}).\sin(\varphi_{2\gamma}) + \cos(\alpha_Z).\cos(\gamma_Z).\cos(\varphi_{2\gamma}).\sin(\varphi_{1\alpha})}{C}$$

$$K_{Fc} = \frac{\cos(\alpha_Z).\cos(\beta_Z).\cos(\varphi_{1\alpha}).\sin(\varphi_{2\beta}) - \cos(\alpha_Z).\cos(\beta_Z).\cos(\varphi_{2\beta}).\sin(\varphi_{1\alpha})}{C}$$

Where for C is represent:

$$C = \det\begin{vmatrix} -\cos(\alpha_Z).\cos(\varphi_{1\alpha}) & \cos(\beta_Z).\cos(\varphi_{2\beta}) & \cos(\gamma_Z).\cos(\varphi_{2\gamma}) \\ \cos(\alpha_Z).\sin(\varphi_{1\alpha}) & -\cos(\beta_Z).\sin(\varphi_{2\beta}) & \cos(\gamma_Z).\sin(\varphi_{2\gamma}) \\ \sin(\alpha_Z) & \sin(\beta_Z) & \sin(\gamma_Z) \end{vmatrix}$$

From which it is clear, the factors that affect to the load factors are the following angles:

$$K_{Fa}; K_{Fb}; K_{Fc} = f\left(\alpha_Z; \beta_Z; \gamma_Z; \varphi_{1\alpha}; \varphi_{2\beta}; \varphi_{2\gamma}\right) \quad (3)$$

Where α_Z, β_Z and γ_Z are angles between horizontal plane and respectively wire. $\varphi_{1\alpha}$, $\varphi_{2\beta}$ and $\varphi_{2\gamma}$ are angles between wires projected in horizontal plane.

If the principle of similarity is used - the pillars height, the distances between them and the current load coordinate (X, Y and Z) are proportional to the prototype, then it can be claimed that the angles that determine the value. The load factors will be the same. This will lead to equal values of the factor determining the load in the wires.

From the analysis of the dependencies determining the load in the wires it is clear that for each individual model the weight of the load (the extruder) is important. If we denote the weight of the extruder of the real model of the 3D printer with Q, and the weight of the extruder of the prototype with Q' then the scale between them we have:

$$PS_Q = \frac{Q'}{Q} < 1 \quad (4)$$

Where, PS_Q is called prototype scale for weight.

For examination full deflection of extruder in [10] the following dependencies were used.

$$\Delta l = \Delta la + \Delta lb + \Delta lc \quad (5)$$

The complete deflection of the extruder Δ1 is equal to the sum of the deformations in each of the supporting clone Δ1a, Δlb and Δlc. For clone A the dependence is as follows [10]:

$$\Delta la = \sqrt{(la + \Delta la_{\text{tens.w}})^2 - (la.\cos(\alpha_Z) - \Delta la_{\text{bend}})^2} - \quad (6)$$
$$- la.\sin(\alpha_Z) + \Delta la_{\text{comp}}$$

Where, la – length of wire in clone A, $\Delta la_{tens.w}$ – deformation from tensile in wire A, Δla_{bend} – distortion by bending in pillar A, Δla_{comp} – deformation of compression in pillar A. For the other two clones the dependencies are similar.

We are considering deformation from tensile in wire A for real printer:

$$\Delta la_{tens.w} = \frac{Fa.la}{E_w.A_w} = \frac{K_{Fa}.Q.la}{E_w.A_w} = \frac{K_{Fa}.Q.la}{E_w.\frac{\pi.d^2}{4}} \quad (7)$$

Where, Ew – modulus of elasticity for wires material, Pa, Aw – cross section area for wires, m^2, d – diameter of wire, m;

For prototype deformation in wire A by tensile, we have to write:

$$\Delta la_{\text{tens.w}}' = \frac{Fa'.la'}{E_w'.A_w'} = \frac{K_{Fa}'.Q'.la'}{E_w'.A_w'} = \frac{K_{Fa}'.Q'.la'}{E_w'.\frac{\pi.d'^2}{4}} \quad (8)$$

Where, Ew' – modulus of elasticity for prototype wires material, Pa, Aw' – cross section area for prototype wires, m^2, d' – diameter of prototype wire, m;

If we divide prototype deformation $\Delta la_{tens.w}$' on deformation for real printer $\Delta la_{tens.w}$ we can get the deformation scale of the prototype protrusion for tensile strains in the $PS_{\Delta l\ tens.w}$. Where, if the $K_{Fa}' = K_{Fa}$ is replaced, at the geometric scale of the prototype PS_G = const = la'/la, and modulus of elasticity of wire materials are equal may be recorded:

$$PS_{\Delta la_{tens.w}} = \frac{\Delta la_{tens.w}'}{\Delta la_{tens.w}} = \frac{\frac{K_{Fa}'.Q'.la'}{E_w'.\frac{\pi.d'^2}{4}}}{\frac{K_{Fa}.Q.la}{E_w.\frac{\pi.d^2}{4}}} = \frac{Q'.la'.d^2}{Q.la.d'^2} = \quad (9)$$

$$= PS_Q.PS_G.\left(\frac{d}{d'}\right)^2 = PS_Q.PS_G.\left(\frac{1}{PS_{dw}}\right)^2$$

Where, for d'/d we can write is equal of PS_{dw} – prototype scale of wire diameter.

If we represent at tensile stresses in wires for the real model and the prototype to have normal operating conditions in both cases, they should be the same and should not exceed the limit of elasticity of the material. In this case, we can record:

$$\sigma_{tens} = \frac{F_a}{A_w} = \frac{K_{Fa}.Q}{A_w} = \frac{K_{Fa}.Q}{\frac{\pi.d^2}{4}} = const;$$

$$\frac{K_{Fa}.Q}{\frac{\pi.d^2}{4}} = \frac{K_{Fa}'.Q'}{\frac{\pi.d'^2}{4}}; \quad (10)$$

$$\left(\frac{d'}{d}\right)^2 = \frac{Q'}{Q} \Rightarrow PS_{dw} = \sqrt{PS_Q}, or\ d' = d\sqrt{PS_Q}$$

It is clear from the deduced dependence that in order to create the same conditions under which the prototype and the real model work, it is necessary to respect the ratios between the different scales.

For bending deformations in pillars for real model of 3D printer - Δla_{bend} can write:

$$\Delta la_{bend} = \frac{K_{Fa}.Q.\cos(\alpha_Z).d_a^3}{3.E.I} \quad (11)$$

And for prototype:

$$\Delta la_{bend}' = \frac{K_{Fa}'.Q'.\cos(\alpha_Z').d_a'^3}{3.E'.I'} \quad (12)$$

Where, E and E' – modulus of elasticity for pillars material, respectively for real model and prototype; I and I' – moment of inertia for cross section of pillars, respectively for real model and prototype, d_a and d_a' – height of pillars respectively for real model and prototype.

In the case pillars materials are same, that modulus of elasticity will be equal:

$$PS_{\Delta la_{bend}} = \frac{\Delta la_{bend}'}{\Delta la_{bend}} = \frac{\frac{K_{Fa}'.Q'.\cos(\alpha_Z').d_a'^3}{3.E'.I'}}{\frac{K_{Fa}.Q.\cos(\alpha_Z).d_a^3}{3.E.I}} = \quad (13)$$

$$= \frac{Q'.d_a'^3.I}{Q.d_a^3.I'} = PS_Q.PS_G^3.\frac{I}{I'} = PS_Q.PS_G^3.\frac{1}{PS_I}$$

Where, for ratio between moments of inertia for cross section of pillars *I'/I* can be write as PS_I and called prototype scale for pillars moment of inertia.

Looking at the maximum bending stresses at the base of the pillars and aligning them with those of the prototype, similar to the normal stresses in the wires examined before, we can write:

(14)

$$\sigma_{\max.bend} = \frac{M_{bend}}{W_{bend}} = \frac{K_{Fa}.Q.\cos(\alpha_Z).d_a}{W_{bend}} = const;$$

$$\frac{K_{Fa}.Q.\cos(\alpha_Z).d_a}{W_{bend}} = \frac{K_{Fa}'.Q'.\cos(\alpha_Z').d_a'}{W_{bend}'};$$

$$\frac{W_{bend}'}{W_{bend}} = \frac{Q'}{Q}.\frac{d_a'}{d_a} \Rightarrow PS_W = PS_Q.PS_G, or\ W_{bend}' = W_{bend}.PS_Q.PS_G$$

Where, W_{bend} and W_{bend}' - resistance moment of inertia for cross section of pillars, respectively for real model and prototype, PS_W – prototype scale for resistance moment.

From dependence (6) it remains to determine the component that records the pillars compression for which it can be written:

$$\Delta la_{comp} = \frac{Fa.\sin(\alpha_Z).d_a}{E.A_p} = \frac{K_{Fa}.Q.\sin(\alpha_Z).d_a}{E.A_p} \quad (15)$$

And for prototype:

(16) $$\Delta la_{comp}' = \frac{Fa'.\sin(\alpha_Z').d_a'}{E'.A_p'} = \frac{K_{Fa}'.Q'.\sin(\alpha_Z').d_a'}{E'.A_p'}$$

If we compare the two dependencies, taking into account all the assumptions made above, we introduce a scale for the deformations from the compression of the pillars and designate it with $PS_{\Delta lcomp}$. Also, if for the relationship between the cross-sectional area of the pillars we write that $PS_{Ap} = Ap'/Ap$, them:

(17) $$PS_{\Delta la_{comp}} = \frac{\Delta la_{comp}'}{\Delta la_{comp}} = \frac{\frac{K_{Fa}'.Q'.\sin(\alpha_Z').d_a'}{E'.A_p'}}{\frac{K_{Fa}.Q.\sin(\alpha_Z).d_a}{E.A_p}} =$$

$$= \frac{Q'.d_a'.A_p}{Q.d_a.A_p'} = PS_Q.PS_G.\left(\frac{1}{PS_{Ap}}\right)$$

If we substitute the value for the deformation of clone A with the scale numbers, we have examined up to now we have:

(18)

$$\Delta la = \sqrt{\left(\frac{la'}{PS_G} + \frac{\Delta la_{tens.w}'.PS_{dw}^2}{PS_Q.PS_G}\right)^2 - \left(\frac{la'}{PS_G}.\cos(\alpha_Z) - \frac{\Delta la_{bend}'.PS_I}{PS_Q.PS_G^3}\right)^2} -$$

$$- \frac{la'}{PS_G}.\sin(\alpha_Z) + \frac{\Delta la_{comp}'.PS_{Ap}}{PS_Q.PS_G}$$

The resulting relationship shows the relationship between the real deformation in clone A of the 3D printer and the components of the individual deformations. For Δla', using the geometric relationship between the deformations discussed in [10] can be recorded:

(19) $$\Delta la' = \sqrt{(la' + \Delta la_{tens.w}')^2 - (la'.\cos(\alpha_Z) - \Delta la_{bend}')^2} -$$

$$- la'.\sin(\alpha_Z) + \Delta la_{comp}'$$

These dependencies can also be written for the other two wire clones. The relationship of Δla'/Δla can be written as $PS_{\Delta la}$ and for the other two branches $PS_{\Delta lb}$ and $PS_{\Delta lc}$. And for the total sag of the prototype extruder we have:

(20) $$\Delta l' = \Delta la' + \Delta lb' + \Delta lc'$$

3. Solution of the examined problem

The theoretical dependencies revealed on the one hand the deformations of the prototype extruder and on the other hand the relationship between the deformations of the prototype and the deformations of the real object. In order to visualize the results of the above dependencies, the following graphs have been developed. Fig. 2 shows the variation of the deflections for prototype extruder with the following geometric and weight characteristics shown in Tabl.1.

***Table 1**: Conceptual design parameter of Delta Wired 3D Printer for prototype and real model*

	Prototype	Real model	Type of prototype scale	Value of prototype scale
Height of pillars [mm]	600	6000	PS_G	0,1
Wires diameter [mm]	0,3	10	PS_{dw}	0,03
Weight of extruder [kgf]	0,3	300	PS_Q	0,001
Pillars cross section diameter x thickness [mm x mm]	Ø8,0	Ø256x8,0	-	-
Pillars cross section area [mm^2]	50,3	6232,9	PS_{Ap}	0,00807
Pillars resistance moment for cross section [mm^3]	50,26	374754,3	PS_W	0,000134
Pillars moment of inertia for cross section [mm^4]	201,1	47968550	PS_I	0,0000042

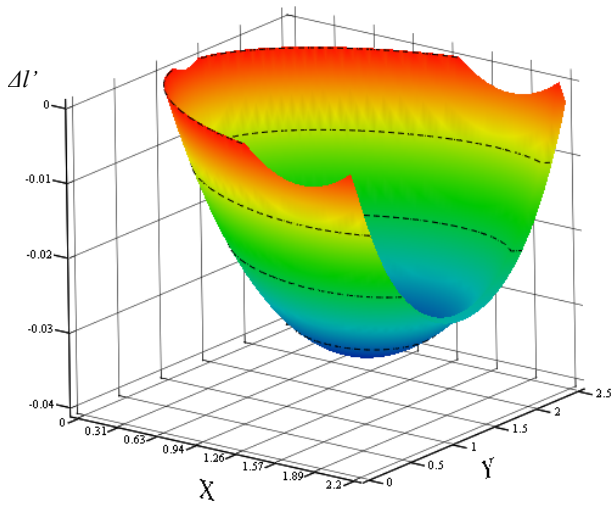


***Fig.2** Extruder deflection depending on the X and Y coordinates in the prototype working area with the geometric parameters listed in Table 1*

The fig. 2 is based on dependencies (20 and 19) and shows the projection of the prototype extruder at different points of the work area.

The use of the scale coefficients shown in Table 1 enables the dependence (18) to determine the load shedding of the real model calculated by the geometric characteristics of the prototype. Graphically, this flap is shown in fig. 3.

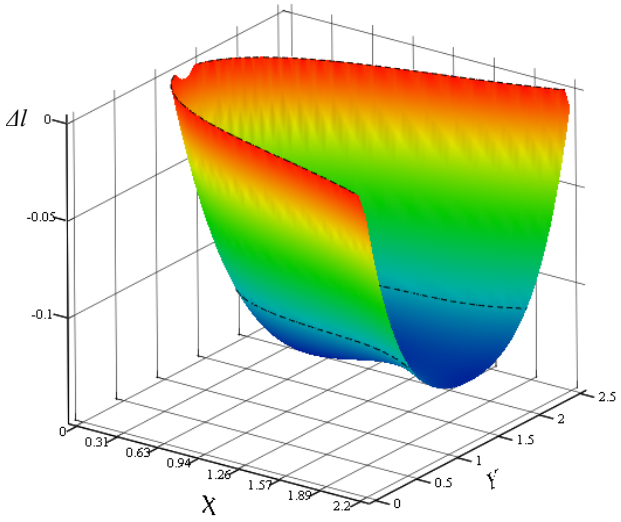


***Fig.3** Extruder deflection depending on the X and Y coordinates in the real printer working area with the geometric parameters listed in Table 1*

The scale between the prototype deformations and the real printer can be determined with the following dependence:

(21) $$PS_{\Delta l} = \frac{\Delta l'}{\Delta l}$$

Where, $PS_{\Delta l}$ is prototype scale for extruder deflection.
The graphical change of $PS_{\Delta l}$ is shown in Figure 4.

4. Results and discussion

Through a theoretical analysis of the relationship between the geometric and operational parameters of a real model and a prototype of the delta wired 3D printer, the dependencies that can be used in the design for real model and the prototype of the printer are reached. Important for the operation of such a printer is the stability expressed by the deflection of the load.

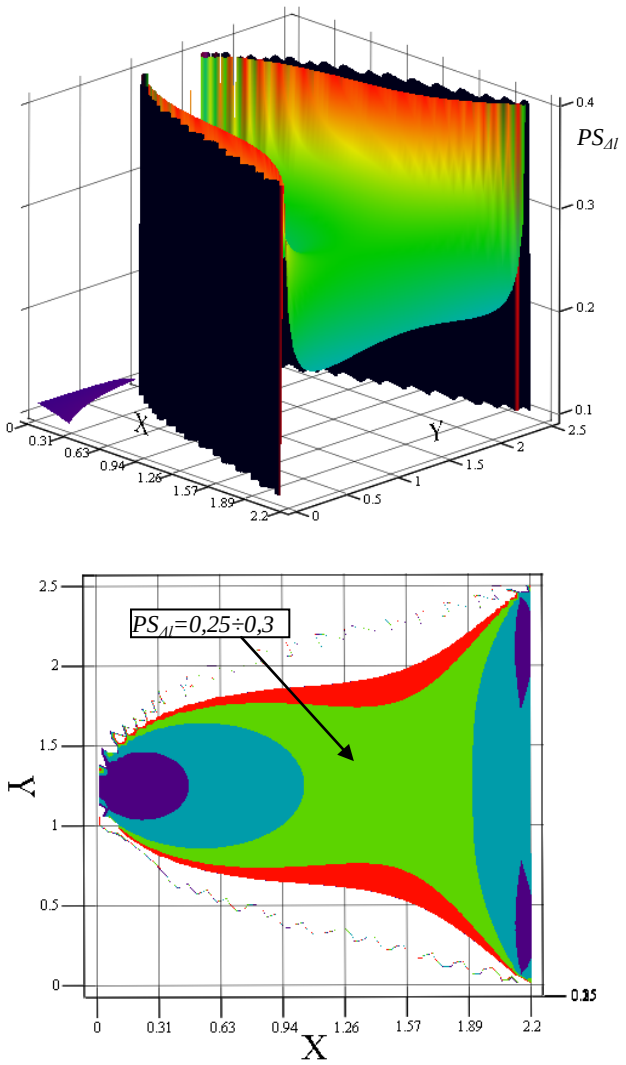


Fig.4 *Surface and contour plot of prototype scale for extruder deflection depending the coordinates X u Y*

The resulting dependencies and outcomes are applicable in the following cases:

- dependencies (10 and 14) may be used to create the prototype of the delta wired 3D printer to determine the dimensions of the design elements of the prototype so as to create the same operating conditions of the real model and the prototype;
- in order to establish the veracity of the deformation model considered, the prototype will be compared and the deformations measured in the course of its work will be compared with those obtained theoretically;
- by detecting real deformations in the prototype, the deformations that will be obtained in the real object, subject to certain scales, can be identified in practice by using the data obtained;
- it was found that the translational coefficients between the complete deformation of the prototype and that of the real model are constants but differ depending on the current coordinate of the extruder. In the zone of the ground top of fig.4, it is shown in green that prototype scale for extruder deflection takes values of 0.25 ÷ 0.3. This means that the deformations of the real object will be 3,3 ÷ 4 times bigger than the deformations of the prototype.

5. Conclusion

From the theoretical research on the way of working, the geometric elements and the scale that connects the prototype and the real model of the delta wired 3D printer, the necessary connectivity of the two models has been elucidated, and transistor dependencies have been established taking into account the geometric dimensions of the models. Through the research, real data derived from the prototype model can be transformed into data that will eventually be obtained when building a real model.

It turns out that if we build a prototype of a 3D printer on the scheme under consideration and we define a specific value for the load deflection at given coordinates. Then we create a working - real printer model with the scale shown in Table 1, we can guess what the real model deflection will be. This makes it easier to make decisions about the construction of the real model, as well as the possibility of predictability of future results.

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NBIC TECHNOLOGIES FOR A SYSTEM OF INTELLECTUAL SUPPORT OF INNOVATIVE ACTIVITIES OF INDUSTRIAL ENTERPRISES

NBIC-ТЕХНОЛОГИИ СИСТЕМЫ ИНТЕЛЛЕКТУАЛЬНОГО ОБЕСПЕЧЕНИЯ ИННОВАЦИОННОЙ ДЕЯТЕЛЬНОСТИ ПРОМЫШЛЕННОГО ПРЕДПРИЯТИЯ

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Abstract: *Methodical approaches to the creation of NBIC technologies for a system of intellectual support of innovative activities of industrial enterprises (SISIA IE) of the second integration level as a complex of research, educational and production units that generate high-level intellectual products for the operating and innovative production were considered. As examples of integration model realization have been given the functional nanomaterials based on polymer, oligomer matrices and blends for protective, sealing and tribotechnical systems of machines, mechanisms and technological equipment of industrial enterprises and enterprises of the chemical industry.*
KEYWORDS*: NBIC TECHNOLOGIES, NANOMATERIALS, INTELLECTUAL PRODUCTS, INNOVATIVE POTENTIAL, SYSTEM APPROACH, INTEGRATION*

1. Introduction

An analysis of trends in the development of continental government structures and intergovernmental formations shows that there is no alternative to the strategy of innovative development due to a combination of a number of favorable and unfavorable factors associated with fundamental changes in the geopolitical situation during a relatively small historical period, progressive localized population growth, depletion of basic raw materials, ecological conditions of the single continents, world's ocean and the planet [1-9].

This necessitates a deep and systematic study of the multifaceted problem of the impact of innovations on macroeconomic and socio-political development trends both of single regions and state and supranational formations. In this aspect, the task of development of the methodological principles for the formation and development of an innovation strategy for economic entities of various functionality and forms of ownership.

An analysis of the features of the development of the world economic system shows that the strategy of sustainable development of a socially-oriented state is based on the realization of functional innovations in various spheres of the societies functioning. These innovations are combined by a complex of NBIC-technologies with the defining role of new generation nanomaterials.

Innovations that form the modern material, technological and administrative base of industrial production are the result of the intellectual activity of various participants in the life cycle of products – scientific research institutes of the National Academy of Sciences, institutions of higher education, professional institutes for the retraining of personnel, industrial enterprises of various forms of ownership and industry affiliation [3].

Definitely that there is an obvious need for the creation of a specific infrastructure that can ensure the practical organization of innovation policies at the state, regional and subject levels. Practical experience in the creation and functioning of such an infrastructure exists in the industrially developed countries and in the states of the post-union social, political and economic space [2, 3, 5, 6, 8, 9].

Before, we proposed a methodology for the formation of a system of intellectual support of innovative activities of industrial enterprises (SISIA IE) which allows to generate intellectual potential for a permanent increase in the share of innovative products at the total volume of manufactured goods [7].

At the same time, for the practical realization of the SISIA IE in the activities of economic entities, there is need to develop approaches for its integration with the real infrastructure of the industrial enterprise.

The purpose of this study was to develop an algorithm for the functioning of the intellectual support system in the production activities of economic entities of the regional industrial complex during creation of functional nanocomposite materials based on high molecular weight matrices for use in metal-polymer systems of various designs.

2. Research methods

The main method of this research is a system analysis of the features of the Grodno region industrial enterprises functioning. System analysis made it possible to identify the features of the development and practical application of intellectual resources with various functionality in the production activity of economic entities with different levels of innovative development. We focus primarily on the nanocomposite materials obtained by modification of thermoplastic matrices using nanoscale particles with different structure and production technology. The practical approbation base for the developed nanocomposites was Grodno region industrial enterprises have special emphasis on the innovative development – Belcard JSC, Grodno Azot JSC, Grodno mechanical plant JSC, Belvtorpolymer JSC, Zwetlit UE.

3. Results and discussions

The analysis of the research of domestic and foreign scientific schools in the field of the formation and development of the postindustrial economy, defined as the "knowledge economy" ("new economy") demonstrates the need for a system approach to the organization, development and intensification of innovation activities of industrial enterprises [5-7]. The main idea of the system approach is the permanent increase of the capacity (ability) of economy entities to produce innovative products with high parameters of consumer characteristics. Such parameters ensure sustainable economic and social development of the industrial enterprise in the near and far term in accordance with the basic principles of the National Sustainable Development Strategy of the Republic of Belarus adopted at the legislative level.

The most important criteria for the realization of system approach is the creation of conditions for the generation of intellectual products of various functionality. These conditions determine all the stages of the productive activity of a economy entity in accordance with the current legislation regulation of economic, technological, social, organizational and other rules and laws.

For the practical realization of the system approach in accordance with the requirements of the national strategy, a system

of intellectual support of innovative activities of industrial enterprises (SISIA IE) was developed and the principles of its formation and functioning in the interests of development of economic entities of various departmental subordination, functionality and ownership were determined [7]. The presence of basic and variable components in the SISIA IE creates stable prerequisites for the creation of intelligent products of various types, the use of which in the real production process ensures the manufacturing of industrial products with high parameters of consumer characteristics. The realization of these industrial products creates an economic basis for functioning. At the same time, the share of innovative products that have fundamentally new parameters, new consumer value and create conditions for expanding of the occupied market sector or creation of fundamentally new sectors that guarantee permanent sustainable economic development of industrial production in the long term, is increasing. High-level innovations based on new types of materials and technologies create prerequisites for the development of the economy entity in the occupied sector of the market and allow the manufacturer to control the tendencies of its functioning by a consistent (controlled) change of varieties, called the "innovation line".

In this work we will consider the methodology for the realization of the developed SISIA IE in the industrial enterprise of the machine building profile.

To support the effective functioning of the SISIA IE, its infrastructure should include components that ensure the generation of intelligent products for special purposes and their realization in the form of objects of industrial and intellectual property which determine the activities of an industrial enterprise in accordance with the requirements of the subjects of the regional and state regulatory legal base.

These components of the SISIA IE infrastructure include:

- educational component;
- research component;
- production component.

These components are integrated by organizational criterions under the specialized innovation cluster type structure with an appropriate system of administration, economic control and support [3, 7].

The presence of educational and research components makes it possible to realize the integration principle in the formation of aggregate intellectual resources including tangible and intangible intellectual assets belonging to higher educational institutions, a regional industrial enterprise, and a specialized research subdivision [3]. Integration takes place under the internal research at the enterprise in the field of innovative development or tasks of regional, sectoral or state scientific and technical programs.

The feature of the SISIA IE intellectual resources is their adaptation to the real production process and high efficiency of use in the interests of innovative development of a specific industrial enterprise. In addition, the integration principle of its formation makes it possible to change its components depend on the problems of innovative development and carrying out their updating (improvement) in accordance with changing trends in the functioning of the regional, state and global markets.

The functioning of the components of the SISIA IE is carried out as follows.

The presence of an educational component in the form of branches of profile departments of regional and other higher educational institutions (Figure 1) allows to carry out essentially new functions in the interests of an industrial enterprise:

- practical-oriented training of engineers adapted to the current production;
- targeted training of research staff for the realization of internal research;
- practical-oriented training for innovative production;
- targeted retraining of engineering and technical staff and professional development of personnel to reflect trends in innovative development.

The realization of these functions of the SISIA IE educational component allows to increase the intellectual potential of the subdivisions included in the infrastructure of the industrial enterprise in the form of a system of specialized departments that are subordinate to the main specialists – Chief Engineer (CEn), Chief Technology Officer (CTO), Chief Mechanic (CM), Chief Power Engineer (CPE), Chief Accountant (CA), Chief Economist (CEc). The functioning of the educational component, in the activity of which the leading specialists of the enterprise take part, makes it possible in the conditions of the existing infrastructure to realize the principle of practical-oriented training of engineering and technical staff provided by the Education Code of the Republic of Belarus. Also, the terms of adaptation of young specialists to the conditions of current production are sharply reduced and opportunities for the inflow of intellectual resources of the advanced level are created. At the same time, the educational component carries out targeted training of research personnel for a specialized research department for systemic internal research.

The studies conducted under their own innovation development plan or assignments of state, regional and sectoral scientific and technical programs create the conditions for the development of innovations for various functionality, which are the basis of innovate activity. Participation of leading researchers in the educational process of branches of profile educational departments raises the level of professional training of students, include developing practical skills in research activities under the specific projects.

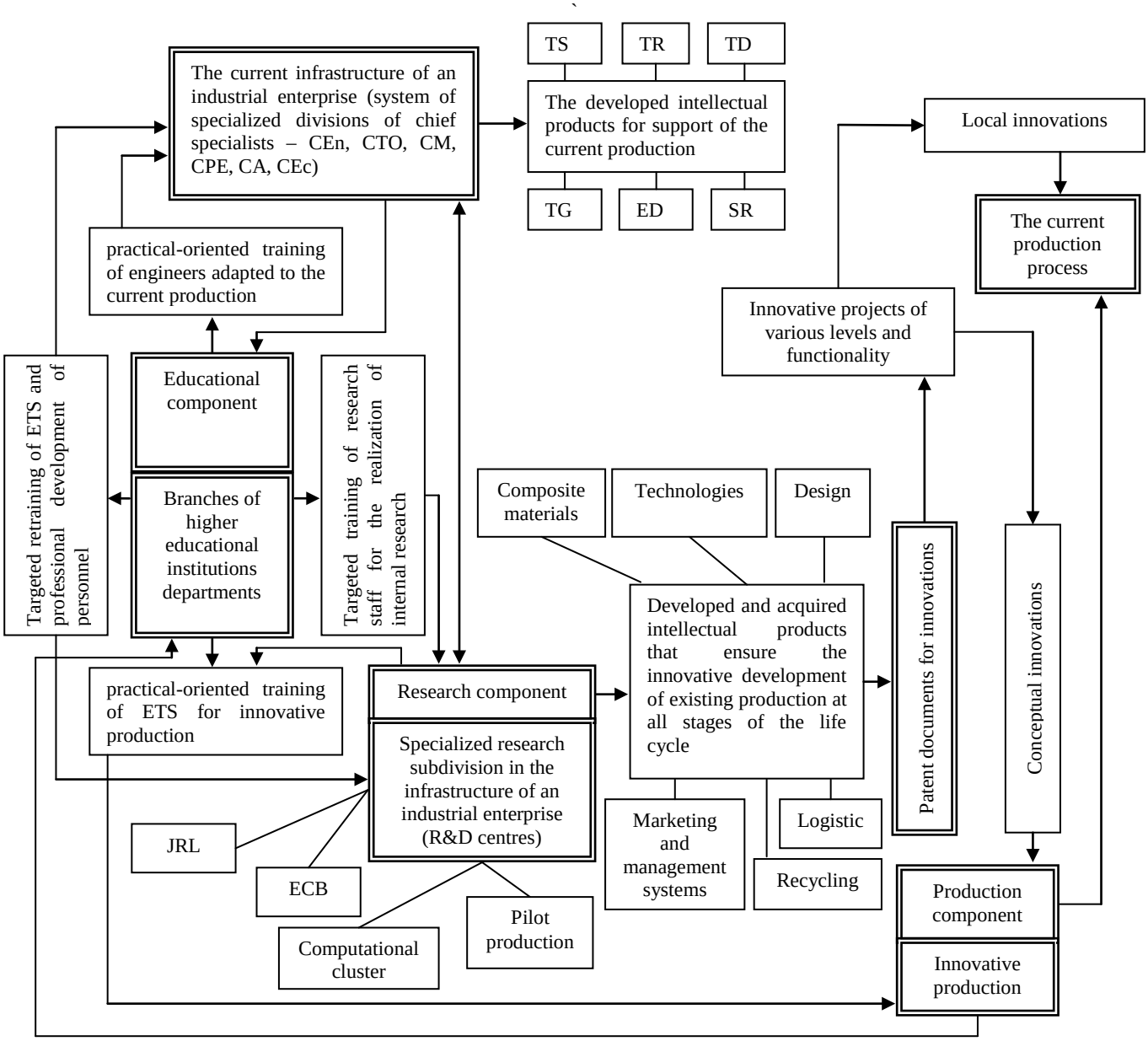
The presence of an educational component allows to solve the clearly expressed problem of staffing of innovative production, which is segregated in the actual infrastructure of an industrial enterprise into an independent subdivision. The increasing of professional competencies of specialists trained at branches of profile educational departments is facilitated by the participation in the educational activity of leading specialists of innovative production.

The necessary function of the SISIA IE educational component is the organization of targeted retraining of engineering and technical staff and professional development of personnel on the basis of modern achievements of fundamental and applied research realized in the system of the National Academy of Sciences and Higher Educational Institutions taking into account the traditional system of the enterprise's activities.

Thus, the SISIA IE educational component forms the intellectual potential of various infrastructural subdivisions of the industrial enterprise and provides the prerequisites for increasing of the innovation susceptibility of all production activities participants regardless of job competencies and education basic level. The generated intellectual potential, which is in permanent improvement and development, is realized in the form of intellectual products with various functionality, level and application area.

A system approach to intellectual support will allow the development of intelligent products both ensuring the current production process (Technical Specification (TS), Technical Regulations (TR), Technical Documentation (TD), Technical Guidelines (TG), Occupational Protection and Safety Regulations (SR)) and products that determine the strategy of innovative development in accordance with the concept of the life cycle of innovative product. Among such intelligent products are new types of composite materials, energy-, resource-saving and high technologies (high-tech), new product designs, quality management systems, systems of management and marketing, supply chain logistics systems, technologies for recycling of technological waste and depreciated products in accordance with the requirements of environmental legislation.

An important feature of SISIA IE is the development of a complex of patent documentation for created intellectual products in the form of industrial property items (IPI). It allows to ensure the system protection of the occupied market sector and the long-term perspective of its development through the consistent introduction of modifications which are part of the general "line of innovations".



CEn – Chief Engineer;
CTO – Chief Technology Officer;
CM – Chief Mechanic;
CPE – Chief Rower Engineer;
CA – Chief Accountant;
CEc – Chief Economist;
TS – Technical Specification;
TR – Technical Regulations;
TD – Technical Documentation;
TG – Technical Guidelines;
ED – Electronic Data;
SR – Occupational Protection and Safety Regulations;
ETS – Engineering and Technical Staff;
JRL – Joint Research Laboratories;
ECB – Electronic Component Base;
R&D centres – Research and Development Centres

Figure 1 – The main directions of structural modification in materials science and technology of polymer composite materials

Thus, the developed algorithm of the SISIA IE functioning allows to form the intellectual products (intellectual resources of industrial enterprise) that constitute a variety of innovative projects, the realization of which make it possible to carry out production activities and increase the share of innovative products in the total output product. The developed relatively low level innovations (local innovations, maintenances) allow to support a high level of current production and improve its organizational, technological, material, personnel, economic security. High level innovations form the basis for effective activity of the SISIA IE production component that functions as a specialized innovative production.

The testing of SISIA IE as part of the second integration level model at industrial enterprises of the Grodno region enabled to develop the functional nanomaterials based on polyamides, fluoroplastics and polyolefins for the production of tribotechnical coatings for automotive components, compressors sealing elements for liquefied gases and structural components for energy-saving systems. The methodological approach to the creation of nanomaterials with high parameters of functional characteristics

consisted in the introduction of nanoscale (carbon-, metal- and silicon-containing) particles into polymer matrices at the stages of obtaining materials, processing them into products and preoperational treatment.

Experimental and industrial application of products and coatings from the developed nanocomposites based on aliphatic polyamides (PA6, PA6.6), polytetrafluoroethylene (PTFE), primary and regenerated polyolefins (PP, HDPE, LDPE) at the enterprises of the Grodno region was carried out. A patents for an invention and normative technical documentation regulating the using of nanocomposites in machine building were developed.

4. Conclusions

The directions of system intellectual support of innovative activity of regional industrial enterprises were considered. The perspective of the methodological approach based on the implementation of the integration principle of the intellectual potential of the enterprise by combining the intellectual resources of research, educational and industrial institutions and organizations with the use of a cluster scientific-educational and production structure was shown. The effectiveness of the cluster innovative structure was realized due creation of the nanocomposite materials based on thermoplastics for use in the machines, mechanisms and technological equipment with high performance parameters.

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COMPETENCY PROFILE OF THE INNOVATIVE ENTERPRISES

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***Abstract**: Innovative enterprises have a key role in the recognition and the sustainable development of the knowledge-based economy. The different innovative enterprises have different contribution and value for the economy and the social development. The R&D personnel and its acquired and developed competencies are basic characteristics of the innovative firms. On the base of the R&D personnel's competencies a company competency profile is designed. This model may improve the innovation activity and the organizational performance of the enterprise. It can be used for making differentiation between innovative enterprises and on is base to be delivered conclusions on their competency competiveness. The competency profile can be useful for choosing what kind of innovations to be produced and in what innovate projects the company may participate. These innovative projects need concrete and specific competency tools. The competency profile works within a framework for improvement of the whole competency management of the innovative enterprise and introducing the best performance management practices for the R&D personnel.*

Keywords: COMPETENCY, INNOVATIVE ENTERPRISE, PERFORMANCE, R&D PERSONNEL, COMPETENCY MODEL

1. Introduction

Innovative enterprises are essential in today's knowledge-based economy with their ability to generate, create, develop, transfer and integrate knowledge in the form of new products, services and processes. Trends in developed economies are centered on increasing their dependence on knowledge, information and technology and on the developing and enhancing the qualification of the human resources, engaged in research, development and innovation. The innovative enterprise have a key role and a crucial importance in the growth and development of the economy and society [1, 2]. The creation and development of high-technology enterprises is a priority for the economy and policy of the European Union. These businesses require significant financial and highly qualified human resources to be directly involved in creating high added value innovations [3]. Different innovative businesses have a different contribution and value to the economic and social development. Innovative enterprises can be characterized with increased scientific research and development activity and with employment of highly qualified personnel with specific professional qualifications and work experience. Therefore innovative enterprises are able quickly to respond to changes in consumer demands as well as to the new perspectives of the scientific and technological progress. Most of the enterprises in Bulgaria do not have their own research potential. A small part of the big hi-tech enterprises in our country have developed research and development units that mainly transfer technology or finance translation and clinical research. In Bulgaria, the largest number of innovative enterprises are in the sectors: Information Technologies, Engineering and Consulting, Financial Intermediation. By the year 2020, about 1/4 of all employees are expected to work in innovative and creative businesses in Bulgaria, accounting for around 40% of GDP. This requires a certain professional qualification and personnel's competence that are related to the production of high added value products [4].

One of the most significant features of innovative enterprises is the personnel, involved in innovation activities and their characteristics - educational level and professional experience. The share of scientific and engineering personnel in the total number of employees in innovative enterprises is above average.

Recognizing that research and development (R&D) employees are the most important resource for creating innovations, the innovative enterprise has to adopt a competency framework emphasizing the management of human resources to achieve excellent performance as well as results that are relevant to the organization's innovation strategies [5].

The competency profile indicates the competencies of the organisation that underlie successful performance in a given role and includes information that will be helpful in preparing for staffing processes, performance evaluations, identifying learning and development needs and career planning. The profile will be used in performance discussions between managers and employees to identify innovation competencies that need development.

The competency profile framework provides an overarching structure under which each enterprise has to develop its own tools of competencies and behavioural indicators for its own jobs or job families.

2. Research and Development Personnel

Employment in the knowledge-based economy is characterized by increasing the demand and hiring of highly qualified specialists with specific skills and competencies. The main advantage of innovative enterprises is the highly qualified research and development (R&D) personnel with a professional structure and specific competency profile consistent with the specific of the innovation activity of the enterprise. The professional structure of innovative enterprises is characterized by the significant share of researchers, engineers, technical specialists and innovation managers.

Management and development of human resources in innovative enterprises is essential for the creation of innovations. Managers should improve the innovation performance through hiring people with innovation capacity and competencies. Key innovation competencies have to be identified and developed in the enterprise in order to increase the organizational competitiveness. They need to be developed and improved by creating an inner environment that stimulates creativity, innovation and entrepreneurship. This is possible through the implementation of a holistic and integrated competency management approach that provides opportunities for purposeful improvement and development of personnel's competencies. Competency management in innovative enterprises helps to build and develop research personnel, stimulates and supports the growth of innovation potential and innovative business solutions. According to [4], the entity, that organizes, conducts, maintains, stimulates and develops innovation in the enterprise, is the R&D personnel. The researchers, together with the technical associates, represent the human resources directly responsible for the creation, implementation and dissemination of new knowledge and innovations in the enterprise [4, 6, 7]. People are generators, analysts, and innovators in the enterprise. R&D personnel includes the specialists with the highest educational level and best-developed professional competencies. These are researchers, technologists, designers, programmers and others who have the potential to create, absorb, transfer and use new knowledge for the development of innovation.

There are different classifications that try to categorize the personnel, engaged in innovation activity in the enterprises [8, 9, 10]. According to the National Statistical Institute (NSI), the personnel involved in innovation activities is divided into researchers, technical personnel and support staff (from 2012 the NSI brings together the

categories of "Technical staff" and "Support staff" in one general category "Other R&D personnel"). According to the National Classification of Professions and Positions these specialists refer to the categories - analytical specialists, technical specialists and other applied specialists. According to the functional activities, the following personnel categories can be defined in innovative enterprises: 1) managers; 2) administrative personnel; 3) researchers; 4) technical personnel; 5) support staff (Fig. 1).

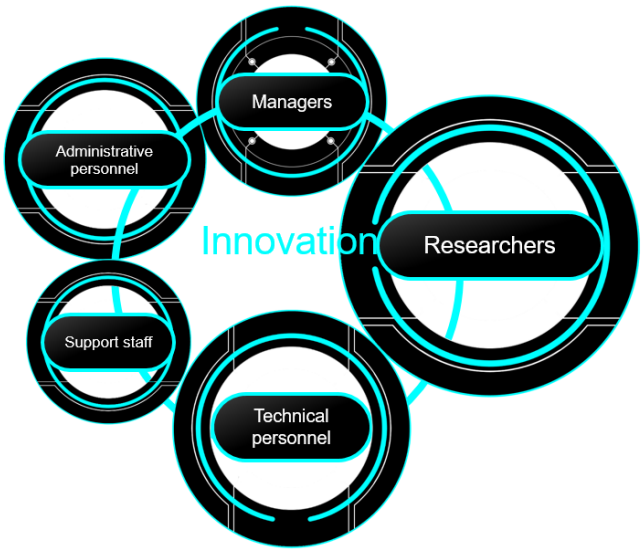


Fig. 1. *Personnel categories in innovative enterprises*

This distribution is more typical for medium and large enterprises. In small enterprises personnel categories are less clearly distinguished and employees often combine job functions and activities. The figure shows the different ratios of the categories of personnel in an innovative enterprise. Differences in circle' size indicate the predominant number of collaborators, engaged in a certain innovation functional activity. Each of the categories - administrative personnel, researchers, technical and support staff have specific competencies, educational and professional levels.

Managers and administrative personnel are committed to planning and managing the operational aspects of researchers' work. In some enterprises, the management function can also be executed by the researchers. Researchers in innovative enterprises have priority-specific competencies and they are mostly engaged in scientific research and innovation activity. Typically, the various innovation professionals are scientists and engineers with scientific and technical background and can generate innovative ideas and quickly to respond to the innovations made by the competitors. Very often, researchers are managers of innovative projects or teams. The innovation themes are related to different scientific and applied disciplines.

3. Competencies of the R&D Personnel

Innovation requires knowledge, ideas, cognitive abilities and creativity. This requires innovative enterprises to work with interdisciplinary teams and professionals with different professional qualifications [11]. The characteristics of the R&D personnel, involved in innovation, can be analyzed by the quantity and quality of their work and their professional competencies. Different personnel categories, engaged in innovation have different educational, professional and knowledge requirements.

Competencies are a set of knowledge, skills, abilities and attitudes that are necessary for successful performance in a given professional role or in an enterprise [12, 13]. Competencies of the personnel engaged in innovation are valued at different levels of the enterprise - in selection, when an entity should choose employees with specific skills for the purpose of future project, in planning a career growth and development. Depending on the different stages of innovation activity, the competency requirements of R&D personnel are different.

Competence is an expression of the professional and personal development of the employee, depending on the competency model for the job and the requirements of the standards, adopted in the company. The identification of key competencies and their improvement through the design of a competency model is the base for appraisal and performance management.

Competency model is a competency framework which describes what behaviour is needed to achieve the best results at a given position, organizational level, or specific function [13, 14, 15, 16]. It combines multiple competencies that, used together, determine the successful work and organizational performance. There are many classifications of competencies that divide them according to different criteria. For the purpose of this paper, the classification for basic, functional and specific competencies is adopted.

Basic competencies - these are typical and required for the whole enterprise abilities and attitudes.

Functional competencies - characteristics that are required for a particular function or unit, e.g. innovations.

Specific competencies - specific competencies are required for a particular profession, position or activity. Developing innovations requires knowledge and experience in the relevant field related to the core business of the enterprise.

Innovative work requires the accumulation and sharing of knowledge, working in project teams and building productive working relationships and collaboration both within and outside the enterprise. The innovation team includes collaborators with different contributions to successfully achieving innovation goals. Some of them are powerful in generating ideas, performing analyzes, setting guidelines for work. Other participants have strengths in support, assistance and collaboration. Third group are best in the implementation of the practical plans, in the observance of deadlines, in the elaboration of various details [17]. This, together with the peculiarities of innovative enterprises, predetermines the wide variety and complexity of the requirements for the R&D personnel.

Identifying and scheduling the competencies of the R&D personnel will help managers to plan and organize innovation work better. Competency management will have an impact on work performance and human resource management functions and activities such as job design and job description, recruitment and selection, training and development, talent and career management. By developing the competencies of the R&D personnel, the added value that people create in the enterprise will increase. In order to create more innovations in the enterprise, it is necessary to attract and develop highly qualified professionals with specific knowledge and skills, with higher motivation and higher productivity. Qualification of the personnel in innovative enterprises is higher than in traditional enterprises where manufacturing personnel is predominate and in which the personnel qualification may vary widely [15, 18, 19].

According to [20], key competencies of researchers can be grouped into three groups: scientific competencies, project and team management skills, and interpersonal competence. On the basis of researched multiple and different competency models [18, 19, 20, 21, 22 and others] the competencies of R&D personnel can be grouped as it is shown in Table 1. Competency groups are summarized for all personnel categories in innovative enterprises. Some of the competencies are not mandatory for researchers, who are directly involved in creating innovations, such as Leadership competencies. The results of the innovation activity depend directly on the professional and personal competencies of the collaborators acquired through formal education, training, lifelong learning programs as well as in the work process. Professional competencies correspond to the functional and specific competencies, while the personal competencies

correspond to the basic ones. Personal competencies are manifested through a specific attitude and demonstrated behavioural pattern. Competencies such as teamwork and interpersonal skills are general and usually they are required for all employees in the enterprise.

Table 1. *Generalized groups of competencies for all categories of personnel, engaged in innovation activities*

Competency group	Example of competencies
Basic competencies	Communication, teamwork, creative problem solving, analytical and conceptual thinking, interpersonal skills, self-discipline, customer relationship management, flexibility, professionalism
Functional competencies	Knowledge and skills for the core of business processes - financial and business knowledge, project and process management, human resources management
Specific competencies	Scientific knowledge - specialized knowledge in a concrete scientific field, consulting, design and instruction
Technical competencies	Knowledge, skills, abilities, required for the technical analyses and performance of the products and services
Administrative competencies	Knowledge and skills for maintaining the operational work
Leadership competencies	Leadership, vision, teamwork, situation evaluation, conflict management, mentoring and training of employees
Personal competencies	Creativity, imagination, intelligence, initiative, achievement orientation, interest in new ideas, persistence in overcoming difficulties and obstacles, self-confidence, believe in the success of the enterprise, taking risks, a skill to overcome the resistance of others

Depending on the personnel's category competencies are required and developed for the different innovation activity. An important feature of the innovator is his/her personality traits which distinguish him/her from all other specialists in the same position and who perform the same routine tasks and duties.

4. Competency profile of the innovative enterprise

The competency profile of the innovative enterprise shows the actual status of the competencies owned by its associates. This is a set of all competencies for a particular unit, position or group of positions.

The competency profile is a model that combines different classifications of competencies. Competencies are combined by function and activities. On the one hand - basic, functional and specific and on the other - scientific, technical, administrative, leadership and managerial (Table 2). The R&D personnel has predominantly specific competencies and managers - functional.

Table 2. *Competency profile of the innovative enterprise*

Functional competencies / Personnel competencies	Basic competencies	Functional competencies	Specific competencies
Managerial and administrative competencies	++	+++	+
Research and innovation competencies	+	++	+++
Technical and support competencies	+++	+	++

Diagram models of the competency profiles of two different innovative enterprises are shown in Fig. 2. The basic, functional and specific competencies form the inner layer of the enterprise's profile, and the other competencies divide it into shares, depending on how much percentage or share the enterprise owns. The company's competencies are the sum of the competencies of the collaborators working in it. They are employed with a specific set of competencies which improve, develop and meanwhile acquire new skills in the work process. In each share of scientific, technical and managerial competencies, the amount of basic, functional and specific competencies is different, for example, the specific competencies are predominant for the researchers, while for the executive positions these are the basic competencies.

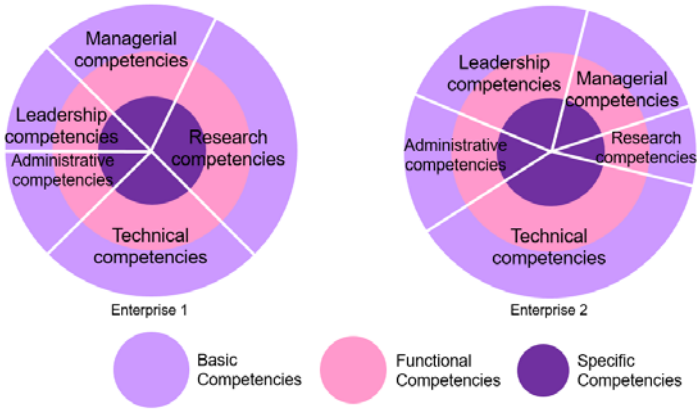


Fig. 2. *Competence profile of the innovative enterprise*

The competency profile of the innovative enterprise is a model for managing the competencies of the R&D personnel. With its help the enterprise's profile is compared to the requirements for innovation and specific competencies used in a particular innovation activity. The competency profile can be used to identify the shortage of competencies in a given direction that the collaborators in the enterprise have to acquire or develop. It can be used to identify in which innovation stages and areas there is a need to recruit additional personnel and with what qualifications. It is also useful to identify what innovation skills to be trained and to assess how long it will be need to develop the necessary competencies, whether through retraining or mentoring. The competency profile can serve as evidence that an enterprise has a specific set of competencies - competence in a certain field of innovation activity. The competency profile can serve the leadership of the innovative enterprise and helps the choice of partner enterprise in a business field, depending on its role and what needs to be achieved in the joint innovation project. The account will determine which enterprise to be selected as a subcontractor, supplier or a customer partner.

The competency profile is a very helpful tool for the human resources management as well as for the work and organizational performance management. The comparison between the role of the enterprise and its current state of innovation will determine the positive or negative balance of specific competencies it requires. This comparison can be made on an annual basis, monitored and traced over time.

The competency profile consists only of proven and verified competencies and can be compared with the competency model that is required and developed during the reporting period on the basis of participation in innovation projects. It is important to have a balance between the competencies owned by the enterprise and the ones, needed for the relevant innovation activity or project, because if there is a discrepancy, there will be a shortage of knowledge and skills or if there is a surplus, it means inept management of the potential and the

abilities of the employees. It will lead to undue expenses and a risk of demotion or loss of highly qualified personnel will appear.

5. Conclusions

The competency profile of the innovative enterprises is a model for enterprise competency management. It contains a set of the competencies owned by the innovative enterprise and a quantitative measurement tools. Competencies can be measured with ballistic assessment or degree of proficiency. Competence assessment scale is a description of the individual grades showing the actual level of innovation competence. The model can be used to evaluate and compare different categories of innovative enterprises and on its basis to explore, compare and establish the relationship between the innovation activity of the enterprise and the competencies of the personnel, employed in it. Another dependency may indicate the relationship between formal education and competencies needed to create innovation. There may be a link between the type of innovation and the availability of a certain type of competencies, as well as the dependence on the number of employees in a particular category of personnel and the most appropriate ratio for that. The competency profile can be used to evaluate the individual contributor as well as to evaluate the various teams and departments within the enterprise, and when the percentage is broken, managers seek out people to supplement it with their knowledge, skills and professional experience.

By comparing different competency profiles, conclusions can be made about what makes one enterprise more innovative than another. In this way, the management will know what competencies to look for when recruiting and selecting R&D personnel and when training and developing collaborators. The competency profile can be used to direct employees to a specific type of innovation activity for the needs of the innovative enterprise. It is also possible to distinguish between the different hierarchical levels in the enterprise - which competencies are increased at the expense of others as they are applied in everyday routine work and innovative projects. This shows that, depending on the job performed and the specific work tasks, some competencies are more important and more common than others. Even if a contributor has a specific competency profile, he must apply the competencies that are required to do the job, while the others remain hidden and they are not used, which in a longer period may lead to impairment or loss of competencies.

Not all enterprises that are innovative carry out R&D unit and have a category of researchers among the personnel categories. Professionals who generate ideas for innovation, develop and implement them are called innovators. These people may be not scientists and researchers but have the knowledge and the innovation competencies to recognize and to apply new ideas, methods and processes. Regardless of the category of personnel and occupation of the enterprise, each employee can and have to participate in the creation of innovations. Depending on the personnel category the innovator has some of the following competencies - scientific, technical, administrative and managerial competencies.

When assessing people at the entrance, managers rely on their innovation potential and personal development. The competencies that characterize the enterprise's innovation activity are specific to the different innovative businesses.

The personnel engaged in innovation in innovative enterprises have a higher level of education and a higher qualification, so its specific competencies are more prominent. Professional competencies are related to the nature of the work, while personal competencies help with relationships with managers, other employees in the company and with customers. The personal characteristics of the innovation personnel are focused on developing creativity, motivation and adaptability to change. Specific and functional competencies are predominant in innovative enterprises and concern a larger number of people in an enterprise than in traditional enterprises with more basic competencies. Specific and functional competencies predetermine the competitive advantage of the enterprise. In order to facilitate and improve the choice of competencies required for the work performance of each group of positions, a competency model can be designed and developed. The best practices for managing job performance use targeting competencies to a specific type of innovation tasks and projects. For that purpose specific innovation competencies are needed.

The competency profile of the innovative enterprises can be used in choosing a partner enterprise in a business field, depending on its role and what needs to be achieved in the joint innovation project. In this respect, one more definition of an innovative enterprise can be added: an innovative enterprise is one that has a certain type of competence or a ratio of competencies as well as a ratio of personnel categories with specific and functional competencies. It is possible to define specific competencies for manufacturing and executive personnel but it is more difficult and specific to do it for researchers and innovation managers depending on the innovation subject, industry and other characteristics of the innovative enterprise. Properly designed and applied competency profile will help managers to achieve better business results and organisational performance, to enhance the innovation competitiveness, developing the enterprise in line with its strategic goals.

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REUSE OF SOFTWARE ENGINEERING

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Abstract: *Reuse-based software engineering is a software engineering strategy where the development process is geared to reusing existing software. The move to reuse-based development has been in response to demands for lower software production and maintenance costs, faster delivery of systems, and increased software quality. More and more companies see their software as a valuable asset. They are promoting reuse to increase their return on software investments.*

Keywords*: Software engineering, reuse of software engineering, applicaton frameworks, software product lines, COST integration, ERP*

The availability of reusable software has increased dramatically. The open source movement has meant that there is a huge reusable code base available at low cost. This may be in the form of program libraries or entire applications.

There are many domain-specific application systems available that can be tailored and adapted to the needs of a specific company. Some large companies provide a range of reusable components for their customers.

Standards, such as web service standards, have made it easier to develop general services and reuse them across a range of applications.

Reuse-based software engineering is an approach to development that tries to maximize the reuse of existing software. The software units that are reused may be of radically different sizes:

- ***Application system reuse*** The whole of an application system may be reused by incorporating it without changing into other systems or by configuring the application for different customers. Alternatively, application families that have a common architecture, but which are tailored for specific customers, may be developed.
- ***Component reuse*** Components of an application, ranging in size from subsystems to single objects, may be reused. For example, a pattern-matching system developed as part of a text-processing system may be reused in a database management system.
- ***Object and function reuse*** Software components that implement a single function, such as a mathematical function, or an object class may be reused. This form of reuse, based around standard libraries, has been common. Many libraries of functions and classes are freely available. You reuse the classes and functions in these libraries by linking them with newly developed application code. In areas such as mathematical algorithms and graphics, where specialized expertise is needed to develop efficient objects and functions, this is a particularly effective approach.

Software systems and components are potentially reusable entities, but their specific nature sometimes means that it is expensive to modify them for a new situation. A complementary form of reuse is 'concept reuse' where, rather than reuse a software component, you reuse an idea, a way, or working or an algorithm. The concept that you reuse is represented in an abstract notation (e.g., a system model), which does not include implementation detail. It can, therefore, be configured and adapted for a range of situations. Concept reuse can be embodied in approaches such as design patterns configurable system products, and program generators. When concepts are reused, the reuse process includes an activity where the abstract concepts are instantiated to create executable reusable components.

An obvious advantage of software reuse is that overall development costs should be reduced. Fewer software components need to be specified, designed, implemented, and validated. However, cost reduction is only one advantage of reuse. In Table.1, they have listed some advantages of reusing software assets.

Table 1

Benefit	**Explanation**
Increased dependability	Reused software, which has been tried and tested in working systems, should be more dependable than new software. Its design and implementation faults should have been found and fixed
Reduced process risk	The cost of existing software is already known, whereas the costs of development are always a matter of judgment. This is an important factor for project management because it reduces the margin of error in project cost estimation. This is particularly true when relatively large software components such as subsystems are reused.
Effective use of specialists	Instead of doing the same work over and over again, application specialists can develop reusable software that encapsulates their knowledge.
Standards compliance	Some standards, such as user interface standards, can be implemented as a set of reusable components. For example, if menus in a user interface are implemented using reusable components, all applications present the same menu formats to users. The use of standard user interfaces improves dependability because users make fewer mistakes when presented with a familiar interface.
Accelerated development	Bringing a system to market as early as possible is often more important than overall development costs. Reusing software can speed up system production because both development and validation time may be reduced.

However, there are costs and problems associated with reuse. There are a significant cost associated with understanding whether or not a component is suitable for reuse in a particular situation, and in testing that component to ensure its dependability. These additional costs mean that the reductions in overall development costs through reuse may be less than anticipated.

Table 2

Problem	**Explanation**
Increased maintenance costs	If the source code of a reused software system or component is not available, then maintenance costs may be higher because the reused elements of the system may become increasingly incompatible with system changes.
Lack of tool support	Some software tools do not support development with reuse. It may be difficult or impossible to integrate these tools with a component library system. The software process assumed by these tools may not take reuse into account. This is particularly true for tools that support embedded systems engineering, less so for object-oriented development tools.
Not-invented-here syndrome	Some software engineers prefer to rewrite components because they believe they can improve on them. This is partly to do with trust and partly to do with the fact that writing original software is seen as more challenging than reusing other people's software.
Creating, maintaining, and using a component library	Populating a reusable component library and ensuring the software developers can use this library can be expensive. Development processes have to be adapted to ensure that the library is used.
Finding, understanding,	Software components have to be discovered in a library, understood and, sometimes, adapted

and adapting reusable components	to work in a new environment. Engineers must be reasonably confident of finding a component in the library before they include a component search as part of their normal development process.

Software development processes have to be adapted to take reuse into account. In particular, there has to be a requirements refinement stage where the requirements for the system are modified to reflect the reusable software that is available. The design and implementation stages of the system may also include explicit activities to look for and evaluate candidate components for reuse.

Software reuse is most effective when it is planned as part of an organization-wide reuse program. A reuse program involves the creation of reusable assets and the adaptation of development processes to incorporate these assets in new software.

Over the past years, many techniques have been developed to support software reuse. These techniques exploit the facts that systems in the same application domain are similar and have potential for reuse; that reuse is possible at different levels from simple functions to complete applications; and that standards for reusable components facilitate reuse. Figure 1 sets out a number of possible ways of implementing software reuse, with each described briefly in Table 3.

Figure 1

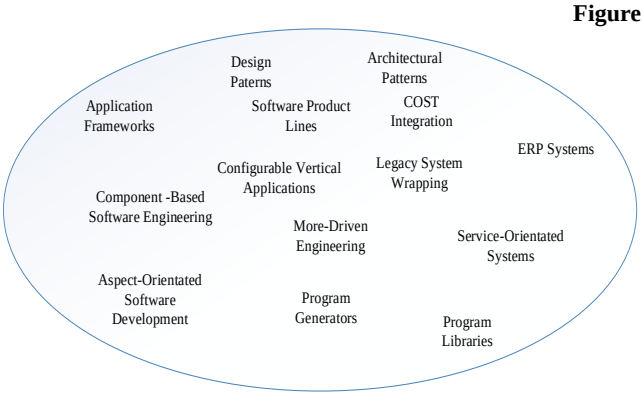


Table 3

Approach	Description
Architectural patterns	Standard software architectures that support common types of application systems are used as the basis of applications.
Design patterns	Generic abstractions that occur across applications are represented as design patterns showing abstract and concrete objects and interactions.
Component-based development	Systems are developed by integrating components (collections of objects) that conform to component-model standards.
Application frameworks	Collections of abstract and concrete classes are adapted and extended to create application systems.
Legacy system wrapping	Legacy systems are 'wrapped' by defining a set of interfaces and providing access to these legacy systems through these interfaces.
Service-oriented systems	Systems are developed by linking shared services, which may be externally provided.
Software product lines	An application type is generalized around a common architecture so that it can be adapted for different customers.
COTS product reuse	Systems are developed by configuring and integrating existing application systems.
ERP systems	Large-scale systems that encapsulate generic business functionality and rules are configured for an organization.
Configurable vertical applications	Generic systems are designed so that they can be configured to the needs of specific system customers.
Program libraries	Class and function libraries that implement commonly used abstractions are available for reuse.
Model-driven engineering	Software is represented as domain models and implementation independent models and code is generated from these models.
Program generators	A generator system embeds knowledge of a type of application and is used to generate systems in that domain from a user- supplied system model.
Aspect-oriented software development	Shared components are woven into an application at different places when the program is compiled.

Given this array of techniques for reuse, the key question is "which is the most appropriate technique to use in a particular situation?" Obviously, this depends on the requirements for the system being developed, the technology and reusable assets available, and the expertise of the development team. Key factors that you should consider when planning reuse are:

- ***The development schedule for the software*** If the software has to be developed quickly, you should try to reuse off-the-shelf systems rather than individual components. These are large-grain reusable assets. Although the fit to requirements may be imperfect, this approach minimizes the amount of development required.
- ***The expected software lifetime*** If you are developing a long-lifetime system, you should focus on the maintainability of the system. You should not just think about the immediate benefits of reuse but also of the long-term implications. Over its lifetime, you will have to adapt the system to new requirements, which will mean making changes to parts of the system. If you do not have access to the source code, you may prefer to avoid off-the-shelf components and systems from external suppliers; suppliers may not be able to continue support for the reused software.
- ***The background, skills, and experience of the development team*** All reuse technologies are fairly complex and you need quite a lot of time to understand and use them effectively. Therefore, if the development team has skills in a particular area, this is probably where you should focus.
- ***The criticality of the software and its non-functional requirements*** For a critical system that has to be certified by an external regulator, you may have to create a dependability case for the system This is difficult if you don't have access to the source code of the software. If your software has stringent performance requirements, it may be impossible to use strategies such as generator-based reuse, where you generate the code from a reusable domain- specific representation of a system. These systems often generate relatively inefficient code.
- ***The application domain*** In some application domains, such as manufacturing and medical information systems, there are several generic products that may be reused by configuring them to a local situation. If you are working in such a domain, you should always consider these as an option
- ***The platform on which the system will run*** Some components models, such as NET, are specific to Microsoft platforms. Similarly, generic application systems may be platform-specific and you may only be able to reuse these if your system is designed for the same platform

The range of available reuse techniques is such that, in most situations, there is the possibility of some software reuse. Whether or not reuse is achieved is often a managerial rather than a technical issue. Managers may be unwilling to compromise their requirements to allow reusable components to be used. They may not understand the risks associated with reuse as well as they understand the risks of original development. Although the risks of new software development may be higher, some managers may prefer known to unknown risks

Application Frameworks & Software Product Lines

It has become clear that object-oriented reuse is best supported in an object-oriented development process through larger-grain abstractions called frameworks. A framework is a generic structure that is extended to create a more specific subsystem or application.

Frameworks provide support for generic features that are likely to

be used in all applications of a similar type.

Frameworks support design reuse in that they provide a skeleton architecture for the application as well as the reuse of specific classes in the system. The architecture is defined by the object classes and their interactions. Classes are reused directly and may be extended using features such as inheritance.

Frameworks are implemented as a collection of concrete and abstract object classes in an object-oriented programming language. Therefore, frameworks are language-specific.

Frameworks are often implementations of design patterns. For example, an MVC framework includes the Observer pattern, the Strategy pattern, the Composite pattern, and a number of others. The general nature of patterns and their use of abstract and concrete classes allows for extensibility. Without patterns, frameworks would, almost certainly, be impractical.

Web application frameworks usually incorporate one or more specialized frameworks that support specific application features. Although each framework includes slightly different functionality, most web application frameworks support the following features: ***Security*** WAFs may include classes to help implement user authentication (login) and access control to ensure that users can only access permitted functionality in the system; ***Dynamic web pages*** Classes are provided to help you define web page templates and to populate these dynamically with specific data from the system database; ***Database support*** Frameworks don't usually include a database but rather assume that a separate database, such as MySQL, will be used. The framework may provide classes that provide an abstract interface to different databases; ***Session management*** Classes to create and manage sessions (a number of interactions with the system by a user) are usually part of a WAF; ***User interaction*** Most web frameworks now provide AJAX support which allows more interactive web pages to be created.

However, frameworks are usually more general than software product lines, which focus on a specific family of application system. For example, you can use a web-based framework to build different types of web-based applications. One of these might be a software product line that supports web-based help desks. This 'help desk product line' may then be further specialized to provide particular types of help desk support.

Frameworks are an effective approach to reuse, but are expensive to introduce into software development processes. They are inherently complex and it can take several months to learn to use them. It can be difficult and expensive to evaluate available frameworks to choose the most appropriate one. Debugging framework- based applications is difficult because you may not understand how the framework methods interact. This is a general problem with reusable software. Debugging tools may provide information about the reused system components, which a developer does not understand.

A software product line is a set of applications with a common architecture and shared components, with each application specialized to reflect different requirements. The core system is designed to be configured and adapted to suit the needs of different system customers. This may involve the configuration of some components, implementing additional components, and modifying some of the components to reflect new requirements.

Software product lines usually emerge from existing applications. That is, an organization develops an application then, when a similar system is required, informally reuses code from this in the new application. The same process is used as other similar applications are developed. However, change tends to corrupt application structure so, as more new instances are developed, it becomes increasingly difficult to create a new version. Consequently, a decision to design a generic product line may then be made. This involves identifying common functionality in product instances and including this in a base application, which is then used for future development. This base application is deliberately structured to simplify reuse and reconfiguration.

Application frameworks and software product lines obviously have much in common. They both support a common architecture and components, and require new development to create a specific version of a system. The main differences between these approaches are as follows:

- Application frameworks rely on object-oriented features such as inheritance and polymorphism to implement extensions to the framework. Generally, the framework code is not modified and the possible modifications are limited to whatever is allowed by the framework. Software product lines are not necessarily created using an object-oriented approach. Application components are changed, deleted, or rewritten. There are no limits, in principle at least, to the changes that can be made.
- Application frameworks are primarily focused on providing technical rather than domain-specific support. A software product line usually embeds detailed domain and platform information. For example, there could be a software product line concerned with web-based applications for health record management.
- Software product lines are often control applications for equipment. This means that the product line has to provide support for hardware interfacing. Application frameworks are usually software-oriented and they rarely provide support for hardware interfacing.
- Software product lines are made up of a family of related applications, owned by the same organization. When you create a new application, your starting point is often the closest member of the application family, not the generic core application.

COST-solution Systems & ERP

A commercial-off-the-shelf (COTS) product is a software system that can be adapted to the needs of different customers without changing the source code of the system. COTS products are adapted by using built-in configuration mechanisms that allow the functionality of the system to be tailored to specific customer needs. For example, in a hospital patient record system, separate input forms and output reports might be defined for different types of patient. Other configuration features may allow the system to accept plug-ins that extend functionality or check user inputs to ensure that they are valid.

This approach to software reuse has been very widely adopted by large companies over the last years, as it offers significant benefits over customized software development:

- As with other types of reuse, more rapid deployment of a reliable system may be possible
- It is possible to see what functionality is provided by the applications and so it is easier to judge whether or not they are likely to be suitable. Other companies may already use the applications so experience of the systems is available.
- Some development risks are avoided by using existing software. However, this approach has its own risks, as discuss below.
- Businesses can focus on their core activity without having to devote a lot of resources to IT systems development.
- As operating platforms evolve, technology updates may be simplified as these are the responsibility of the COTS product vendor rather than the customer.

Of course, this approach to software engineering has its own problems:

- Requirements usually have to be adapted to reflect the functionality and mode of operation of the COTS product. This can lead to disruptive changes to existing business processes.
- The COTS product may be based on assumptions that are practically impossible to change. The customer must therefore adapt their business to reflect these assumptions.
- Choosing the right COTS system for an enterprise can be a difficult process, especially as many COTS products are not well documented. Making the wrong choice could be disastrous as it may be impossible to make the new system work as required.
- There may be a lack of local expertise to support systems development. Consequently, the customer has to rely on the vendor and external consultants for development advice. This advice may be biased and geared to selling products and services, rather than meeting the real needs of the customer.
- The COTS product vendor controls system support and evolution. They may go out of business, be taken over, or may

make changes that cause difficulties for customers.

Software reuse based on COTS has become increasingly common. There are two types of COTS product reuse, namely COTS-solution systems and COTS-integrated systems. COTS-solution systems consist of a generic application from a single vendor that is configured to customer requirements. COTS-integrated systems involve integrating two or more COTS systems (perhaps from different vendors) to create an application system. In Table 4 they summarize the differences between these different approaches:

Table 4

COST-solution Systems	COST-integrated Systems
Single product that provides the functionality required by a customer	Several heterogeneous system products are integrated to provide customized functionality
Based around a generic solution and standardized processes	Flexible solutions may be developed for customer processes
Development focus is on system configuration	Development focus is on system integration
System vendor is responsible for maintenance	System owner is responsible for maintenance
System vendor provides the platform for the system	System owner provides the platform for the system

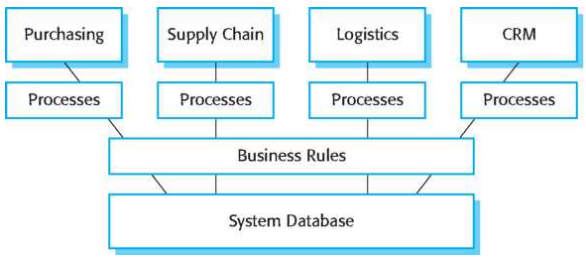
COTS-solution systems are generic application systems that may be designed to support a particular business type, business activity, or sometimes, a complete business enterprise. For example, a COTS-solution system may be produced for dentists that handles appointments, dental records, patient recall, etc. At a larger scale, an Enterprise Resource Planning (ERP) system may support all of the manufacturing, ordering, and customer relationship management activities in a large company.

Domain-specific COTS-solution systems, such as systems to support a business function (e.g., document management), provide functionality that is likely to be required by a range of potential users. However, they also incorporate built-in assumptions about how users work and these may cause problems in specific situations.

ERP systems are large-scale integrated systems designed to support business practices such as ordering and invoicing, inventory management, and manufacturing scheduling. The configuration process for these systems involves gathering detailed information about the customer's business and business processes, and embedding this in a configuration database. This often requires detailed knowledge of configuration notations and tools and is usually carried out by consultants working alongside system customers.

A generic ERP system includes a number of modules that may be composed in different ways to create a system for a customer. The configuration process involves choosing which modules are to be included, configuring these individual modules, defining business processes and business rules, and defining the structure and organization of the system database. A model of the overall architecture of an ERP system that supports a range of business functions is shown in Figure 2.

Figure 2



The key features of this architecture are: Number of modules to support different business functions; Defined set of business processes, associated with each module, which relate to activities in that module; Common database that maintains information about all related business functions; Set of business rules that apply to all data in the database.

Both domain-specific COTS products and ERP systems usually require extensive configuration to adapt them to the requirements of each organization where they are installed. This configuration may involve:

- Selecting the required functionality from the system
- Establishing a data model that defines how the organization's data will be structured in the system database.
- Defining business rules that apply to that data.
- Defining the expected interactions with external systems.
- Designing the input forms and the output reports generated by the system.
- Designing new business processes that conform to the underlying process model supported by the system.
- Setting parameters that define how the system is deployed on its underlying platform.

COTS integration can be simplified if a service-oriented approach is used. Essentially, a service-oriented approach means allowing access to the application system's functionality through a standard service interface, with a service for each discrete unit of functionality. Some applications may offer a service interface but, sometimes, this service interface has to be implemented by the system integrator

SUMMARY:

Most new business software systems are now developed by reusing knowledge and code from previously implemented systems. There are many different ways to reuse software. These range from the reuse of classes and methods in libraries to the reuse of complete application systems. The advantages of software reuse are lower costs, faster software development, and lower risks. System dependability is increased. Specialists can be used more effectively by concentrating their expertise on the design of reusable components. Application frameworks are collections of concrete and abstract objects that are designed for reuse through specialization and the addition of new objects. They usually incorporate good design practice through design patterns. Software product lines are related applications that are developed from one or more base applications. A generic system is adapted and specialized to meet specific requirements for functionality, target platform, or operational configuration. COTS product reuse is concerned with the reuse of large-scale, off-the-shelf systems. These provide a lot of functionality and their reuse can radically reduce costs and development time. Systems may be developed by configuring a single, generic COTS product or by integrating two or more COTS products. Enterprise Resource Planning systems are examples of large-scale COTS reuse. You create an instance of an ERP system by configuring a generic system with information about the customer's business processes and rules. Potential problems with COTS-based reuse include lack of control over functionality and performance, lack of control over system evolution, the need for support from external vendors, and difficulties in ensuring that systems can interoperate.

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PRODUCTION SYSTEMS SAFETY, MODELLING, SIMULATION AND THE POSSIBILITY OF AUTOMATION OF A PRODUCTION WAREHOUSE AS A KEY COMPONENT IN CIM SYSTEMS

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Abstract: *this paper deals with the safety, modeling, simulation and the possibility of automation of a production warehouse as a key component on CIM systems. The manufacturing has been changed significantly by using information systems. Using electronic data processing in the production systems and beyond, automatic protocols are derived and flow both on confirmation of the order and in economic aspect of the raw material. Also, information systems are used in planning and controlling the production, including machines, equipments and entire production process, as well as a lot more opportunities have been provided for the operator. But, security of the production systems is one of the concerns which are elaborated in this paper. Production systems play an important role in industrial and economic development of a country. Recent years, there was a tremendous change in the technology of production systems. Such changes happened as a result of advances in the field of hardware and software technology, which are directly or indirectly related to modeling and simulation of production systems. In this paper, we will investigate the possibility of automation of a production warehouse as one of the key components of CIM technology. Simulations are new and very attractive area. Nowadays they have become indispensable engineering tools for solving engineering tasks, leaving behind the traditional analytical methods. They include design, analytical and optimisation tasks of complex production systems, computer architecture, biological and military systems etc. This is made possible, because of failure to gain good results by the analytical methods, which is the case also for simple systems too. In the group of traditional methods are distinguished: arrays method (querying theory), different heuristic mathematical methods etc.This paper also deals with modelling and simulation of flexible system for electrical machine assembling by ARENA software.*

Keywords: *PRODUCTION SYSTEM, SAFETY, CRYPTOGRAPHIC, SIMULATION, CIM, WAREHOUSING.*

1. Introduction

Manufacturing systems are very complex systems. Calculation, optimization and management of such systems require lot efforts, which are followed by very large volumes for the transfer and processing of data. So these systems are complex and created by man, so they are artificial and are systems with other systems in the world, communicating and exchanging information with the other systems. Within them there is always flow of goods, energy and informations, and therefore they are part of dynamic systems.

In order to place a product in the market, financial resources, human resources and technological resources are needed, and then we must start with design, production and finally marketing and selling the product. With the recent technological developments these market demands can only be satisfied by the manufacturers who are ready to make their products better in terms of quality, faster in terms of time and cheaper in terms of cost.

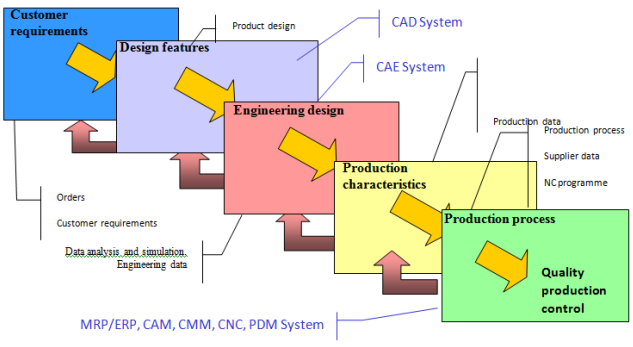


Fig. 1*. From customer needs to production process*

The flexible mounting system of electric motors is a rather complex system. In order for it to be explained and understood more easily it should be divided into several subsystems. This system consists of the following main subsystems:

Technical subsystem
Computer subsystem
Human subsystem
Other subsystems.

Manufacturing systems are very complex systems. Their calculation, optimization and management require very large calculations, followed by a very large volume in the transfer and processing of data. They are open systems there is always movement of goods, energy and information, and therefore they are part of dynamic systems.

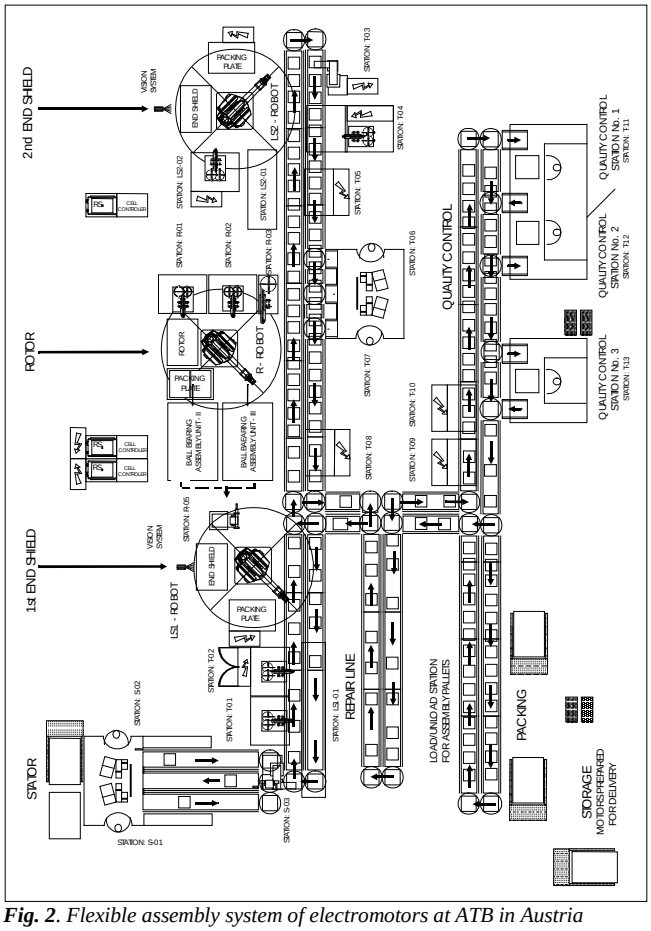


Fig. 2*. Flexible assembly system of electromotors at ATB in Austria*

In most cases we are dealing with output products in a form of numerable units, one by one or in groups, thus discrete and very

rarely in continuous or combined form. Therefore, they are not linear systems but a various functions which are often very complex, and can not be solved by any analytical method. They are stochastic and open systems, and a lot of random variables act on them. These systems are known as flexible systems, where after each type is produced with a very small action, they can easily adapt to the new type of production.

2. *Information sub system of flexible system for electromotor assembling*

In the context of the programming interfaces will are referring to the so-called protocols. Protocols represent the "language" of components. Protocols depend on the operating systems which are installed in the computers, but in this paper is mentioned well known and the most compatible protocol: TCP / IP (Transmission Control Protocol / Internet Protocol). This protocol provides the rules of exchange of information through various system components in the networks with different operating systems and with different hardware components. Currently this protocol is the most used and is very suitable for the design of networks with different topologies in both small and large enterprises. This protocol will be used for the case of the flexible system for electrical machine assembling.

In Fig. 3 is shown the information subsystem of flexible system of electrical machine assembling. As is shown on the top of the hierarchy lies the internet network. For each customer is given the opportunity to communicate on the enterprise server via TCP / IP protocol. This means that nowadays is not necessary to go physically to the enterprise or faxing a document and in order to order the products, but this is done automatically by the computer system on-line within 24 hours. So, every day we will have the list of the orders which are processed in the appropriate planning unit of the enterprise.

On the top level is the production planning system. Each order has an external priority as a scale of order urgency. The priority scale has 10 points, from 0 to 9. Priority 0 is given to orders which are not to be processed yet. The normal urgency is priority 5, a very good order is priority 9 and a not urgent order is priority 1.

The first level of contact with the outer world is a WAN (Wide Area Network) and constitutes the wide network of computers. Large enterprises such as Ford, BMW etc have this kind of wide networks, while small enterprises are connected to the internet with LAN-Local Area Networks.

The second level is therefore LAN, which in the practice represents a part of the enterprise (eg sections of planning, design, finance, etc.), each of them collects a number of computers. Production planning of flexible system for electrical machine assembling is followed by building of so-called "Queue of awaiting messages." This range has a trapezoidal shape, giving us the means that such messages are not treated equally, but each of these has a certain priority. The messages at bottom of trapeze are urgent messages. In contrast to those which lie at the beginning and represent the messages that can wait for a while to be executed?

Ordering of these messages by following such a hierarchy is based on the strategic interests of the enterprise. For practical purposes, it should be known accurately which are messages that should begin the installation process and what it look like the order of products assembly process. This is so-called off-line simulation and is assigned a rank of optimal one dimensional Queue of messages, by taking into account the preliminary phase. The designed Queue in this way is called FIFO (First In First Out), which is afterwards broken down, starting from the first and finishing with the last.

The third level of network is called DPCS (Distributed Process Control Systems). This level represents directly some smaller subsystems in the production process. This level role is to inform the central system for the failure / performance of processes and activities in the assembly process. At this level it is performed so called On-Line simulation for the purpose of division of work to the assembling system resources. At this stage is performed so-called resource reservation which results in the construction of Queues of parts, pallets, workers etc. Word On-line means that we are dealing directly with the processes, in the literature this is known the Scheduling activity. Scheduling is the final level where depending on the reaction of the system me must take decision for production process.

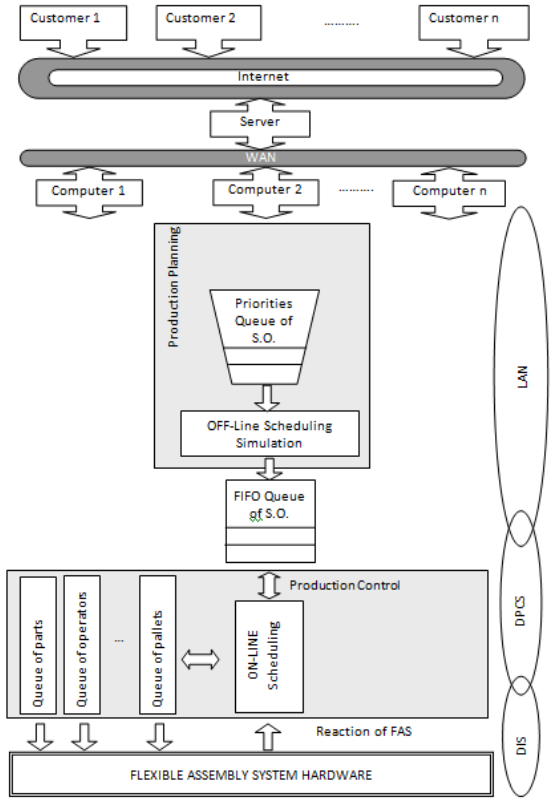


***Fig. 3**. Information subsystem of flexible system for electrical machine assembling*

Fourth level of the information subsystem, of the flexible assembling system is called DIS (Distributed Systems Interface). This is the final level of information subsystem which has a very important task to transfer the information through devices and sensors. These are components that have direct physical contact with system components, with their feedback links showing whether the goal is achieved or not. In the most cases in the literature this is known as peripheral subsystem, where the operator through various keyboards provides technological instructions.

System Inventory Manager which is shown in Fig. 4, is used for registration, maintenance and the classification of stocks, warehouses, inventory, etc. Inventory Manager System is an autonomous fast and efficient system and consumes a limited system and human resources. Its administration is very simple and quick. All what a manager should do is: to assign users and their rights and to make backup of database in regular intervals.

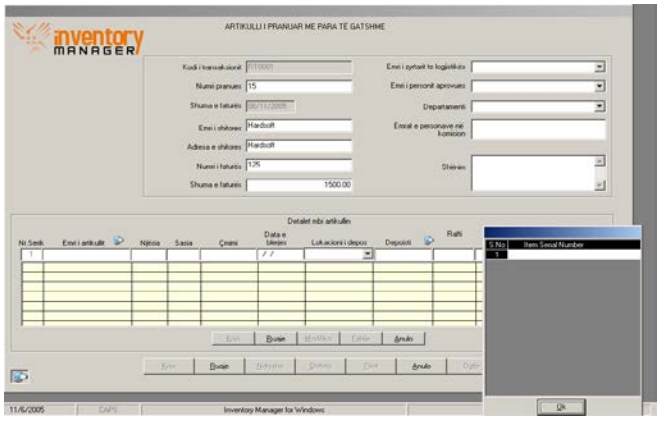


***Fig.4.** Inventory Manager Interface*

3.System Analysis, Goal Definition and Simulation

Activities at the flexible system of the electrical machines assembling are very complex, and needs to be described in detail. For purpose of modelling, only main points of them will be subject of analysis.

The system which is considered for analysis from the entry at the first conveyor as a resource point up to the exit from conveyor as an absorbing point for the parts, and is built by following resources:

- Human resources,
- Industrial robots,
- Pallets with ID chips,
- Rolling conveyors.

In Fig.5 is shown graphically the path of all entities that circulate in the flexible assembling system. The path of material flux through working stations contains following elements:

- Input / Output points of the system given by rectangle,
- Stations given by small circle denoted by R (Resource),
- Logic points or system nodes given as parallelepiped (N-Node),
- Straight lines represent the conveyors,
- Arrows show the direction of the material flux.

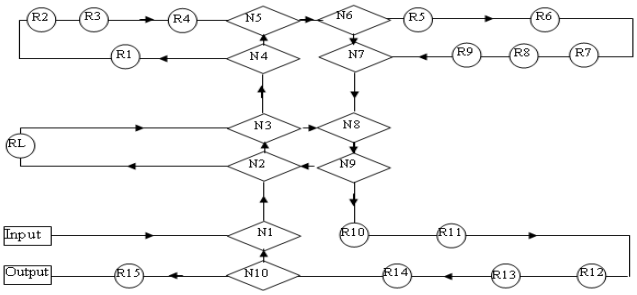


Fig 5. *Scheme of material flow through the assembling flexible system*

System input represents the source of entities, indicating the input boundary of the system, while output or so-called disappearance point of entities is output boundary of the system. But, the subject of study is analysis of the inner part of the system by considering that all external activities are reduced in two points, input and output. Such approximation brings to the definition the system boundaries.

System allows change the number of resources at working station and also change of material flux depending on overfeed of the system with pallets and to change the frequency of material flux. Therefore, the system input and number of the engaged resources are considered as variables. In the other side, the system is influenced by different demands of the consumers which are made in different timing and in various quantities. These are representing stochastic effects that interfere and put condition to the system itself. The aim of the simulation is to achieve a maximum level of rent ability based on these demands, conditions, schedule and resources.

It is adopted that:

C_{Ri} - are the costs for *i* resources for the simulation period, *i=1,..,n,*

C_{Mi}- are the material costs of specified product *i*, for *i=1 to n (Euro)*

C_{Ti} - are the costs for waiting time of product-Entity Flow Time *i* of the system, for *i*=1 *to n (Euro)*

Ψ - is the objective function.

By the simulation process we are trying to minimise the objective function. This means that if decrease of the costs is achieved the main goal of optimisation is met, meaning that "with minimum utilisation of resources the maximum production volume is obtained, satisfying technical and organization conditions of the system".

Mathematical model is expressed by:

$$min(\Psi) = min\left[\sum_{i=1}^{n} C_{Ri} + \sum_{i=1}^{n} C_{Mi} + \sum_{i=1}^{n} C_{Ti}\right] \quad (1)$$

If *k*- simulations are executed then function (1) has form as given in (2):

$$min\left(\sum_{j=1}^{k} \Psi_j\right) = min\left\{\sum_{j=1}^{k}\left[\sum_{i=1}^{n} C_{Rij} + \sum_{i=1}^{n} C_{Mij} + \sum_{i=1}^{n} C_{Tij}\right]\right\} \quad (2)$$

So, the simulation that in the best way fulfils the criteria is adopted. This operation is realized with **OptQuest** package which will be described later.

At **OptQuest** is chosen the option:

$$min\left(\sum_{j=1}^{k} \Psi_j\right) \approx = \text{minimize}\{\text{Entity.Flow.Time}\} \quad (3)$$

In this case, the only goal was the definition of the objective for our experiments in the assembling flexible system.

4.Entering Samples for assembling at flexible system

Another important point of the simulation is to generate data for the working stations known as samples, which is made in manual and automatic way. Once the system is equipped by a device for identification of pallets and because the system has the possibility of communication with central computer, in this way there is possibility for automatic tracking of data. The data that must be entered in this case are listed in the following:

- Time of arrival of piece at the x station and type,
- Time of piece processing at the station,
- The time between the fall of assembling system and the duration of the fall,
- Schedule of the system, short and long breaks, changes and other organisational restrictions

5. System Simulation

System simulation and the animation ascheme is shown in the Fig 6.

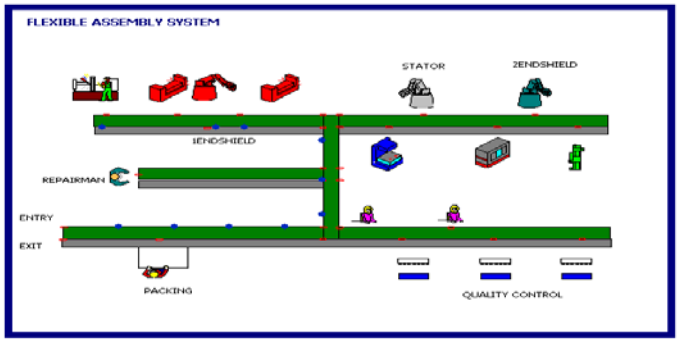


Fig 6. *Animation scheme of system simulation*

In Table 1 is presented the exploitation of the resources at respective assembling stations for the flexible system. Simulation was carried out during 5760 seconds, with material flux of one part per second. The **Arena** program in its **Reports** windows shows: **Replica 1,** Start Time=250,00 [sec], Stop Time= 5760,00 [sec], Time Unit=sec, Resources Utilization.

If **a** simulations are made and we want all of our results to lie somewhere in the 95% of the confidence interval, then we need to look whether the required number of simulations has been made.

$$a^* = [a\,(h/h^*)] \quad (4)$$

If a^* is larger than 1, than additional simulations needs to be carried out in Arena Software, while simulation methods of flexible assembly system are given at Fig.7.

Table 1. *Resources utilisation in the simulation process*

	System Resources	Instantaneously Utilisation	Number Busy	Number Scheduled	Number Seized	Schedule Utilisation
1	Resource 01	1	1	1	1.102,00	1
2	Resource 02	1	1	1	552	1
3	Resource 03	1	1	1	394	1
4	Resource 04	1	1	1	365	1
5	Resource 05	0,93	0,93	1	366	0,93
6	Resource 06	0,79	0,79	1	364	0,79
7	Resource 07	0,98	0,98	1	362	0,98
8	Resource 08	0,92	0,92	1	361	0,92
9	Resource 09	0,78	0,78	1	359	0,78
10	Resource 10	0,9	0,9	1	356	0,9
11	Resource 11	0,98	0,98	1	337	0,98
12	Resource 12	0,85	0,85	1	336	0,85
13	Resource 13	0,73	0,73	1	334	0,73
14	Resource 14	0,66	0,66	1	333	0,66
15	Resource 15	0,6	0,6	1	331	0,6
16	Resource 16	0,79	0,79	1	215	0,79

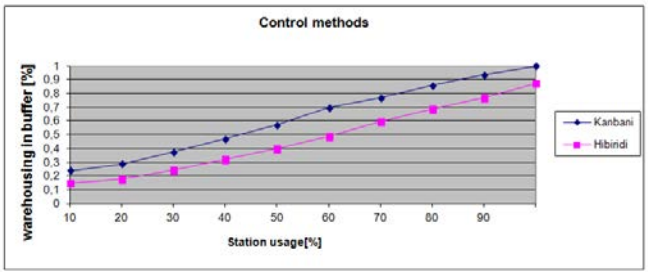


Fig 7. *Simulation Methods at flexible assembly system in ATB*

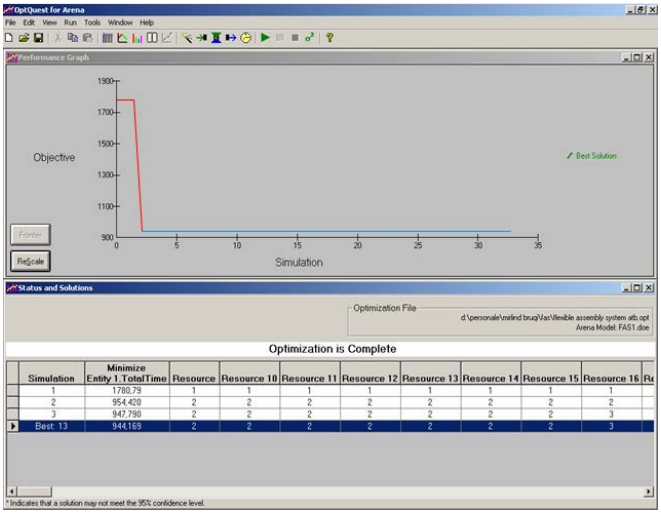


Fig 8. *Simulation results*

5. Conclusions

The demand for storage systems with high degree of automation have been decreased over the last years, this happened for two reasons: (1) a trend toward the reduction of the amount of stored inventory and (2) trend toward ' Just-in -Time ' systems, which reduce the work in process.

The purpose of the management of purchase and materials units is the existence of two or more suppliers. The idea has been that through the competition to have price reduction and to reduce the risk of supply shortage.

For a given company in order to successfully compete in the global market the supplier of high quality and with acceptable price and delivery time is needed.

Inventory Manager will compile a list of suppliers and then develop a program to improve technical capacity of suppliers, quality, delivery and prices.

Inventory Program Manager, is used for the management of warehouses, starting from the registration and distribution of items throughout the process, then placing the supplier and customer, time, type, quantity of purchase and supplies, reporting about the warehouse state related to each item separately, reports on the status of each supplier and buyer and so on.

Flexible systems for assembling are part of the most sotisficated systems of the time. As such they have the possibility to pas from an assembly programme to another in a very short period of time. The flexibility of such systems is the main property. In this way the pas from one assembling system to another is made in automatic or semi-automatic way or manually, by the replacement of the auxiliary devices of robots and machines.

But besides the positive side these systems also have their negative side. Very often in such systems are mounted also different products, and the managerial point of view this is heavy duty because of prior planning and preparations. These preparations include tasks of choosing an optimal or suboptimal scenario of material, energy and information flow, including human resource organisation. The selection of such scenarios is made through different optimisation algorithms such are: finite, limited and random enumeration.

Module varies from one system to another, thus this module must be built for each and specific system.

6. Acknowledgement

I would like to take this opportunity to express my gratitude to the (*) correspondent author of this paper, Ramë Likaj, for the professional contribution given to obtain the results for this paper.

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LOGISTICS PERFORMANCE INDEX (LPI) AND INCENTIVES FOR LOGISTICS PERFORMANCE IMPROVEMENT IN BULGARIA

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Abstract: *The article presents an assessment of the current logistics performance in the Republic of Bulgaria. The logistics performance of the country is evaluated in terms of the components affecting the logistics regulations and operations. The role of the Logistics Performance Index (LPI) is outlined as well as its methodological background. As LPI level is a function of numerous factors, the enhancement of logistics performance asks for large-scale reforms both from the private sector and policy makers. It is ascertained that it is vital to define the relationship between LPI and the logistics policy objectives thus transforming LPI individual values into applicable actions.*

Keywords: LOGISTICS PERFORMANCE, TRADE LOGISTICS, LOGISTICS PERFORMANCE INDEX

1. Introduction

Indicators for measuring the national logistics performance are vital for efficient policy and operational regulations. The World Bank's Logistics Performance Index (LPI) is a valuable tool that allows for comparison and measurement of the transport and trade facilitation policies of countries. The analysis of the components of the countries' LPI ensures for improvement of freight transport efficiency and identification of options for better international cooperation. Efficient and competitive trade logistics at national and regional levels requires profound multilevel assessment of the transport and trade regulations, taxes, investment in infrastructure and transport corridors. The present article presents evaluation of the trade and transport policy via a case study of Bulgaria. Detailed presentation of the LPI and its methodology are outlined followed by a study presenting the effect of the diverse policy measures on Bulgaria's logistics performance.

2. Overview of the Logistics Performance Index (LPI)

LPI is an internationally adopted tool for measuring the trade and logistics facilitation in a given country. LPI promotes the understading of key issues and options for improvement of logistics performance. The LPI entails several components assessing the logistics environment: customs clearance performance, quality of transport infrastructure, competitive and efficient shipment process, logistics process quality, international tracing of shipments, international shipments frequency.

LPI also allows for assessment of logistics performance trends while performance is measured through a five-point scale. The general LPI of a country is the weighted average of the above mentioned componenets. In addition, the LPI is a tool providing quantitative data on specific aspects of country's export and import procedures, delivery times, costs related to supply chains, customs clearance procedures and the percentage of shipments subjected to physical inspection [2].

Policy measures have direct impact on a country's image as a business environment or foregin investments. The efficiency of the transportation system and inventory are directly related as higher turnover allows for shorter delivery time, higher responsiveness to demand changes and lower costs of transportation. On the other hand, transport infrastructure has a significant impact on the productivity and the cost structure of businesses [3]. The efficiency of the logistics systems is vital for ensuring economic development and attracting foreign investment. The index is applied for identification of the issues and opportunities as concerns each country's transport infrastructure, logistics and supply chains efficiency. Countries at similar performance levels may have substantially different ranks, especially in the middle and lower country income ranges [5].

The LPI report of the World Bank presents the countries' weighted average of LPI. To account for potential sampling error and the LPI's limited domain of validity, LPI scores are calculated with approximate 80% confidence intervals over the standard error of LPI scores across all respondents [1]. The case study of Bulgaria is based on a general view analyzing the various processes and existing bottlenecks that affect substantially the logistics competitiveness.

3. Logisitcs performance in Bulgaria: issues and challenges

The case study is based on several stages. The first stage is based on disaggregation of the key components of logistics performance, outline of the current state and planned transport infrastructure, policies and logistics services bottlenecks that impact the counties' trade competitiveness. The first stage was carried out via collecting information from official reports and statistical data. The next stage concentrates on evaluation of the state of transport policy environment via interviews with several companies specialized in logistics services. Thus the effect of the policy regulations on Bulgarian freight and logistics performance based on the LPI is evaluated. Bulgaria has an important geographical position and as such plays an important role in transportation and trade between Europes and Asia. The development within the adjacent regions - the Black Sea countries, the Balkan countries, the Mediterranean, the Caucasus region and the Middle East have further promoted the importance of Bulgaria as an important transport node. The newest available World Bank Logistics Performance Indicator ranking (LPI 2016) places Bulgaria in a relatively fair position ranking number 72 among 160 countries, with an overall score of 2.81 on a scale from one to five. Figure 1 presents Bulgaria's overall LPI score and LPI's components in 2016 as compared with the levels of the region.

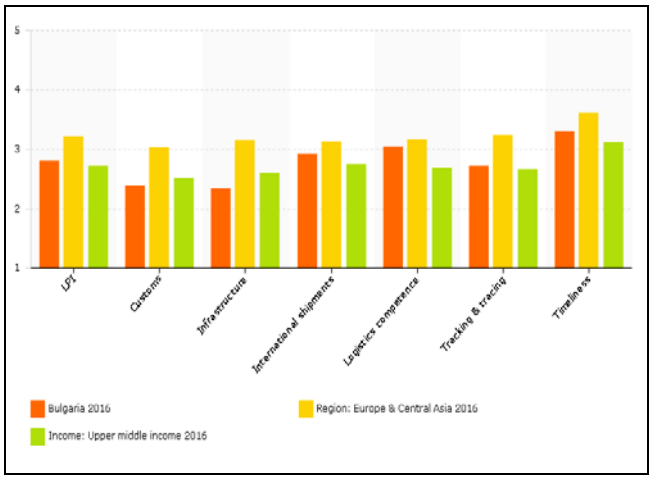


Figure 1. *Bulgaria's LPI and regional comparison in 2016 [7]*

The general LPI score of Bulgaria for the period 2007-2016 is based on the scores of four LPI components and is presented in Figure 2.

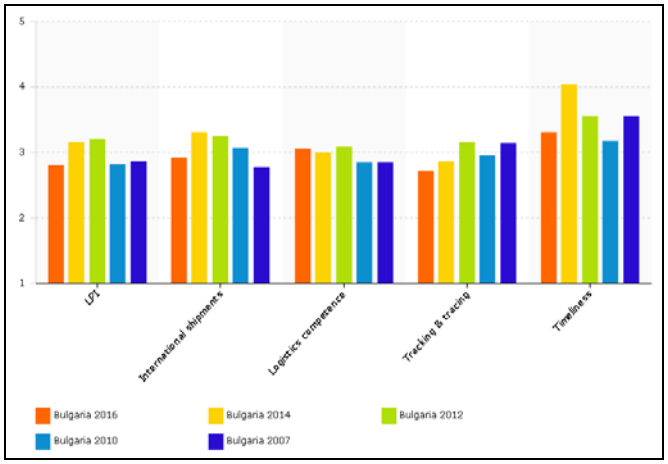


Figure 2. *Bulgaria's LPI score trend for the period 2007-2016 [7]*

The considerable increase in Bulgaria's general LPI score between 2012 and 2014 is the outcome of the enhancement in transport infrastructure (both road and ports development), improvement of international shipments tracing and facilitation of customs procedures via adoption of National Single Window in customs administration. The levels of timeliness of international deliveries have been dropping since 2014 while tracking and tracing of shipment have risen.

According to [4] enhancement of logistics quality have a better impact on exports than on imports. In general, 10% increase in the specific exporters' LPI score leads to increase by over 60% of bilateral imports, all other factors being equal. For Bulgaria the effect would be +21% for import and +30% for export if Bulgaria's LPI could reach that of the average high-income OECD countries. Comparable levels of this impact can be evaluated for the rest of the LPI components. For example, an increase by 10% of infrastructure quality (as a LPI component) would result in 30% increase of seaborne trade. Thus the LPI components correlations give an insight on the relations between international trade development and logistics performance. Further, a 15% enhancement of the customs procedures quality indicator would result in an increase by 35% for bilateral trade flows, including seaborne trade. As mentioned, the development of infrastructure is vital for ensuring connectivity. Presently, the inland transportation connections are still not well developed due to lack of investment. Rail transportation is also at a stage of being underdeveloped mainly due to non-sufficient equipment and maintenance. As for Bulgaria, infrastructures in maritime and rail transport rank below average, with a ranking of 53rd in quality (Figure 3).

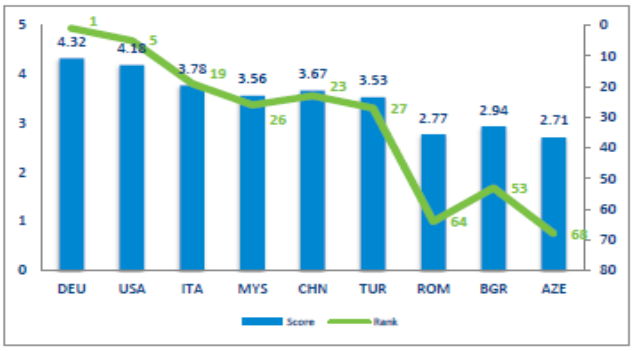


Figure 3. *Transport infrastructure quality: LPI score and rank among 160 countries [1]*

The possible improvement of LPI infrastructure quality score would depend on financing from EU projects and policy actions for the enhancement of transport infrastructure competitiveness and activisation of private stakeholders' participation in infrastructure development. During the last decade, the logistics connectivity has been considerably improved via construction of Trakia highway, ensuring for better connectivity via the trans-European corridor No 4. The investment plans for the expansion and reorganization of Varna port would result in increase of container handling volumes and storage capacity of dedicated container temrinals. Irrespective of the infrastructure investments in maritime transport, cargo handling in the ports of Varna and Bourgas is still restricted due to lack of efficient hinterland connections. The latter causes higher delays on cargo delivery to the ports and, respectively, longer storage times at the ports prior to delivery to the customers.

The establishment of the National Single Window for shipping and the development of the local Port Community System allows for better communication between all stakeholders. The ease of arranging competitively prices shipments is at a moderate level component – 3.31, commensurate to the levels of other countries in the region (Figure 4).

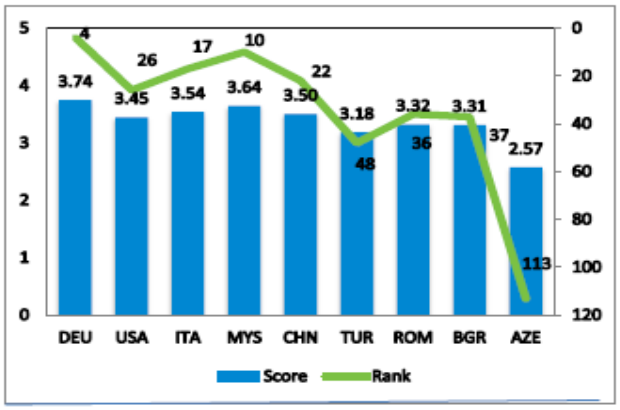


Figure 4. *Ease of arrangement of competitively priced shipments: LPI score and rank among 160 countries [1]*

One of the greatest hindrances to road transport and trade network development is the high costs of energy. For example, diesel fule costs amount at up to 55% of operating costs for long-haul destinations. Having considerably high energy costs in Bulgaria, logistics companies seek to invest in more efficient road vehicles and invest in intermodal transportation solutions, the latter creating a competitive advantage for the company. The incentive to invest in intermodal transport is further impeded by the fragmented market and the small-sized logistics companies resulting in lack of higher profit levels and accessible capital. The lack of appropriate intermodal equipment is another issue for the industry and the country still lacks nationl policy incentives in this respect.

As concerns ease of market acess and attraction of foreign direct investment there are still pending issues mainly due to administrative burdens and lack of coordination between authorities. The latter is an obstacle to the competition in the industry and impedes international transfer of know-how and technological innovations. There is lack of global policy view encompassing the development of the transport networks rather than focusing on a certain transport mode development.

The LPI's component for measuring the quality of logistics services and operations evaluates the general logistics level of a particular country. The performance of Bulgaria in this respect is moderate at a score of 3.0 and ranking 55th among 160 countries.

Despite the highly fragmented market, the country can offer diverse services in logistics ranging from customs representation, transportation, bonded warehousing and intermodal services. Road and maritime transportation are well developed in terms of quality services as well as forwarding and supporting services.

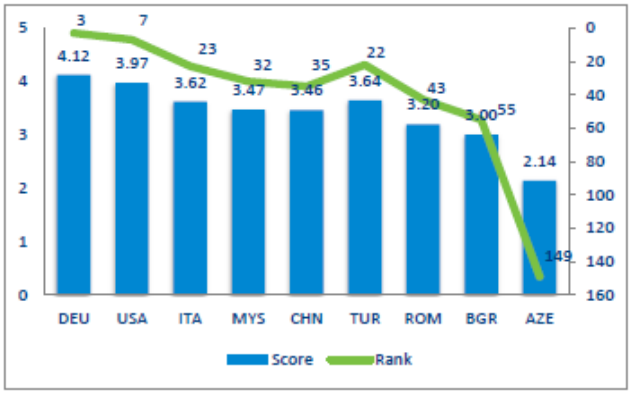


***Figure 5**. Quality of logistics services: LPI score and rank among 160 countries [1]*

The private sector for providing logistics servies is highly internationalized mainly due to EU companies' mergers and acquisitions. Generally market entrance is less difficult for EU companies. The latter is a direct factor for increase of sector competition and transfer of know-how and franchise. One of the main issues on a national level is the lack of skilled personnel with expertise and insufficient research and development. Although, at a national level, there are several programs for development of professional education in logistics and transportation same still lack practice orientation especially for lower management levels.

Tracking of shipment is the outcome of the expanded communication between logistics stakeholders via introduction of ICT solutions. Higher level of traceability ensures for safer and reliable supply chains and lowers business risk. Nevertheless, the LPI score of the ability of tracking and tracing shipments in Bulgaria is still at a moderate level of 2.88 ranking the country 76th in 2014 (Figure 6).

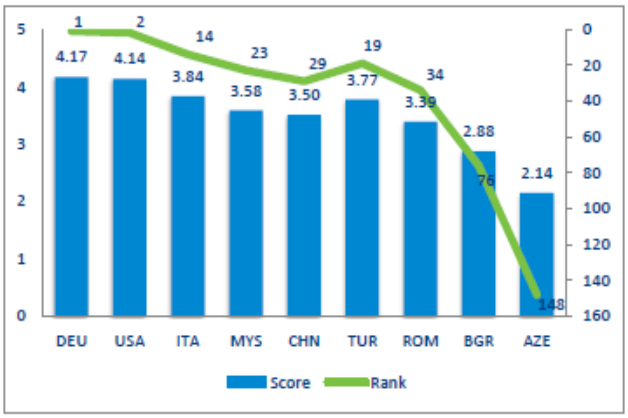


***Figure 6**. Ability to track and trace consignments: LPI score and rank among 160 countries [1]*

There is a need to introduce widespread use of ICT solutions especially for exchange of information between the public and private sectors. Thus the tracking and traceability performance will be improved via collecting and processing of information on all shipments, services and government regulations. Furthermore, companies' product information, services specifics and freight rates will be easily accessed by potential customers. The main issue impeding the investment of ICT in logistics is the high risk of investment and the associated uncertainties – for example, national communication polices. Hence, policymakers need to keep up with the rapid development of ICT and develop a stable communications framework that is conducive to logistics planning by the private sector [5].

The reliability of delivery times is measured by the timeliness of shipments in reaching destination. The performance of Bulgaria for this LPI component is relatively high as compared to other countries – score of 4.04 and ranking 24th (Figure 7). Generally, the duration of shipment will depend on the type of product, logistics servies provided, the transportation distance as well as on various external factors (political and war risks, unfavorable weather, etc.)

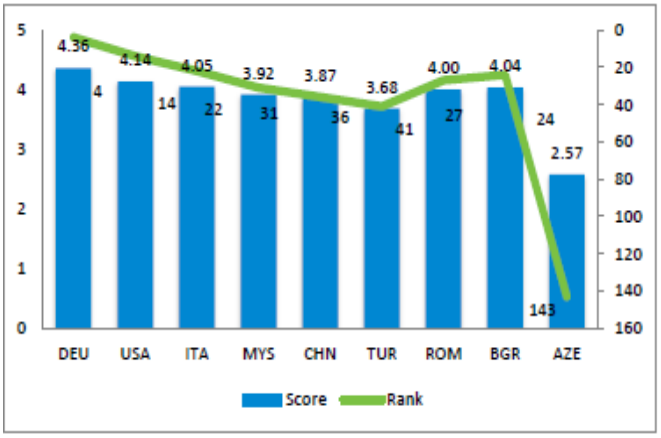


***Figure 7**. Timeliness of shipments in reaching destinations: LPI score and rank among 160 countries [1]*

The reliability of the supply chains is generally measured by the timeliness of the delivery. However, longer lead times do not always mean unreliability but instead are the outcome of steady demand trends and higher predictability. On the contrary and due to the present market situation, maritime transshipments are causing the highest level of delivery delays mainly affected by the operators need to cut on costs. As concerns road transport, indirect routes are often used which have capacity restrictions. The latter leads to longer delivery times and, respectively, to higher shipment costs. For the reason of capacity constraints of some of the roads, trucks are also experiencing longer off-duty periods which creates further burden on costs.

Border crossing procedures may also create uncertainties and unpredictability causing delays for road transportation thus leading to higher costs for the customers and sometimes loss of business opportunities. For example, in 2014 a transit permit crisis that loosed the border between Turkey and Bulgaria for almost two weeks has created a truck queue of over 10 kilometres, waiting for border crossing [5]. Transporters immediately turned to alternative routes to transport goods to Europe, yet the absence of one of the major and cheapest transit options has created huge losses [5].

4. Conclusion

The present article has outlined the significance of policy development for enhancement of logistics performance. The application of efficient policies in this respect will improve the stakeholders' capability to trade more competitively on international markets. For Bulgaria, it is vital to ascertain a clear correlation between LPI's performance indicators and the national transport policy. The latter will allow for transforming LPI's indicator values into corresponding actions and promote further development.

The results of this study show that despite the moderate levels of logistics performance in Bulgaria there is still room for improvement as concerns quality of infrastructure and logistics services. As discussed, the overall LPI score is a function of diverse factors having intricate internal correlation. It is evident that the improvement of logistics performance is a long-term and complex objective which requires large-scale reforms and long-term policy undertakings.

Port infrastructure in Bulgaria is still underdeveloped mainly due to the unavailability of reliable hinterland connections with highways and railways which creates longer dwell time in ports and terminals. Further, the predominance of road transportation and

higher energy costs cause higher transportation and maintenance costs, unfavorable impact on the environment, traffic congestion and lower level of road safety.

The logistics performance in Bulgaria is mainly upheld by the private sector stakeholders. In addition, during the last five years, the government has implemented various actions for development of logistics competencies in the private sector – competition promotion, introduction of quality standards, subsidizing of professional organizations, decreasing the administrative burden of business licensing and introduction of industry standardization. Due to diverse externalities the main focus should be on business risk prevention and lowering of investment risks in order to reduce the vulnerability of the logistics systems. The introduction of ICT solutions will lead to higher risk visibility of the network and will promote the application of advanced and efficient policy actions.

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POSTAL MARKET DEVELOPMENTS IN SERBIA

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Absract: *The postal services market is facing big challenges, both on global and national level. Besides e-substitution, a liberalization of the postal market contributes to the greater extent to this phenomenon. The purpose of this paper is to examine a state of the postal market in Serbia and main developments, considering a trend in the number of postal operators, number of services, service diversification, relation between letter and parcel market, etc.*

KEYWORDS: MARKET, UNIVERSAL SERVICES, COMMERCIAL SERVICES, OPERATORS, LIBERALIZATION, INCOME

1. Introduction

The postal sector is constantly evolving, and the direction and way of future development implies changes in many spheres of social life. Given that there is a global need for exchange of goods and commodities in the world market, as well as the revolution electronic communications, postal sector, both in the world and in Serbia is faced with solving many problems in such an environment requires the selection of the most effective strategies to overcome all challenges imposed by modern times.

The postal industry has traditionally been part of the national post office, later the public postal operator, but all dynamic environment, the obligations prescribed by the legislation of the European Union, increased and all concrete customer requirements lead to the fact that the private operators are free to compete in a liberalized market.

As the presence of information and communication technologies increases, in the future, replacement of existing postal technologies is expected. At the same time, the reasons for the stagnation or the reduced number of services provided by the public postal operator are reflected in the increase in the number of postal items by private postal operators.

To be competitive, the public postal operator should provide services according to the needs and attitudes of users. The modern concept of operations include not only the measurement of market share in competition with the competition and the keeping the customers, but also continuous research and assess the quality of services by the users themselves [5, 6].

There is competition in the Republic of Serbia, both from the aspect of the substitution of postal services, and in the presence of an increasing number of service providers on the market.

The aim of this paper is to determine the state of the business of the public postal operator after partial liberalization, in view of the last few years of work, based on the volume of postal services.

In the second part of the paper briefly shows the trend of development of the postal sector. The third chapter deals with the postal market in the Republic of Serbia, from the aspect of the volume, in view of the number of services provided and the income from postal services is shown. Analysis was based in disclosure of the significance of postal markets follows looking at the type of service, as well as service providers. In this case it is the universal postal service and commercial services, as well as public and private postal operators as well as service providers in Serbia.

The fourth chapter provides concluding observations.

2. Trends in the development of the postal sector

New information and communication technologies, reform, global economic and financial crisis and efforts to combat poverty have continued to affect the postal sector.

The economic situation in all countries is the subject of economic studies whose aim is to facilitate the allocation of costs, encourage partnerships, associations and integration of networks and the birth of global public funds.

The growth of postal flows and sectors depends on market segmentation, supply and demand, regulatory models, universal postal and economic sustainability of organizational and postal economic models.

Today, the situation is such that almost all European postal operators have implemented traditional business change programs in order to face the challenges of market liberalization and electronic substitution of classic postal services. All operators, and especially traditional, due to their size and market role, should consider ways to adapt to a constantly changing market.

Establishing efficient and comprehensive postal systems in developing countries is important both from an international and national perspective. Successful maintenance of the postal service and the development of the postal market requires efficient cooperation of all the members of the World Postal Union [1].

3. Postal market in the Republic of Serbia

The postal services in the Republic of Serbia are increasingly based on the principles of competitiveness. In the postal services market in Serbia, according to the data of the Regulatory Agency for Electronic Communications and Postal Services, in 2016., the license for the provision of postal services was owned by 54 operators [3]. Analyzing the previous years, there is an increase in the number of operators presenting commercial services, since the universal postal service is performed exclusively by the public postal operator. Public postal operator is a provider of postal services who is obliged to provide an universal postal service and has an exclusive right to provide reserved service. Among the operators in the field of commercial services are operators from abroad and from the group of global integrators such as DHL, Fedex, TNT and UPS.

3.1. Volume postal services

The postal market according to the annual reports on the work of the Regulatory Agency for Electronic Communications and Postal Services related to the analysis of the postal services market in the period from 2011. to 2016., in terms of the volume of postal services, indicated that by 2012. postal services recorded growth, which was in contrast to the trend in European countries, and that a decline was identified from that period.

Universal postal service is a set of postal services that are constantly provided on the territory of the Republic of Serbia, under the same conditions for all the customers, within the prescribed quality and with accessible prices.

Value-added services are postal services commercial services that have specific requirements in terms of quality (time and place

of receipt and delivery, speed of transmission, electronic tracking of shipments from receipt to delivery, etc.) And transfer mode, which can be marked as courier, express, rapid, hybrid, etc [4].

In 2015. in the Republic of Serbia, about 315 million postal services were implemented, which is 2% less than in 2014, this trend is still present. The largest number, 93%, consists of services from the universal postal service, and they record a decline in the market, while commercial services are growing. It is important to remind that the license for providing the universal postal service and authorized to perform commercial services has only public company "Serbian Post", while other operators have licenses for the performance of commercial services [2].

In 2016., around 311 million postal services were implemented in the Republic of Serbia, which is 1% less than in the previous year. This year, services in the field of universal postal services were involved and 91% of the total volume of services [3].

Table 1: *Postal services market 2011-2016.*

Type of service	Volume in a thousand units per year					
	2011	2012	2013	2014	2015	2016
Universal postal service	304537	314865	308923	301542	291399	283488
Commercial services	12632	15613	18104	20350	23288	27186
TOTAL	317169	330478	327026	321892	314627	310674

Commercial services also grow in other European countries. The growth of commercial services is influenced by several factors, which include, amongst other things, more specific customer demands, commodity, e-commerce, service distribution of packages within trade chains.

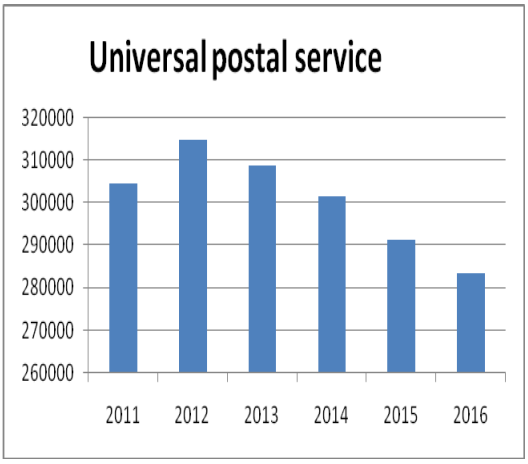


Chart 1*: The trend of universal postal services 2011-2016.*

When it comes to market analysis in relation to service providers, and as the goal of the market analysis in Serbia in this paper, it is important to look at it, it could be said the simplest partition, which is the volume structure from 2011. to 2016. with regard to the provision of services by the public postal operator and private operators.

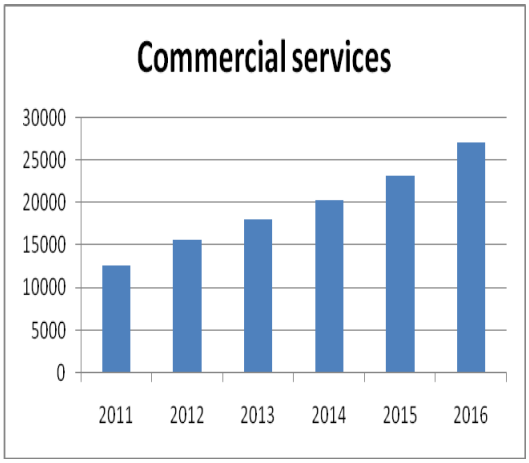


Chart 2*: The trend of commercial services 2011-2016.*

Table 2: *Structure of volume by operators 2011-2016.*

Operators	Volume in a thousand units per year					
	2011	2012	2013	2014	2015	2016
Public postal operator	308776	320079	314605	307422	298132	291607
Private operators	8393	10399	12421	14470	16495	19067
TOTAL	317169	330478	327026	321892	314627	310674

In the observed period, there is a decrease in the number of services provided by the public postal operator and the rapid growth of services provided by private operators.

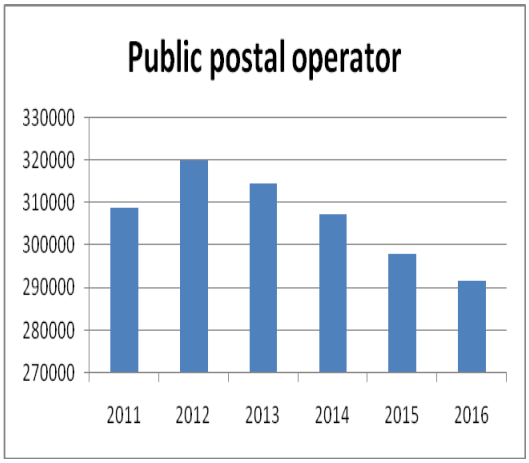


Chart 3: *Participation of postal operators on the market in the period 2011-2016. – the public postal operator*

The trend of reducing traditional postal services has been present in the European Union for many years, which has been recorded in the Republic of Serbia for the fifth consecutive year.

The share of universal postal services in total services is still extremely high (around 90%). In Europe, the average annual transfer of 135 billion items, including about 72 billion letters and 4 billion packages that transit through the territory of Europe.

It is important to note that the income from postal services accounts for 1% of national GDP (150 billion euros). In Europe, in postal services, there are about 2 million people employed, which daily connects about 800 million users [3].

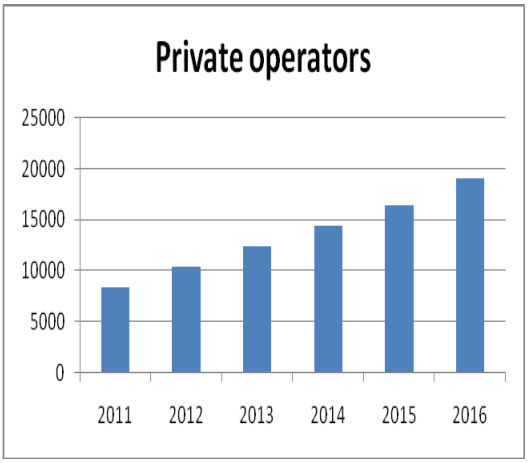


Chart 4: *Participation of postal operators on the market in the period 2011-2016. - private operator*

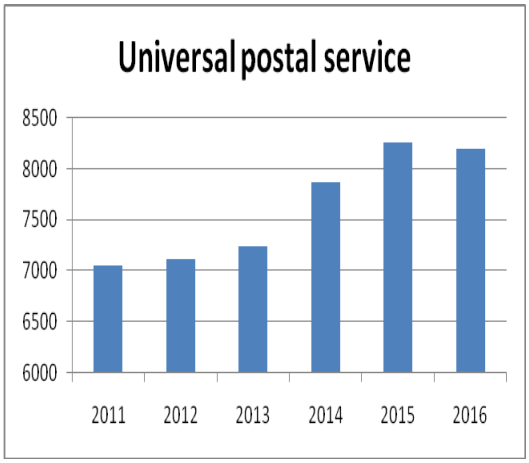


Chart 5: *The trend of income from universal postal service 2011-2016.*

3.2. Income of postal services

When it comes to the income of the postal industry, according to International Post Corporation (2015), it can be determined that there is an increase in income, which includes postal and logistic services, while packet and express services account for the largest contribution to overall income growth.

It is important to point out that in the postal services market in Serbia in 2015. income in Serbia was more than 16 billion dinars, which is about 0.4% of the projected GDP. Although a decline in the volume of services was recorded, the realized income was by 7% higher than in the previous year. Income from universal postal services has recorded growth of 5%, while income from commercial services has increased by 10%. The growth trend of commercial services continues, but with lower rates [2].

In the postal services market in 2016., in Serbia, although a decrease in the volume of services was recorded (1%), the realized income was higher by 4.7%, compared to the previous year. This is the first time a decline in incomes from universal postal services has been recorded (0.8%), while the income from commercial services has recorded growth of more than 10% this year. Commercial services are continuously growing, so in 2016., the growth rate is almost 11% [3].

Table 3: *The income of universal and commercial postal services*

Type of service	Income in millions of dinars					
	2011	2012	2013	2014	2015	2016
Universal postal service	7057	7119	7245	7871	8264	8197
Commercial services	4777	5573	6396	7099	7809	8639
TOTAL	11834	12692	13641	14970	16073	16836

In the total income, the public postal operator participates with more than 60%, while private operators have realized close to 40% of the incomes on the market of the Republic of Serbia.

The growth trend in the participation rate of private operators in total income continued in 2016., ranging from 30% in 2011. to 40% in 2016.

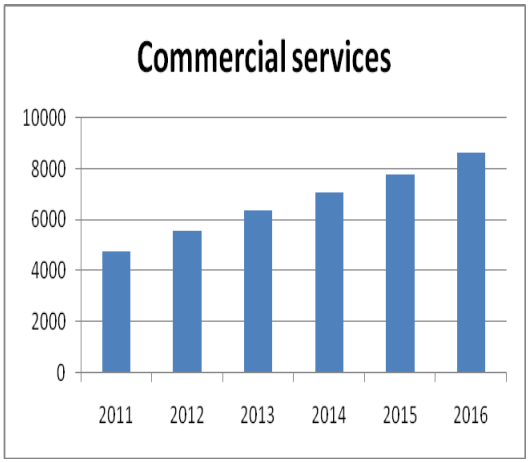


Chart 6: *The trend of income from commercial services 2011-2016.*

The income of the public postal operator increased by 1% compared to 2015., amounting to close to 10.4 billion dinars. In the income from the postal services of the public postal operator, the incomes from reserved services account for around 73.7% (of which letter services constitute 65.8%, money order7.9%), while non-reserved services account for 5.3%, while commercial ones 21% [3].

Table 4: *Income of services of the public postal and private operators*

Operators	Income in millions of dinars					
	2011	2012	2013	2014	2015	2016
Public postal operator	8288	8563	8920	9671	10293	10364
Private operators	3546	4129	4721	5299	5780	6472
TOTAL	11834	12692	13641	14970	16073	16836

Below is a graphical representation of the trend of incomes of the public postal operator and private operators in the Republic of Serbia for the period 2011 - 2016.

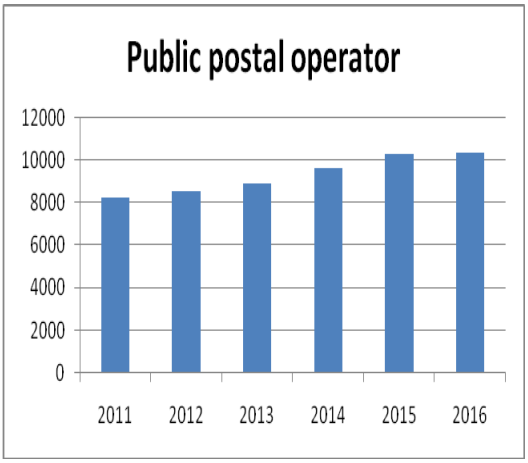


Chart 7: *Trend of income of the public postal operator 2011-2016.*

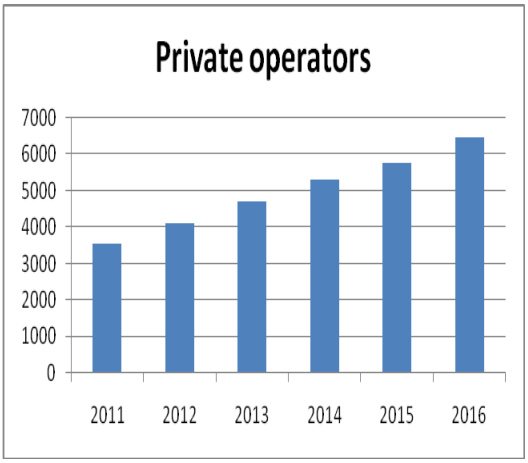


Chart 8: *Trend of income of private operators 2011-2016.*

4. Conclusion

The postal sector is changing rapidly. The traditional services are replaced by digital, which is primarily reflected in the letter items, which declined in many countries. Continuous increase in the number of packages, as a result of the development of e-commerce, suggests that it is necessary to redefine many procedures in the postal industry in order to become a simpler and more accepted purchase of goods over the Internet.

The era of digitization in the modern world imposes the obligation to provide sophisticated services that will respond to the needs of increasingly demanding users, and given the burdensome obligation of the universal postal service provider, the cost, as well as the way of financing, are some of the problems that go beyond national frameworks facing donors Universal postal services, regulators, legislators and other market participants.

Based on the analyzes presented, it can be concluded that the public postal operator faces serious competition, during the period of liberalization marketed in Serbia, which is best reflected in the volume of postal extensions and that from year to year private market operators are increasingly involved in the market. Post of Serbia must find a model of work by which it will be competitive, such as the use of the largest postal network resources, as the potential for market retreat in moments when e-commerce is developing, which causes a growing number of package services.

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