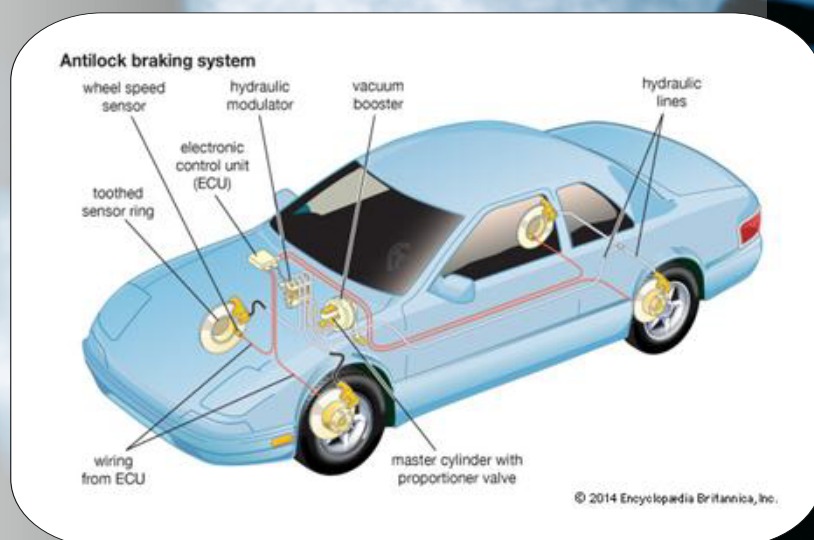


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Spectral analysis of vibration application for the metallurgical electric furnace main fan bearings condition evaluation

Dmitry Litvinov¹, Andris Priževaitis².
Riga Technical University, Liepaya affiliate – Liepaya, Latvia
E-mail: dmitrijs.litvinovs@rtu.lv¹, pasniedzejs.rtu@inbox.lv²

Abstract: Vibration diagnostics of rotary equipment is one of the reliable methods for preventing accidents and predicting equipment life. This article will discuss the theoretical principles of the impeller's fan bearings spectral analysis of vibration, as well as the method practical application.

KEYWORDS: VIBRATION DIAGNOSTICS, LIFETIME PREDICTION, ANALYSIS OF THE BEARINGS CONDITION.

1. Introduction

All metallurgical enterprises have a large amount of rotor equipment. All this equipment has rolling bearings. These bearings are very important components of the equipment. When the bearing fails, the equipment becomes unusable. Therefore, it is necessary to constantly monitor the condition of the bearings.

It is very important to determine the defect in time, make a forecast for its development, order the necessary spare parts and to plan the repair. To do this, the company should have a non-destructive testing service for equipment, which should regularly examine critical equipment and provide recommendations. This is especially important for responsible equipment, which directly affects the manufacture of products. Therefore, timely repair of this equipment can save a lot of money.

2. Mathematical calculation of vibration information frequencies of rolling bearings

Rolling bearing's work in centrifugal fans or electrical motors composition and at presence faults in it can influence on a vibration and modulating it processes with the followings fundamental frequencies [1]:

- Rotation frequency of movable ring in relation to immobile: f_{rot} ;
- Rotation frequency of separator in relation to an outer ring:

$$f_r = \frac{1}{2} \cdot f_{rot} \cdot \left(1 - \frac{d_{sr}}{d_r} \cdot \cos(\alpha) \right) \quad (1)$$

Where: d_{sr} - solid of revolution diameter;

$d_r \approx \frac{1}{2}(d_{out} - d_{in})$ - Diameter of separator;

d_{out} - Diameter of outer ring;

d_{in} - Diameter of inner ring;

α - contact angle of bodies and rolling paths;

- Rolling frequency of solid revolution on an outer ring:

$$f_{out} = \frac{1}{2} \cdot f_{rot} \cdot \left(1 - \frac{d_{sr}}{d_r} \cdot \cos(\alpha) \right) \cdot z = f_r \cdot z \quad (2)$$

Where: z - revolutions number of solids;

- Rolling frequency of solid of revolution on an inner ring:

$$f_{in} = \frac{1}{2} \cdot f_{rot} \cdot \left(1 + \frac{d_{sr}}{d_r} \cdot \cos(\alpha) \right) \cdot z = (f_{rot} - f_r) \cdot z \quad (3)$$

- Rolling frequency of solids of revolution in relation to the surface of rings:

$$f_{sr} = \frac{1}{2} \cdot f_{rot} \cdot \frac{d_r}{d_{sr}} \cdot \left(1 - \frac{d_{sr}^2}{d_r^2} \cdot \cos^2(\alpha) \right) \quad (4)$$

Expressions (Eq.1, Eq.2, Eq.3, and Eq.4) are evaluating only basic harmonics frequencies in the vibration spectrums and envelope of its high-frequency components at the different types of defects [1].

3. Vibration diagnostics of the main centrifugal fan.

The object of vibration diagnostics is the impeller's bearings of the main centrifugal fan of the electric furnace.

To enhance the outflow of exhaust gases from the working space of the electric furnace, 4 fans are required: 3 main fans and 1 booster fan. An electric furnace installed at one of the metallurgical enterprises is necessary for the smelting of metal scrap and the production of fittings.

This article discusses an example of vibration diagnostics for the main fan Nr.1. The smoke exhaust unit consists of a centrifugal smoke fan and a driving electric motor. During the experiment, the bearings of the impeller of the main centrifugal smoke fan were controlled (see Fig. 1.).

On the empeller shaft of the fan, 2 control points were selected (see Fig.1):

Point Nr.1 - Floating bearing TYPE SNL 226 TG (bearing C2226 - C3);

Point Nr.2 - Fixed bearing TYPE SNL 226 TG (bearing 22226 E - C3);

The operating mode of the unit is round-the-clock. Vibration sensors - accelerometers were installed horizontally.

Point Nr.1



Point Nr.2

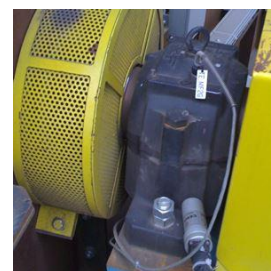


Fig.1. The impeller of the main exhaust fan mounted in the bearing housings with control points of vibration.

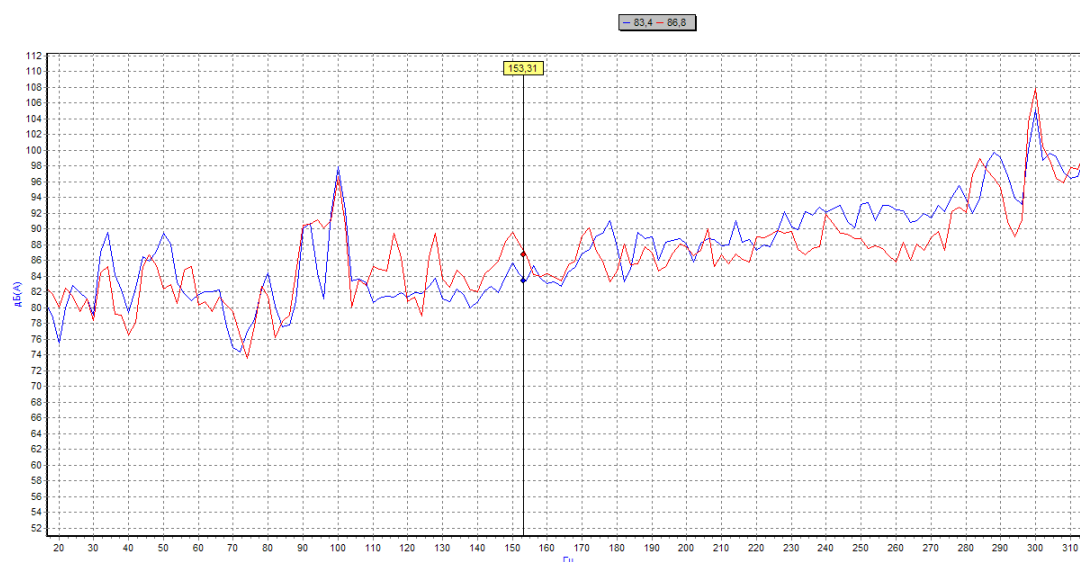


Fig.2. The part of vibration direct spectrum (point Nr.1).

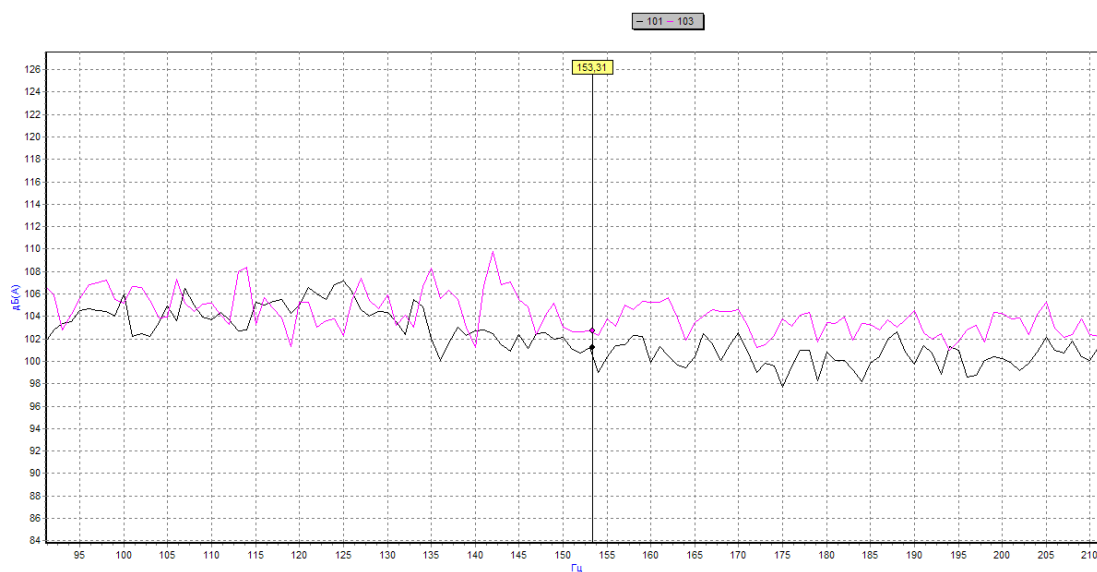


Fig.3. The part of vibration envelope spectrum (point Nr.1).

4. The vibration diagnostics route of the main fan impeller's bearings

The vibration monitoring of the main fan impeller's bearings is possible in two ways:

1. Use a portable system for collecting and analyzing information.
2. Using a stationary system for collecting and analyzing information.

Which system to use – the company must decide. If in the company is separate NDT (nondestructive testing) service, preferable to install a stationary vibration monitoring system.

The stationary monitoring system is needed above all things for a multimode strength equipment, guided an auxiliary personnel. Exactly personnel errors is more frequent than all are the defects multiplying reason of the guided equipment, which it must find out practically instantly (for a few turns of rotor) for failure timely prevention [2].

On Figure 4 the simplified structure of the vibration monitoring and diagnostics stationary system is shown [2].

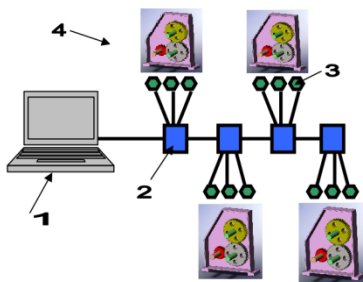


Fig.4 Structure of the vibration monitoring and diagnostics stationary system [2].

- 1 - The computer with special software; 2 - The Signals transformation card in digital form; 3 - Vibration sensors; 4 – Supervising equipment [2].

During vibration monitoring of the main fan impeller's bearings has been used route, consisting of the following components:

1. **Direct spectrum AS1** dB(A): - $F_l = 800\text{Hz}$; the number of lines in the spectrum - 400; the number of averages - 10.
2. **Envelope spectrum ES1** dB(A): limit frequency - $F_l = 400\text{Hz}$; bandpass filter - $F_a = 10\text{kHz}$; the number of lines in the spectrum - 400; the number of averages - 12.
3. **Overall level of vibration OVLV** dB(A): Detector - RMS; bandpass filter - $F_a = 10 - 25\text{kHz}$; the number of samples - 6.
4. **Time signal TS** (m/s^2): the sampling frequency - 1024 Hz; bandpass filter - $F_a = 8\text{kHz}$; the number of samples - 4000.

In the system of vibration diagnostics that was used in this study, there is the software for automatic diagnostics. But if in doubt, you can examine the spectra, the time signal of vibration and the vibration level manually. For instance, when checking and analyzing the vibration of the impeller bearings, the state of the points Nr. 2 is in satisfactory condition. The condition of the point Nr. 1 is much worse.

The automatic diagnostic program gives a warning that there is wear of the bearing's rolling elements and the separator - 5% with 50% probability, as well as the imbalance of the rotor 12dB with 90% probability. Therefore, it was decided to reduce the time interval between the dates of control. Figure 2 shows the direct

spectrum of vibration control with an interval of 2 weeks for point Nr. 1. Figure 3 shows the spectrum of the vibration envelope control with an interval of 2 weeks for point Nr. 1.

Figures 2 and 3 shows parts of the vibration spectra: the direct spectrum (see Fig. 2) and the envelope spectrum (see Fig. 3). Each figure shows the spectrum for 07/06/2012 (blue line) and 07/19/2012 (red line), respectively. In each figure, on the spectrum graphs, a frequency of 153.31 Hz is selected, which corresponds to the frequency of rolling elements rotation along the inner ring of the bearing.

Analyzing this example, we can conclude that the condition of the bearing is deteriorating and it is necessary to take appropriate measures, for example, to analyze the quality of bearing lubrication.

5. Conclusions

The analysis of the vibration spectra of the main smoke exhaust fan impeller's bearings of the electric melting furnace conducted in this study allows to conclude that constant monitoring and analysis of the bearing's vibration can significantly increase the equipment's life. Based on the study's results, it is obvious that the condition of the bearings of the equipment may gradually deteriorate, and may deteriorate very rapidly. Therefore, it is very important not only to know the condition of the bearings at the moment, but also need to analyze the situation to find out the reasons for the deterioration of the technical condition of the equipment. To ensure timely monitoring and analysis of vibration, it is necessary to have the appropriate equipment and trained personnel.

All these activities makes possible to significantly reduce the costs of the equipment, to extend the term of its operation, as well as improve the quality of products. The company must have a diagnostic service (NDT - nondestructive testing) that provides vibration monitoring and forecasting the state of the equipment. It is also necessary to establish the system of remote monitoring equipment and portable systems. The cost of equipment and software for the diagnosis is usually recouped within a year at its regular use.

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A fuzzy logic-based Anti-Lock Braking Systems

Illir Shinko, Enxhisa Shurdha, Bexhet Kamo, Elson Agastra, Klodian Dhoska
Polytechnic University of Tirana, Albania

ishinko@fti.edu.al, enxhisa.shurdha@fti.edu.al, bkamo@fti.edu.al, eagastra@fti.edu.al, kdhoska@upt.al

Abstract: In today's automobile industry, the need to adjust the speed of the vehicle and stabilize the wheels control is still a task due to road conditions and traffic. The Anti-lock Braking System (ABS) is a tool used in automobiles to prevent wheels from locking while brakes are pressed. The objective of this work is the maintenance of the wheel slip value to a desirable slip ratio as the vehicle model is simulated using a fuzzy logic controller. The analyses are made based on the slip ratio, angular velocity and stopping time.

Keywords: FUZZY LOGIC CONTROLLER, ANTI-LOCK BRAKING SYSTEMS, TIRE MODEL, FRICTIONAL FORCE

1. Introduction

The industries of car manufacturing have always struggled to provide the best driving experience and yet one of the challenges of their work is ensure total safety. Among all the features a vehicle includes there is still a lot of improvement to be done on the systems that control its movement. Anti-Lock Braking system (ABS) [2, 4-6, 8, 10-12] is one of these features which nowadays is a pre-attached technology to the brakes implementation to prevent wheels from slipping while rapid stops. Road surface conditions may vary therefore an active system is required to stabilize the vehicle after the driver has lost steering control. The friction between tires and the road surface tends to be reduced after the brakes are pressed. It is an ABS system's duty to detect the locked wheels and to quickly release the brakes. In this way the vehicle's drift could be avoided so technically the drivers also the vehicles safety would be provided. Basic functionality of braking includes shorten stopping distance, steerability during braking through ABS system and stability during braking to avoid overturning. In this study, Fuzzy Logic [1] has been used as an adaptive controller for the simulated system model in order to enhance the performance of the vehicle).

The organization of the paper is as follows: In session 2 we describe the anti-lock braking system background and its components and a practical idea of how it is implemented in vehicles. It also describes the mathematical model of the non-linear quarter tire model and provides the details of the respective functions for the essential features. Session 3 will introduce Fuzzy Logic and a discussion on its application for the ABS system. The developed Simulink model of the Fuzzy controlled ABS system will be represented in session 4. Detailed analyses and the numerical results will be provided in session 5. Finally, conclusions and recommendations for future work will be emphasized in session 6.

2. Anti-Lock Braking System Грешка! Източникът на препратката не е намерен.

The ABS System [7, 9] also known as anti-skid braking system is an automobile safety system that prevents the lock of the vehicles wheels as the brake pedal pressure is applied. Considering the emergency cases that can happen in traffic or under different circumstances where the road's surface might be very unpredictable, slippery or uneven it is necessary that the driver would be able to maintain the control of steer and vehicle stability on short distance stops. Ideally, while a vehicle is in motion, when brake pedals are hardly applied, this system would reduce the wheel speed and provide the shortest stopping distances.

Let us emphasize how the brake system works. The braking process starts when the driver commands the brake pedal position which is translated into a brake pressure by the electronic control unit. The brake pressure results in a braking force on the brake disc which becomes a braking wheel torque at the wheel. The braking torque on the wheels creates a negative longitudinal force to decelerate the vehicle. Thus, the moment the driver hits the brake pedal it applies pressure at the hydraulic system that causes brake

pedals to squeeze against the discs. That causes the vehicle to slow down by reducing the speed of both vehicle and the wheels. An important indicator of a vehicle speed is slipping ratio. The difference in the wheel speed and vehicle speed is defined by this factor.

$$\text{Slip ratio} = \frac{\text{vehicle speed} - \text{wheel speed}}{\text{vehicle speed}} \times 100\% \quad (1)$$

The implementation of the system is as illustrated in Fig. 1

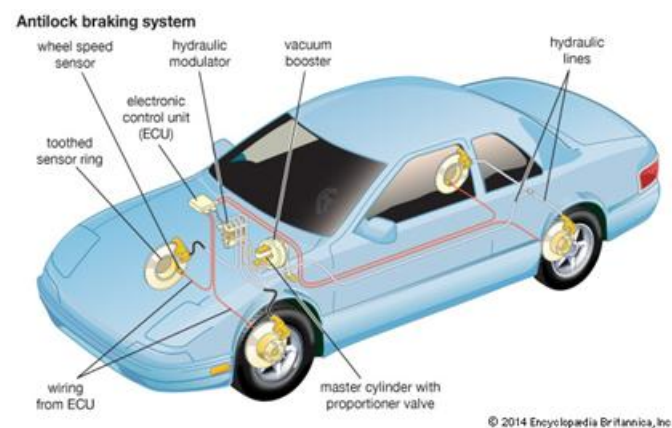


Fig. 1: ABS System Components.

The four main components are speed sensors, a pump, pressure release valves and controller. The sensors which are a combination of a toothed wheel, electromagnetic coil or magnet and a Hall Effect Sensor are used to calculate the acceleration and deceleration of the wheel. The toothed wheel is fitted to the rotating wheel hub proximately close to the magnetic sensor. There are four sensors, one per each wheel and sometimes they are placed on the differential. The sensor primarily detects a change in acceleration in the longitudinal direction of the vehicle and outputs it to the ABS control module. The Electronic Control Unit, shortly known as ECU is the controller that receives information from each individual speed sensor. In case it receives a signal from the sensor that a wheel has lost friction with the ground, it activates the ABS modulator.

The ABS system detects the right moment when a specific wheel is about to lock after the brake pedal is hit and the wheel speed is being reduced rapidly than the rest and quickly opens a pressure release valve in the hydraulic system that reduces the brake pressure on this specific wheel. The system automatically does this process in pulse form to prevent the wheels from locking. The modulator actuates the braking valves on and off. Hence, the pressure in the brake pipe is lowered. The wheel begins to rotate faster and tends to achieve the same speed as the rest. The valves might be separated in some systems or combined in others and they might work in three different positions. In either case, they communicate with the controller and the pump to add or release pressure from individual wheel brakes. The modulator valve has an

addition hold phase more like a cycle (5-6 times per second) which maintains pressure till the vehicle comes to a controlled stop. This process might be repeated continuously until the wheels reach equal speed. The valves suffer from clogging problems which causes them to have difficulty in opening, closing or change position. Thus the system might result in failure due to inoperability of the valves and the valves should be frequently checked. As discussed above the other component of the system was the pump. Once the pressure is released from the valves of the system, it needs to be restored on the individual wheel brakes when required. The pump status is adjusted by the controller in the required pressure level. While pump is cycling the driver might experience some vibration on the pedal. The cycling happens at a range of milliseconds thus the vibration is naturally felt.

2.1 Mathematical Model

In this session a briefly explanation of the mathematical formulation for the model is provided considering a simplified quarter vehicle model (Fig. 2). We begin by developing the linear braking model parameterized according to the Pacejka model (2002)[9] known as Magic Formula. Table 1 shows the notations used below.

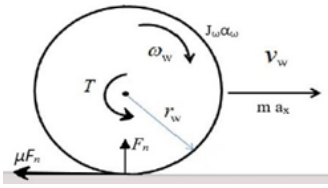


Fig. 2: Quarter car model.

Table 2: Notation used in problem formulation.

Notation	Meaning
α_ω	Wheel angular acceleration
a_x	The linear acceleration
F_n	Vertical force
V_x	Vehicle linear velocity
ω	Angular velocity
R	Radius of tire
λ	Wheel slip
m	Mass of tire
T_b	Braking torque
a, b, c	Road coefficients
T_d	Actuator Time delay
J	Inertia

The torque at the wheel center is as given above:

$$J_\omega \alpha_\omega = \mu R F_n - T_b \quad (2)$$

$$m a_x = -\mu \times F_n = m \frac{dv_x}{dt} \quad (3)$$

$$\lambda = \frac{V_x - \omega R}{V_x} \quad (4)$$

$$\mu_x = a(1 - e^{-b\lambda} - c\lambda) \quad (5)$$

$$T_d = e^{-\tau s} \frac{a}{s+a} T_{ref} \quad (6)$$

3. Fuzzy Logic Controller

The performance of the proposed model has been tested against general variations in road conditions. The theory of fuzzy sets and rules that was initially developed by Zadeh can be used to evaluate these imprecise linguistic statements directly. Considering the easy adaptation of fuzzy logic controller to varying road surfaces, traffic or uneven pavement the implementation of this controller for the actual model would give us some benefits. When compared to other types of controllers, fuzzy controller has shown better performance and effectivity. This soft computing system doesn't need a precise

model. Moreover Fuzzy logic has the ability to make decision even with uncompleted information and provides effective means of capturing the approximate nature of the physical world and human-way of thinking logic. In this study we use MATLAB environment as a useful tool to determine the Fuzzy rules for the Fuzzy Inference System. The purpose of the controller is to keep the slip at a desirable optimal value 0.1. The method we have used is Mamdani as shown in Fig. 3.

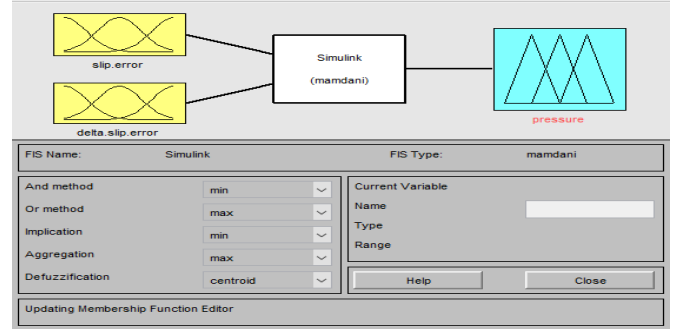


Fig. 3: FIS for the proposed model.

The FIS has two inputs, respectively the first one determines slip error values (actual slip minus the fixed slip ratio of 0.1) and the second is the difference rate in slip error which is the vehicle deceleration. Nomenclature used for the rule base is as follows: NB -Negative Big | NS- Negative Small ZE- Zero | PS – Positive Small | PB –Positive Big

Rules are determined in Fig. 4.

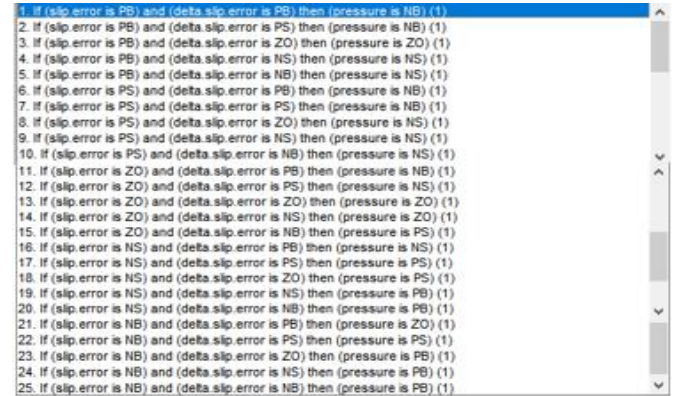


Fig. 4: Rule base for the two inputs

The Fig. 5 describes the relation of pressure as output and the two input data.

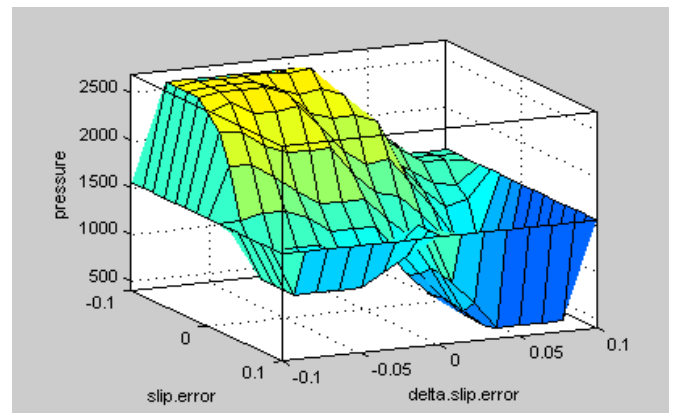


Fig. 5: Surface viewer for the fuzzy inference system.

4. Fuzzy Controlled ABS Simulink model

In this session we tend to use as a nonlinear control scheme the fuzzy controller attached to the tire model proposed for the ABS system. The corresponding data for subsystems values are put in MATLAB source code. Fuzzy logic Controller block is linked with the FIS we described in session III. Figure 6 shows the full Simulink vehicle model.

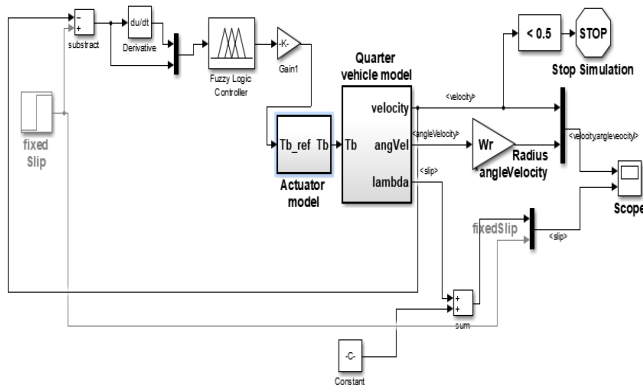


Fig. 6: Simulink vehicle model.

The actuator subsystem refers to the equation (6) which is a first order model used for simplifying the design, where T_d is the actuator time delay and the T_s is the saturated value, the parameter a is a pole set to a value of 70. The second subsystem is the tire model described by the equation (5) of the longitudinal friction coefficient where λ is the slip value and coefficient a , b , c determine road conditions. The fixed slip value is set to 0.1 referred to the Pacejka tire model. Test are made on dry asphalt condition as we have emphasized earlier.

5. Simulation Results

After the simulation of the model we continue to describe the graphics that we derived. Fig. 7 shows the deceleration of the vehicle.

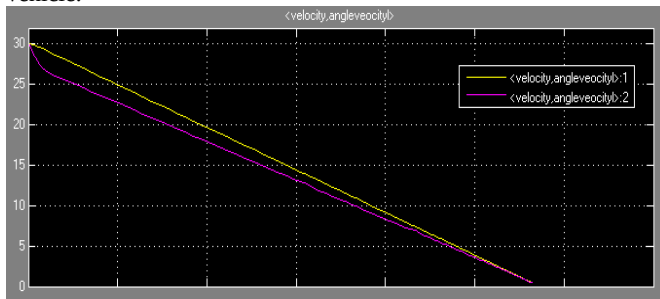


Fig. 7: Model results for velocity deceleration

As we can see from the graphic lines, the starting value is a velocity of 30km/h given by the yellow line. The stopping time is approximately 2,80 seconds where the vehicle comes at halt. This is a great value compared to other controller systems. Fuzzy Logic controller tends to respond faster when brakes are applied. Thus, it could make this controller more preferable to other systems.

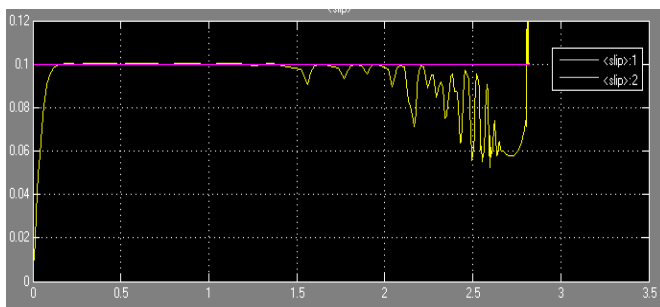


Fig. 8: Slip Ratio

From the Fig. 8, we can observe the desired slip ratio of the vehicle once the brakes are pressed. We can see the curves of its line as it rises up to a fixed desired slip value. This settling time is approximately 0,15 seconds which is still a very short time when compared to other controllers. We can strongly emphasize that the system stabilization is achieved faster and fuzzy controlled systems are more robust.

6. Conclusions

ABS system control is treated as a nonlinear system designed with a soft computing controller as it is fuzzy logic controller. In this work, we use this controller to define the required parameters as slip ratio and angular velocity. The simulation results showed the good performance achieved when using fuzzy logic controller. This is due to its ability to provide shorter stopping distance and smaller slip ratio of the vehicle as the brakes are pressed. The fixed slip ratio of 0.1 has shown good results in ABS system model. The stopping time is quite small and this system performs better than some other works with different controller for the ABS system. Further consideration must be taken in the future and other simulations with different road condition will be performed.

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Thermodynamic analysis of three-cylinder steam turbine from combined cycle power plant

Vedran Mrzljak, Jasna Prpić-Oršić, Ivan Lorencin, Nikola Anđelić

Faculty of Engineering, University of Rijeka, Rijeka, Croatia

E-mail: vedran.mrzljak@riteh.hr, jasna.prpic-orbic@riteh.hr, ilorencin@riteh.hr, nandelic@riteh.hr

Abstract: The paper present thermodynamic analysis of three-cylinder steam turbine, which operates in a combined cycle power plant. It is performed analysis of each turbine cylinder and of entire steam turbine. Comparison of steam turbine cylinders shows that intermediate pressure cylinder develops the highest real power and has the highest efficiencies while low pressure cylinder has the highest ideal (isentropic) power, the highest loses and the lowest efficiencies – therefore, improvement potential of the low pressure cylinder is the highest. Entire observed steam turbine has an energy efficiency equal to 86.58 % and exergy efficiency equal to 89.26 %, what is lower in comparison to high power steam turbines from some conventional land-based steam power plants but also higher in comparison to low power marine steam turbines.

KEYWORDS: STEAM TURBINE, COMBINED CYCLE POWER PLANT, THERMODYNAMIC ANALYSIS

1. Introduction

Combined cycle power plants are complex systems which consist of at least one gas turbine (Brayton process) and of at least one steam turbine (Rankine process) [1]. A connection between those two processes is heat recovery steam generator (HRSG) which uses exhaust heat from gas turbine(s) to produce steam for steam turbine [2]. HRSG must be carefully designed with an aim to utilize entire possible heat from exhaust gases and simultaneously to always produce steam of required operating parameters [3].

Literature review offers many analyses of combined cycle power plants. Exergo-economic and environmental analyses of solar integrated CCPP is presented [4]. Thermo-economic analysis of 300 MW CCPP can be found in the research of Oh et al. [5]. Liu and Karimi [6] proposed a new operating strategy for improving part-load performance of the analyzed combined cycle power plant. Riboldi and Nord [7] analyzed the integration of a wind farm into an offshore combined cycle power plant. In [8] can be found research about optimizing neural networks for combined cycle power plant electrical power output estimation.

In this paper is presented a thermodynamic analysis of three-cylinder steam turbine, which operates in a combined cycle power plant. It is performed calculation of efficiencies and losses for each cylinder and for the entire steam turbine. Obtained results show that by taking into account all the cylinders, low pressure cylinder has the lowest efficiencies (and the highest losses), therefore possible improvements should be based firstly on this cylinder.

2. Analyzed steam turbine description, characteristics and operating parameters

General scheme of the analyzed steam turbine (along with operating points required for thermodynamic analysis) is presented in Fig. 1. Each cylinder is of single flow without steam extractions. All the cylinders are connected to the same shaft which drives an electric generator. It should be noted that in Fig. 1 are not presented all the components inside HRSG, presented are only elements through which passes main steam flow streams required for steam cylinders operation.

Steam operating parameters in each analyzed turbine operating point from Fig. 1 (steam mass flow rates, pressures and temperatures) are found in [5] and presented in Table 1. For each operating point, steam specific enthalpy, specific entropy and specific exergy are calculated from known steam pressure and temperature by using NIST-Refprop 9.0 software [9]. Specific exergies in each operating point from Table 1 and throughout this paper are calculated for the ambient pressure of 1 bar (100000 Pa) and the ambient temperature of 25 °C (298 K).

Real (polytropic) and ideal (isentropic) steam expansion processes inside each observed turbine cylinder in h - s diagram are presented in Fig. 2. Ideal process is characterized by always constant steam specific entropy during expansion, while in the real process steam specific entropy increases during expansion from each cylinder inlet to the outlet.

Comparison of ideal and real expansion processes inside each cylinder and for a whole steam turbine is the baseline for energy (isentropic) analysis, therefore in Table 2 are presented steam specific enthalpies for ideal (isentropic) expansion in each turbine cylinder. Operating points in Table 2 are marked in accordance with expansion processes presented in Fig. 2.

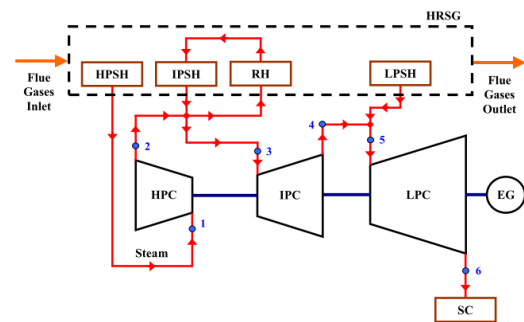


Fig. 1. Scheme of the analyzed steam turbine and operating points

Table 1. Steam operating parameters in each operating point of the analyzed turbine

O.P.*	Pressure (bar)	Temperature (°C)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Specific exergy (kJ/kg)
1	103.27	537.78	39.11	3467.90	6.7028	1474.00
2	17.58	300.25	39.11	3031.60	6.8380	997.40
3	16.87	518.51	54.78	3512.30	7.5676	1260.60
4	1.76	228.03	54.78	2928.00	7.6841	641.53
5	1.69	220.12	62.52	2912.40	7.6715	629.76
6	0.051	33.23	62.52	2440.30	7.9915	62.16

* Operating points refer to Fig. 1.

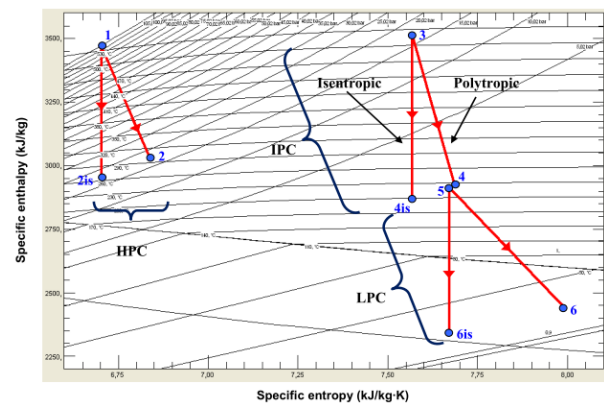


Fig. 2. h - s diagram of real (polytropic) and ideal (isentropic) expansion process in each turbine cylinder

Table 2. Steam specific enthalpies for ideal (isentropic) expansion in each turbine cylinder

Operating	Pressure	Specific	Specific
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Point*	(bar)	enthalpy (kJ/kg)	entropy (kJ/kg·K)
1	103.27	3467.90	6.7028
2is	17.58	2956.30	6.7028
3	16.87	3512.30	7.5676
4is	1.76	2871.30	7.5676
5	1.69	2912.40	7.6715
6is	0.051	2342.20	7.6715

* Operating points refer to Fig. 2.

3. Equations for the energy and exergy analyses

3.1. Energy and exergy analyses of any control volume

Energy analysis of any control volume is defined by the first law of thermodynamics [10, 11]. Mass and energy balance equations for a control volume in steady state, while neglecting potential and kinetic energy, can be expressed according to [12, 13] by using equations:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

$$\dot{Q}_{in} + P_{in} + \sum (\dot{m} \cdot h)_{in} = \dot{Q}_{out} + P_{out} + \sum (\dot{m} \cdot h)_{out} \quad (2)$$

The energy flow of any fluid stream can be calculated according to [14] as:

$$\dot{E}_{en} = \dot{m} \cdot h \quad (3)$$

Exergy analysis of any control volume is defined by a second law of thermodynamics [15]. The exergy balance equation is defined, according to [16], as:

$$\sum (\dot{m} \cdot \varepsilon)_{in} + \dot{X}_{heat} = \sum (\dot{m} \cdot \varepsilon)_{out} + P + \dot{E}_{ex,D} \quad (4)$$

where the exergy transfer by heat ($\dot{X}_{heat}$) at the temperature T can be defined according to [17] as:

$$\dot{X}_{heat} = \sum (1 - \frac{T_0}{T}) \cdot \dot{Q} \quad (5)$$

Specific exergy of fluid stream is defined as [18]:

$$\varepsilon = (h - h_0) - T_0 \cdot (s - s_0) \quad (6)$$

Similar to energy flow, the exergy flow of any fluid stream can be expressed as [19]:

$$\dot{E}_{ex} = \dot{m} \cdot \varepsilon = \dot{m} \cdot [(h - h_0) - T_0 \cdot (s - s_0)] \quad (7)$$

Energy and exergy efficiencies in general form can be defined as:

$$\eta_{en(ex)} = \frac{\text{energy (exergy) output}}{\text{energy (exergy) input}} \quad (8)$$

These governing equations are used in observed steam turbine (and all of its cylinders) energy and exergy analysis.

3.2. Energy and exergy analyses of steam turbine from combined cycle power plant

Energy (isentropic) analysis of observed steam turbine and all of its cylinders is based on comparison of real (polytropic) and ideal (isentropic) expansion processes [20, 21] according to operating points presented in Fig. 1 and Fig. 2 as well as according to steam operating parameters presented in Table 1 and Table 2. Exergy analysis of the observed steam turbine and its cylinders is based on real steam expansion processes only [22].

In Table 3 are summarized and presented equations for the energy analysis of each steam turbine cylinder, while in Table 4 are summarized and presented equations for the exergy analysis of each steam turbine cylinder. Equations for the energy and exergy analyses of the whole steam turbine are summarized and presented in Table 5.

Table 3. Equations for the energy analysis of observed steam turbine cylinders

	HPC	IPC	LPC
Real (polytropic) power	$P_{HPC,re} = \dot{m}_1 \cdot (h_1 - h_2)$	$P_{IPC,re} = \dot{m}_3 \cdot (h_3 - h_4)$	$P_{LPC,re} = \dot{m}_5 \cdot (h_5 - h_6)$
Ideal (isentropic) power	$P_{HPC,is} = \dot{m}_1 \cdot (h_1 - h_{2is})$	$P_{IPC,is} = \dot{m}_3 \cdot (h_3 - h_{4is})$	$P_{LPC,is} = \dot{m}_5 \cdot (h_5 - h_{6is})$
Energy destruction	$\dot{E}_{en,D,HPC} = P_{HPC,is} - P_{HPC,re}$	$\dot{E}_{en,D,IPC} = P_{IPC,is} - P_{IPC,re}$	$\dot{E}_{en,D,LPC} = P_{LPC,is} - P_{LPC,re}$
Energy efficiency	$\eta_{en,HPC} = \frac{P_{HPC,re}}{P_{HPC,is}}$	$\eta_{en,IPC} = \frac{P_{IPC,re}}{P_{IPC,is}}$	$\eta_{en,LPC} = \frac{P_{LPC,re}}{P_{LPC,is}}$

Table 4. Equations for the exergy analysis of observed steam turbine cylinders

	HPC	IPC	LPC
Steam exergy flow-input	$\dot{E}_{ex,HPC,S,in} = \dot{m}_1 \cdot \varepsilon_1$	$\dot{E}_{ex,IPC,S,in} = \dot{m}_3 \cdot \varepsilon_3$	$\dot{E}_{ex,LPC,S,in} = \dot{m}_5 \cdot \varepsilon_5$
Steam exergy flow-output	$\dot{E}_{ex,HPC,S,out} = \dot{m}_2 \cdot \varepsilon_2$	$\dot{E}_{ex,IPC,S,out} = \dot{m}_4 \cdot \varepsilon_4$	$\dot{E}_{ex,LPC,S,out} = \dot{m}_6 \cdot \varepsilon_6$
Exergy destruction	$\dot{E}_{ex,D,HPC} = \dot{m}_1 \cdot \varepsilon_1 - \dot{m}_2 \cdot \varepsilon_2 - P_{HPC,re}$	$\dot{E}_{ex,D,IPC} = \dot{m}_3 \cdot \varepsilon_3 - \dot{m}_4 \cdot \varepsilon_4 - P_{IPC,re}$	$\dot{E}_{ex,D,LPC} = \dot{m}_5 \cdot \varepsilon_5 - \dot{m}_6 \cdot \varepsilon_6 - P_{LPC,re}$
Exergy efficiency	$\eta_{ex,HPC} = \frac{P_{HPC,re}}{\dot{m}_1 \cdot (\varepsilon_1 - \varepsilon_2)}$	$\eta_{ex,IPC} = \frac{P_{IPC,re}}{\dot{m}_3 \cdot (\varepsilon_3 - \varepsilon_4)}$	$\eta_{ex,LPC} = \frac{P_{LPC,re}}{\dot{m}_5 \cdot (\varepsilon_5 - \varepsilon_6)}$

Table 5. Equations for the energy and exergy analyses of whole observed steam turbine

Energy	WHOLE TURBINE	Exergy	WHOLE TURBINE
Real (polytropic) power	$P_{WT,re} = \sum P_{re,cylinders}$	Steam exergy flow-input	$\dot{E}_{ex,WT,S,in} = \sum \dot{E}_{ex,S,in,cylinders}$
Ideal (isentropic) power	$P_{WT,is} = \sum P_{is,cylinders}$	Steam exergy flow-output	$\dot{E}_{ex,WT,S,out} = \sum \dot{E}_{ex,S,out,cylinders}$
Energy destruction	$\dot{E}_{en,D,WT} = P_{WT,is} - P_{WT,re}$	Exergy destruction	$\dot{E}_{ex,D,WT} = \dot{E}_{ex,WT,S,in} - \dot{E}_{ex,WT,S,out} - P_{WT,re}$
Energy efficiency	$\eta_{en,WT} = \frac{P_{WT,re}}{P_{WT,is}}$	Exergy efficiency	$\eta_{ex,WT} = \frac{P_{WT,re}}{\dot{E}_{ex,WT,S,in} - \dot{E}_{ex,WT,S,out}}$

4. Results and discussion

Real (polytropic) developed power of each cylinder and whole steam turbine, calculated according to data from Table 1, is presented in Fig. 3. In real exploitation, HPC develops the lowest real power equal to 17065.75 kW (when compared to other turbine cylinders). LPC develops real power of 29513.99 kW, while the highest real power is developed in IPC (32007.14 kW).

According to ideal (isentropic) steam expansion, Fig. 2, LPC will develop slightly higher power in comparison to IPC (35646.84 kW in comparison to 35113.09 kW), while the ideal power developed by HPC will remain the lowest (as real power) in comparison to the other cylinders.

Real (polytropic) developed power of the whole turbine is equal to 78586.88 kW, while in an ideal situation, when all steam expansion losses are neglected, analyzed turbine will develop ideal (isentropic) power equal to 90771.03 kW.

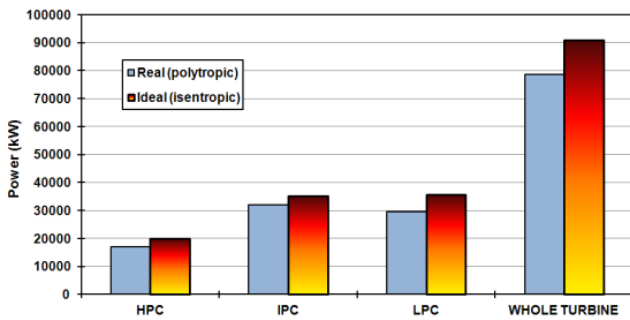


Fig. 3. Real (polytropic) and ideal (isentropic) power of each turbine cylinder and the whole turbine

Steam exergy flows at the input and output of each cylinder and the whole turbine are essential elements in the calculation of exergy destruction and efficiency. Steam exergy flows at the input and output of each turbine cylinder and the whole turbine are presented in Fig. 4.

From Fig. 4 can be seen that when comparing turbine cylinders, the highest steam exergy flow input (69053.92 kW) has IPC, while the highest steam exergy flow output (39013.02 kW) has HPC, what can be explained by a fact that steam after HPC will be used in two other cylinders, therefore high value of steam exergy flow at HPC output can be expected. The lowest steam exergy flow output, equal to 3886.08 kW has LPC, what is also expected because after LPC steam will be delivered to the condenser and will not be used anywhere in the steam turbine process. The high value of steam exergy flow at the LPC output (if occurs) will be indicator of increased losses (unused steam exergy) in the steam turbine process.

The whole observed turbine has a steam exergy flow at the input equal to 166079.34 kW, while steam exergy flow at the output of the whole turbine is 78041.23 kW.

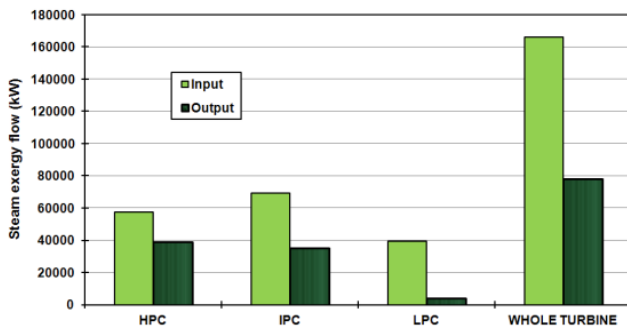


Fig. 4. Steam exergy flows at the input and output of each turbine cylinder and the whole turbine

Fig. 5 presents energy and exergy destructions (power losses) of each turbine cylinder and of entire analyzed steam turbine.

It can be clearly seen that energy destruction of each turbine cylinder and of entire steam turbine is higher in comparison with exergy destruction. If observing turbine cylinders, it can be concluded that both energy and exergy losses increase from the highest to the lowest steam pressure, therefore the lowest destructions (both energy and exergy) has HPC, followed by the IPC, while the highest destructions can be seen in LPC.

Whole observed steam turbine has energy destruction equal to 12184.14 kW, while exergy destruction of the whole turbine, according to presented steam operating parameters (Table 1), is 9451.23 kW.

For each turbine cylinder and for the whole observed steam turbine, exergy efficiencies are higher in comparison to energy efficiencies, Fig. 6.

In comparison to other cylinders, LPC has the lowest efficiencies (both energy and exergy), Fig. 6, due to the highest destructions, Fig. 5. Regardless of higher energy and exergy destructions, IPC has higher energy and exergy efficiencies in comparison to HPC.

The whole observed steam turbine has exergy efficiency equal to 89.26 %, while its energy efficiency is equal to 86.58 %. Calculated energy and exergy efficiencies of the whole turbine lead to conclusion that observed steam turbine has lower efficiencies in comparison to high power steam turbines from some conventional land-based steam power plants [23], but simultaneously higher in comparison to low power marine steam turbines [24, 25].

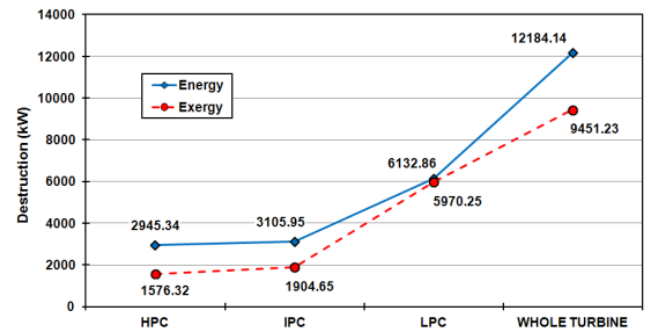


Fig. 5. Energy and exergy destructions (power losses) of each turbine cylinder and the whole turbine

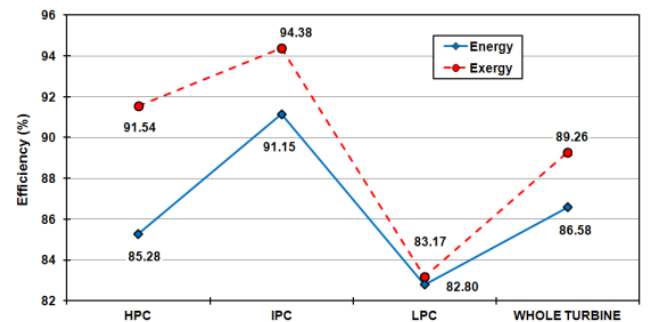


Fig. 6. Energy and exergy efficiencies of each turbine cylinder and the whole turbine

5. Conclusions

This paper presents a thermodynamic analysis of three-cylinder steam turbine, which operates in a combined cycle power plant. It is obtained developed power, energy and exergy efficiencies and losses for each steam turbine cylinder and for the entire steam turbine. The most important conclusions derived from this analysis are:

- When observing steam turbine cylinders, IPC develops the highest real power (32007.14 kW), while LPC has the highest ideal (isentropic) power of 35646.84 kW.
- For each cylinder and entire steam turbine it is observed that energy losses are higher and energy efficiencies are lower in comparison to exergy losses and exergy efficiencies.
- The highest losses and the lowest efficiencies (both energy and exergy) are observed in LPC what along with the highest ideal (isentropic) power show the highest improvement potential for this turbine cylinder (if compared to other cylinders).

Further research about this steam turbine will be based on its optimization and on finding possibilities for improving each cylinder operation, starting with a low pressure cylinder.

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Nomenclature:

Abbreviations:		Greek symbols:	
EG	Electric Generator	ε	specific exergy, kJ/kg
HPC	High Pressure Cylinder	η	efficiency, %
HPSH	High Pressure SuperHeater		
HRSG	Heat Recovery Steam Generator	Subscripts:	
IPC	Intermediate Pressure Cylinder	0	ambient state
IPSH	Intermediate Pressure SuperHeater	D	destruction (loss)
LPC	Low Pressure Cylinder	en	energy
LPSH	Low Pressure SuperHeater	ex	exergy
RH	ReHeater	in	inlet (input)
SC	Steam Condenser	is	ideal (isentropic)
		out	outlet (output)
		re	real (polytropic)
Latin symbols:		S	steam
$\dot{E}$	energy/exergy of a flow, kW	WT	whole turbine
h	specific enthalpy, kJ/kg		
$\dot{m}$	mass flow rate, kg/s		
p	pressure, Pa or bar		
P	power, kW		
$\dot{Q}$	heat transfer, kW		
s	specific entropy, kJ/kg·K		
T	temperature, K or °C		
$\dot{X}_{\text{heat}}$	exergy transfer by heat, kW		

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Investigation of the dependence of axial force and torque on the geometric parameters of carbide micro-drills with variable slopes of spiral grooves

Raul Turmanidze¹, Predrag Dašić^{2,3}, Giorgi Popkhadze¹

Faculty of Transportation and Mechanical Engineering – Georgian Technical University (GTU), Tbilisi – Georgia¹

High Technical Mechanical School of Professional Studies, 37240 Trstenik - Serbia²

SaTCIP Publisher Ltd., 36210 Vrnjačka Banja – Serbia³

inform@gtu.ge¹, popxadzegiorgi@gmail.com¹, dasicp58@gmail.com^{2,3}

Abstract: Micro-drilling (MD or μD) is type of machining (processing) technology used for the drilling of miniaturized parts of small diameter in micro-scale, ie. diameter in a range of a few microns to several hundred microns. In paper is given the dependence of axial efforts and torque on different modes of depth of drilling in micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$ and $f=0.01$ [mm/turn]

KEY WORDS: INDUSTRY 4.0, MICRO-DRILLS, AXIAL FORCE, TORQUE, REGRESSION MODEL.

1. Introduction

The new knowledge society (KS) or knowledge based society (KBS) and "Industry 4.0" condition the accelerated development and use of new technology, materials and production systems in combination with digital technologies: Internet of Services (IoS), Internet of People (IoP), Internet of Things (IoT), Industrial Internet of Things (IIoT), Internet of Everything (IoE), Cloud Computing (CC) and etc. [1-4, 10-11, 13, 17, 19-21, 30-31, 34, 36, 38].

In knowledge society (KS) and "Industry 4.0" and today's fast-paced world with a large number of important applications of one of the most emerging and growing fields of production technologies are micro and nano-machining [22].

Micro- and nano-machining are the most promising technology for the production of miniaturized parts in micro- and nano-scale. Compound micro- and nano-machining is becoming more and more important and popular because of growing demand for industrial products with not only increased number of functions but also of reduced dimensions, higher dimensional accuracy and better surface finish. Micro- and nano-machining are required in a large number of fields like biotechnology, electronics, medicine, optics, aviation's, automobile and communication and etc. [22].

2. Micro-drilling

Micro-drilling (MD or μD) is type of machining (processing) technology used for the drilling of miniaturized parts of small diameter in micro-scale, ie. diameter in a range of a few microns to several hundred microns. Micro-drilling using micro drill bits possesses the same features as that of the macro scale drilling but slightly different ones. This uses a special drill geometry, tool holding devices, drilling cycle and speeds of drilling [15, 22-23, 25]. In paper [14] is presented analysis of dynamic characteristics of micro-drills, in papers [16, 18, 24] is presented analysis of stresses in micro-drills, cutting performance of micro-drills is presented in papers [23] optimization of geometric parameters of micro-drills in papers [27-29, 33, 35], wear mechanisms of micro-drills in papers [37] and etc.

On Fig. 1 is given micro-drilling with micro-drills on the CNC machine of the firm DATRON (Web site: <https://www.datron.com/>).

Micro-drilling is applied in industries such as electronics, aerospace, medicine and automobiles for machining parts with a diameter of several microns, due to a significant uptake in the use of miniaturised products and devices.



Fig. 1. Micro-drilling with micro-drills on the CNC machine of the firm DATRON

A number of different micro-drilling techniques have been developed that can generally be classified into [15]: conventional and non-conventional micro-drilling techniques. Conventional micro drilling makes use of drill bits of different configurations such as: twist, spade, D-shaped, single flute, compound drill and coated micro drill, while non-conventional micro drilling involves electrical, chemical, mechanical and thermal means which include laser, electro discharge machining (EDM), electrochemical machining (ECM), spark assisted chemical engraving (SACE), electron beam (EB), ultrasonic vibration (USV) or combinations of these approaches. These non-conventional micro-drilling techniques include: laser micro-drilling (LMD), electro discharge micro-drilling (EDMD), electrochemical micro-drilling (ECMD), electron beam micro-drilling (EBMD), spark assisted chemical engraving (SACE), ultrasonic vibration micro-drilling (USVMD) and etc. [15, 25]. On Fig. 2 is given overview and classification of laser drilling technologies [12].

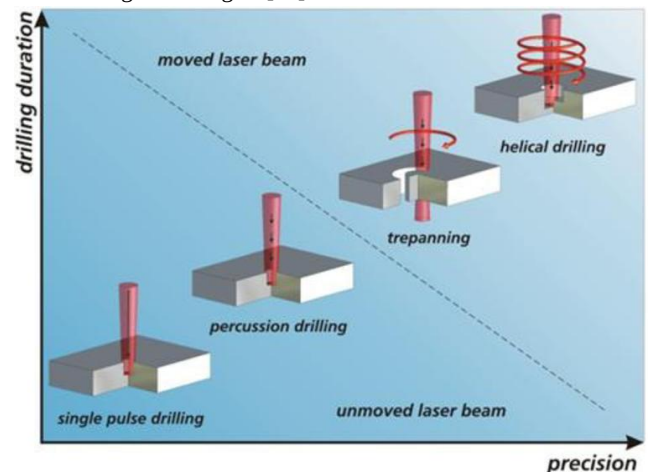


Fig. 2. Classification of laser drilling technologies w.r.t. drilling duration and precision [12]

3. Materials and methods

Experiments were conducted with micro-drills from solid alloy VK60M diameter $\varphi=0,9$ [mm] long spiral groove $l=10$ [mm]. Rake angle and spiral angle grooves respectively $\omega=30^\circ$, rear angle was 18° . The feed of micro-drilling was: $f=0.01$ [mm/turn].

Material for micro-drilling it was fiberglass [27-29, 33].

All experimental investigation were realized in laboratory precision micro instrumental Department "Industrial Technologies Engineering Mechanics", Georgian Technical University (GTU) from Tbilisi (Georgia) in close cooperation with specialists of the Institute of Manufacturing Technology and Quality Management (IFQ) Magdeburg University Otto-von-Guericke (Germany).

To measure the axial effort was the appliance is made on the basis of known methods and existing analogs, measuring element, which is the system of strain gauges mounted on the elastic casing (Fig. 3) [27-29, 33].



Fig. 3. Instrument for measuring axial efforts

Mathematical dependence between torque (T) from depth of drilling (D) during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$ and $f=0.01$ [mm/turn] can be determined by one of the following regression models in the form:

- linear regression model (LRM):

$$T = b_0 + b_1 \cdot D \quad (1)$$

- quadrate regression model (QRM) or 2nd-degree polynomial regression model (PRM2):

$$T = b_0 + b_1 \cdot D + b_2 \cdot D^2 \quad (2)$$

- cubic regression model (CRM) or 3rd-degree polynomial regression model (PRM3):

$$T = b_0 + b_1 \cdot D + b_2 \cdot D^2 + b_3 \cdot D^3 \quad (3)$$

- power regression model (PRM):

$$T = a \cdot D^{b_1} \quad (4)$$

- exponential regression model (ERM):

$$T = a \cdot e^{b_1 \cdot D} \quad (5)$$

- complex power-exponential regression model (PERM):

$$T = a \cdot D^{b_1} \cdot e^{b_2 \cdot D} \quad (6)$$

- logarithmic regression model (LogRM):

$$T = b_0 + b_1 \cdot \ln D \quad (7)$$

The mathematical processing of the experimental data involves the determination of numerical values of the parameters b_0 , b_1 , b_2 , b_3 and a for linear (LRM), quadratic (QRM), cubic (CRM), power (PRM), exponential (ERM), complex power-exponential (PERM) and logarithmic (LogRM) regression models and correlation analysis of the observed regression equations.

Parameter estimation for b_0 , b_1 , b_2 , b_3 and a it was determined using the Levenberg-Marquardt (LM) method and a software

system using this method. The choice of the regression model is realized on the basis of the values of the coefficient of correlation (R), coefficient of determination (R^2) and adjustment coefficient of determination ($\text{Adj}R^2$), according to the methodology described in scientific monographs [5-6] and papers [7-9, 26-29].

4. Results and discussion

4.1. Determination of dependence between axial efforts (P) from depth of drilling (D) during micro-drilling

Measured values for axial efforts (P) [gr.] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$ and $f=0.01$ [mm/turn] are shown in Table 1 and Fig. 4.

Table 1. Measured values for axial efforts (P) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

n [rpm]	Axial efforts (P) [gr.] on different modes of depth of drilling (D)						
	1	2	3	4	5	6	7
10000	260	290	200	310	310	220	320
15000	170	180	150	200	205	155	220
20000	120	140	105	160	160	108	170

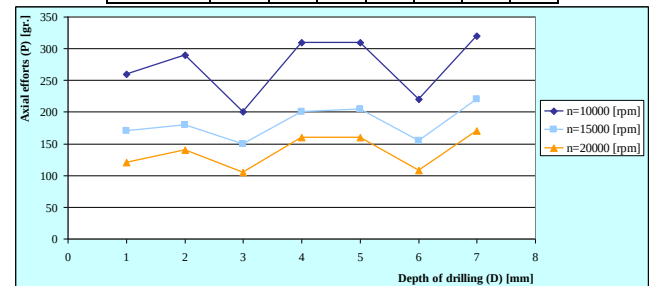


Fig. 4. The chart of axial efforts (P) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

From Table 1 and Fig. 4, it can be concluded that the values for axial efforts (P) [gr.] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$ and $f=0.01$ [mm/turn] range around the indicators of central tendency (Table 2 and Fig. 5).

Table 2. Indicators of central tendency of axial efforts (P) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

Parameters	Sign	n=10000	n=15000	n=20000
Arithmetic mean	AM	272.8571	182.8571	137.5714
Geometric mean	GM	269.0382	181.2145	135.2789
Harmonic mean	HM	264.9859	179.5807	132.9747
Median	Med	290	180	140

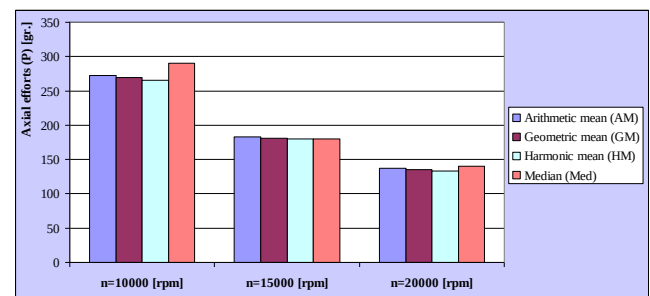


Fig. 5. Graphical representation of indicators of central tendency of axial efforts (P) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

4.2. Determination of dependence between torque (T) from depth of drilling (D) during micro-drilling

Measured values for torque (T) [gr-sm] depending from depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$ and $f=0.01$ [mm/turn] are shown in Table 3 and Fig. 6.

Table 3. Measured values for torque (T) depending from depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

n [rpm]	Torque (T) [gr-sm] on different modes of depth of drilling (D)						
	1	2	3	4	5	6	7
10000	13	24	30	34	38	40	43
15000	12	20	24	25	25	26	30
20000	7	16	19	22	22	23	25

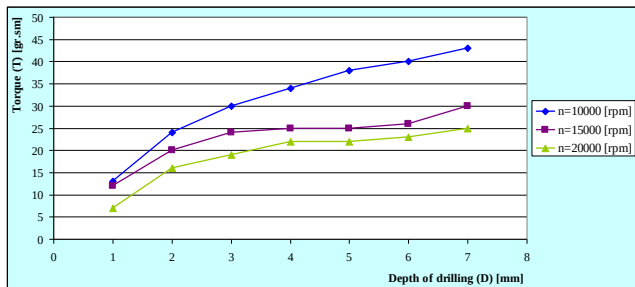


Fig. 6. The chart of torque (T) depending from depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

Values of indicators of central tendency for torque (T) [gr-sm] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$ and $f=0.01$ [mm/turn] is given in Table 4 and Fig. 7.

Table 4. Indicators of central tendency of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

Parameters	Sign	n=10000	n=15000	n=20000
Arithmetic mean	AM	31.71429	23.14286	19.14286
Geometric mean	GM	29.78582	22.37541	17.91481
Harmonic mean	HM	27.35375	21.42016	16.18961
Median	Med	34	25	22

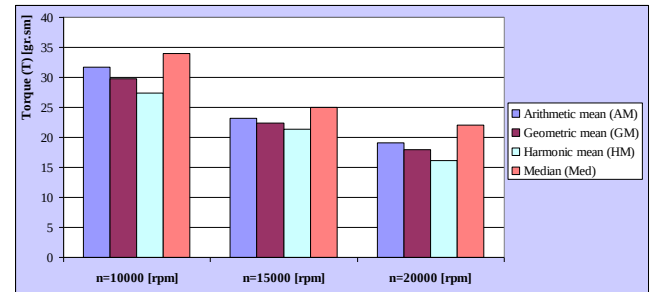


Fig. 7. Graphical representation of indicators of central tendency of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$) and $f=0.01$ [mm/turn]

A comparative analysis of different regression equations of torque (T) [gr-sm] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$, $f=0.01$ [mm/turn] and $n=10000$ [rpm] is given in Table 5 and Fig. 8.

It can be seen from Table 5 and Fig. 8 that all 7 regression equations represent the experimental data well, since their correlation coefficient R is greater than 0.92. This is especially true of the 2nd, 3rd, 6th and 7th equations whose correlation coefficients are greater than 0.994.

Table 5. Tabular view of analysis of different regression equations of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$), $f=0.01$ [mm/turn] and $n=10000$ [rpm]

No.	Title of regression model (RM)	Form of regression equation	R	R ²	AdjR ²
1.	Linear (LRM)	$T=13.14286+4.64286 \cdot D$	0.96109	0.9237	0.90844
2.	Quadratic (QRM)	$T=4.57143+10.35714 \cdot D-0.71429 \cdot D^2$	0.99463	0.98929	0.98393
3.	Cubic (CRM)	$T=-1.42857+17.19048 \cdot D-2.71429 \cdot D^2+0.16667 \cdot D^3$	0.99923	0.99847	0.99694
4.	Power (PRM)	$T=15.98218 \cdot D^{0.5232}$	0.98728	0.97473	0.96967
5.	Exponential (ERM)	$T=17.84783 \cdot e^{0.13545 \cdot D}$	0.92478	0.85522	0.82627
6.	Power-exponential (PERM)	$T=15.2224 \cdot D^{0.85697} \cdot e^{-0.09211 \cdot D}$	0.99748	0.99496	0.99243
7.	Logarithmic (LogRM)	$T=13.16304+35.07391 \cdot \ln D$	0.99708	0.99417	0.99200

A similar analysis can be performed for comparative analysis of different regression equations of torque (T) [gr-sm] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle $\omega=30^\circ$, $f=0.01$ [mm/turn] and $n=15000$ [rpm] and $n=20000$ [rpm].

5. Conclusion

The methodology of comparative analysis and the choice of the regression equation according to the correlation coefficient R and the coefficient of determination R² is of a general character and can be applied generally for the analysis of similar dependencies and processes and systems.

All 7 regression equations of function $T=f(D)$ (sequentially: cubic, complex power-exponential, logarithmic, quadratic, power,

linear and exponential) represent experimental data well, since their correlation coefficient R is greater than 0.92.

The experimental data of function $T=f(D)$ are best represented by cubic ($R=0.99923$; $R^2=0.99847$ and $AdjR^2=0.99694$), and then complex power-exponential regression equation ($R=0.99748$; $R^2=0.99496$ and $AdjR^2=0.99243$) and etc.

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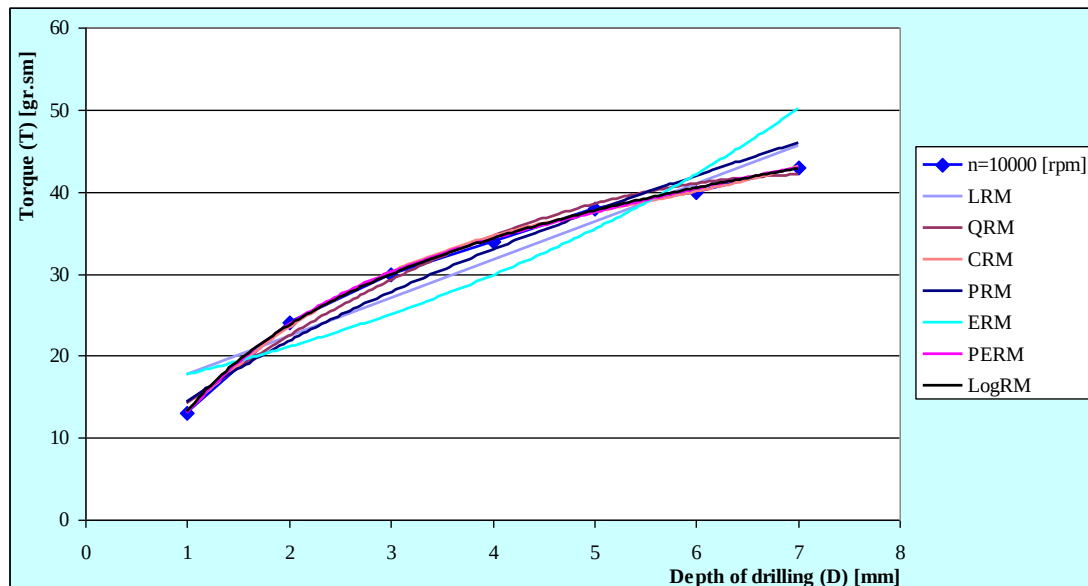


Fig 8. Graphical representation of analysis of different regression equations of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=30^\circ$, $f=0.01$ [mm/turn] and $n=10000$ [rpm])

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Vibration assisted electro-discharge machining of Ti6Al4V alloy using conical shaped tool

Arka Mondal, Subhajit Sahoo, Prithwiraj Roy, Souren Mitra*
 Department of Production Engineering, Jadavpur University, Kolkata, India
 mail.souren.mitra@gmail.com

Abstract: In recent years, the world of material science has observed a wide range of applications of Titanium alloys; especially Ti6Al4V, a grade-V alpha-beta titanium alloy; in biomedical instruments, automobile engineering, aerospace engineering, marine engineering, etc. Shaping this material by conventional machining processes is very difficult because of some of its properties, like high strength, high chemical affinity, etc. That's why non-conventional machining processes, like electro-discharge machining (EDM), have been applied to shape the material. Past researches revealed that in EDM, both the quality of machining and machining rate deteriorate due to accumulation of debris in the machining zone. The present research has been focused to achieve better machining rate and machining quality by incorporating conical tool and vibration in the workpiece. The effects of, both vibration of workpiece and shape of the tool on material removal rate (MRR) and Diametric Over-cut (DOC), have been studied through a planned set of experiments. The result shows that MRR almost doubled using vibration assisted EDM. However, the DOC also increased due to vibration. On the other hand, the use of the conical tool resulted in increased MRR and a reduced DOC. The paper also includes analysis of the effects of peak-current and pulse-on-time on MRR and DOC.

Keywords: EDM, Ti6Al4V, VIBRATION OF WORKPIECE, SHAPE OF TOOL

1. Introduction

Ti6Al4V is a grade-V, $\alpha+\beta$ titanium alloy where aluminum acts as alpha stabilizer and vanadium as beta stabilizer. Beta phase of titanium having BCC crystal structure is more ductile than Alpha phase of titanium having HCP structure, but the strength of beta structure is higher than alpha structure. The properties of alpha-beta alloy, like Ti6Al4V stays in between of both. Ti6Al4V has some specific properties like high strength low weight, high corrosion resistance etc. Because of these properties, it has got extensive uses in biomedical instruments, automobile engineering, aerospace engineering, marine engineering, etc. The need of machining and shaping the material has increased due to its extensive use, but machining of this material with conventional machining processes is very hard due to its high strength and higher chemical affinity. That's why non-contact type unconventional machining process, electro-discharge machining (EDM), has been employed to process this material.

EDM, as shown in Fig.1, is a non-contact type electro thermal non-conventional machining process where spark is generated in between tool and workpiece to machine conductive materials and thus the material is eroded by melting and vaporization. The mechanical properties of materials have no influence in electro-discharge machining as there is no contact in between tool and workpiece, though the thermal properties of the material play an important role. That's why EDM has been employed to machine high strength materials, like Ti6Al4V.

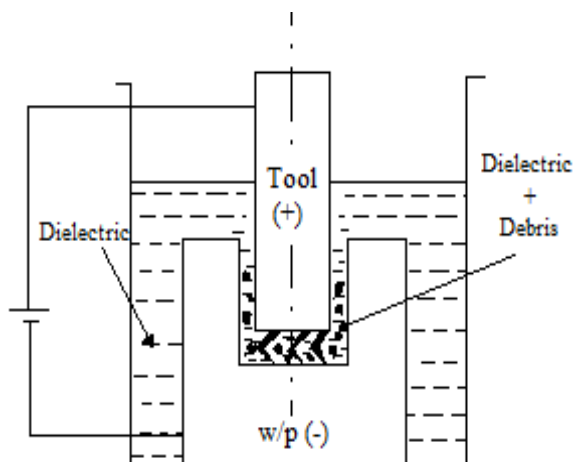


Fig. 1 Basic EDM scheme

Though it has several advantages, the EDM process itself is very slow. The accumulated debris in between tool and workpiece, i.e. in the machining zone, deteriorates the quality of machining and also reduces the machining rate.

In recent years, many researches have been carried out to overcome this problem and to improve the machining rate and quality. G.D'Urso et al.[1] observed the effect of different tool materials; like copper, brass and tungsten carbide; on machining micro-hole on workpiece material; like stainless steel, titanium, magnesium and brass. Two types of tool, cylindrical and tubular, were used there and their respective effects were observed. Vijay Verma et al.[2] studied the effects of different process parameters on machining characteristics in drilling through holes on Ti6Al4V. They also studied SEM images of machined surfaces. Dipraj Banik et al [3] observed the machining characteristics on Ti6Al4V and later optimized the results. Lin Gu et al.[4] used multi-hole inner flushing by using bundled electrode to remove debris in the machining zone easily. They observed better machining quality by doing so. M.P.Jahan et al.[5] studied the effect of low frequency vibration on EDM. They analyzed the hole accuracy, machining rate and surface quality and described a comparative study. A. M. A. Al-Ahmari et al.[6] combined laser beam machining with EDM to achieve better machining rate and quality. A pilot hole was drilled by LBM firstly; later the hole was finished by EDM. Luciano José Arantes et al[7] carried out abrasive jet electro-discharge machining to enhance machinability.

The present research has been focused to achieve better machining rate and quality in drilling through holes on Ti6Al4V workpiece by incorporating conical shaped tool and vibration in workpiece. The effect of both, shape of the tool and workpiece vibration, on material removal rate (MRR) and diametric overcut (DOC) have been studied here and the interaction effects of shape of the tool and workpiece vibration have been analyzed. The paper also includes analysis of the effect of peak current and pulse-on-time on MRR & DOC. Moreover the qualities of drilled holes have been explored.

2. Experimental Set-Up

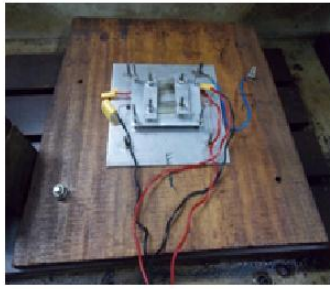
There are three parts of experimental set-up. These are: the basic electro-discharge machine, an external device for workpiece vibration and the specially designed tool.

2.1 Electro-discharge Machine

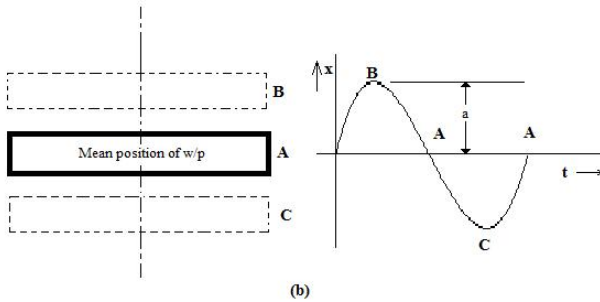
In the present research, ZNC electro-discharge machine along with, Ferrolac 3M EDM oil with side-jet flushing arrangement has been used.

2.2 Workpiece Vibration Device

Fig.2 shows the workpiece vibration device with work holding arrangement. The amplitude of vibration (a) = $4\mu\text{m}$ and the frequency = 400Hz.



(a)



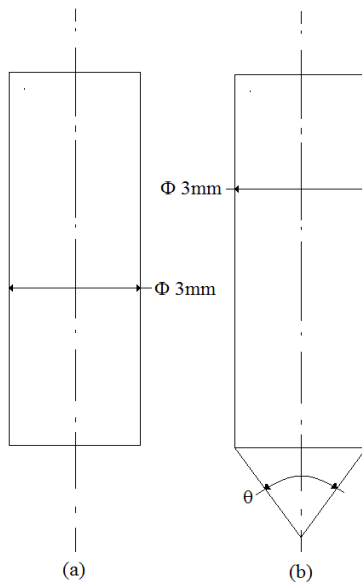
(b)

Fig. 2. (a) Workpiece vibration unit (b) schematic of vibration

2.3 Material

Ti6Al4V has been used as workpiece material here. The workpiece has been sliced in wire-EDM in a square shape of 25mm X 25mm with 1mm thickness.

Two types of specially designed copper tools have been used as shown in Fig.3, one is cylindrical tool and the other one is right circular conical shaped tool with aperture angle of $(\theta) 50^\circ$.



(a)

(b)

Fig. 3 EDM tool (a) cylindrical tool (b) right circular conical shaped tool

3. Experimental Procedure

First the work piece material was sliced in wire-EDM and the tool was made in form of the conical shape as per the required aperture angle. Then, the workpiece vibration device was fixed at the machine base and the workpiece was fixed properly on the work holding device of the workpiece vibration device. After that, the tool of proper shape was fixed in the machine head and the finally the through hole was drilled on workpiece setting the process parameters properly. Then, the process was repeated for next set of experiments according to the experimental plan. The machining performances were evaluated by value of the response parameters,

material removal rate (MRR) & diametric overcut (DOC). Further the hole surfaces were observed by optical microscope.

Material removal rate (MRR):

$$MRR = \frac{w/p \text{ wt. before m/cing} - w/p \text{ wt. after m/cing}}{\text{machining time}} \quad (1)$$

Diametric Overcut (DOC): The difference between top diameter of the hole (D_{top}) (or entry diameter) and tool diameter (D_{tool}) (as shown in Fig.4) is defined as diametric over-cut (DOC).

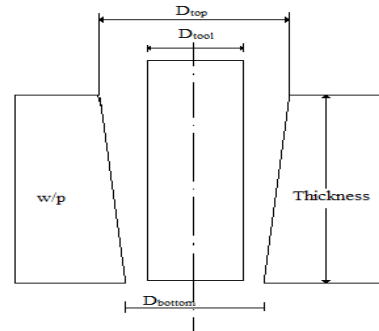


Fig. 4 Drilled hole characteristic

Here, a full factorial set of experiments has been carried out. Table.1 shows the factors selected for experimentation and the levels of each experiment.

Table.1 Parameters & Levels

Process Parameters	Level 1	Level 2	Level 3
Pulse on time(μ s)(T_{on})	10	15	30
Peak current (amp) (I_p)	5	7	—
Aperture angle (degree) (θ)	180 (cylindrical)	50 (cone shaped)	—
Vibration (f)	Without Vibration(0)	With vibration(1)	—

4 Results & Discussions

The experimental results based on the planned DOE are tabulated below.

Table.2. Experimental results

Sl No	f	θ	I_p	T_{on}	MRR (mg/min)	DOC (μ m)
1	0	0	5	10	0.5002	98.5
2	0	0	5	15	0.7673	109.5
3	0	0	5	30	0.7262	152.1
4	0	0	7	10	0.6694	130.0
5	0	0	7	15	0.8434	148.0
6	0	0	7	30	0.9221	184.0
7	0	50	5	10	0.7229	76.0
8	0	50	5	15	1.2803	103.0
9	0	50	5	30	1.0807	126.0
10	0	50	7	10	0.8126	87.0

11	0	50	7	15	1.5140	131.0
12	0	50	7	30	1.5051	121.0
13	1	0	5	10	0.9000	202.0
14	1	0	5	15	1.6080	224.0
15	1	0	5	30	1.5489	275.0
16	1	0	7	10	1.4169	246.0
17	1	0	7	15	2.6000	295.0
18	1	0	7	30	2.5625	330.0
19	1	50	5	10	1.6790	182.0
20	1	50	5	15	2.9100	206.0
21	1	50	5	30	2.5418	242.0
22	1	50	7	10	2.3906	209.0
23	1	50	7	15	3.8024	251.0
24	1	50	7	30	3.4418	252.0

4.1 Analysis of MRR

The ANOVA for MRR is in table 3.

Table.3. Analysis of variance for MRR

Source	DF	Adj SS	Adj MS	F Value	P Value
f	1	10.743	10.743	1373.6	0.000
θ	1	3.0934	3.0934	395.51	0.000
I_p	1	1.6097	1.6097	205.81	0.000
T_{on}	2	2.8035	1.4018	179.23	0.000
$f \times \theta$	1	0.5528	0.5528	70.68	0.000
$f \times I_p$	1	0.6136	0.6136	78.45	0.000
$f \times T_{on}$	2	0.5504	0.2752	35.19	0.000
$\theta \times I_p$	1	0.0035	0.0035	0.44	0.523
$\theta \times T_{on}$	2	0.1547	0.0773	9.89	0.005
$I_p \times T_{on}$	2	0.713	0.0356	4.56	0.043
Error	9	0.0704	0.0078	—	—
Total	23	20.266	—	—	—
R-sq= 99.65% R-sq(adj)=99.11% R-sq(pred)=97.53%					

Table.3 shows that all the p-values, except in case of interaction between aperture angle & peak-current, are in well below permissible range which is 0.05. Comparing the F-values, it is observed that F-value for vibration is way above than others. That's why, vibration has the maximum effect on MRR.

Fig.5 shows the mean effect of process parameters on MRR.

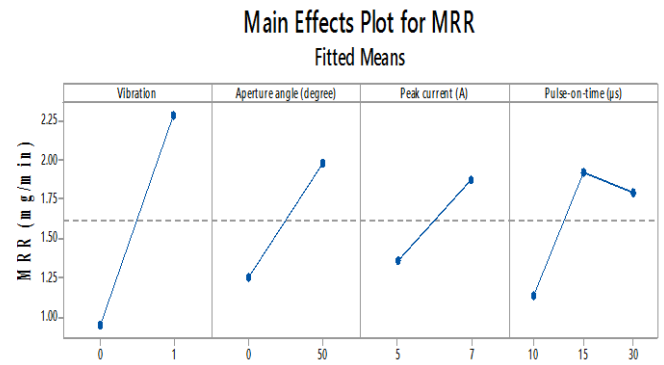


Figure 5. Main Effect Plot for MRR

Fig.5. shows that by applying work piece vibration the MRR has been almost doubled. In case of vibration, during the period of upward acceleration of workpiece, the debris in between tool & workpiece are pushed out of the machining zone. It makes the machining process more stabilized, the number of secondary spark decreases and thus higher percentage of total energy has been utilized to remove intended material. Also, continuous up-down movement of the workpiece results in the formation of vapor bubbles in a low-pressure region that bursts and finally contributes to material removal due to the cavitation effect.

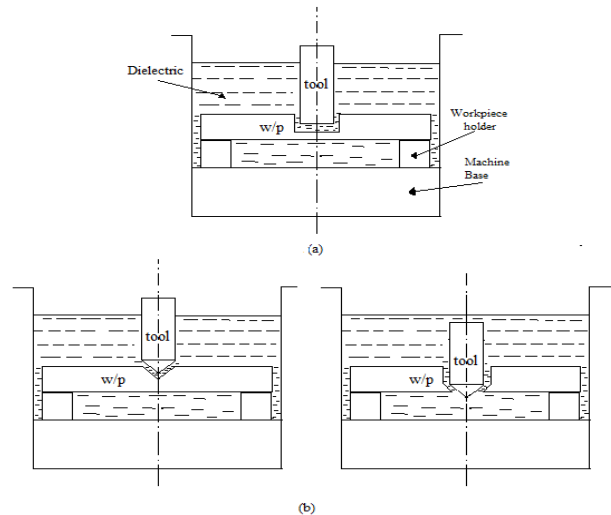


Fig.6. Drilling through hole with (a) Cylindrical tool (b) conical shaped tool

It has been observed that use of conical tool resulted in higher MRR. In case of conical tool, as shown in fig.6, the tool drills a conical hole first, and then in the 2nd stage the vertical portion of the tool finishes the hole drilling a cylindrical shape through hole. In the 1st stage, during conical hole drilling as the tip of the tool faces the workpiece, the energy density at the tip of the tool is very high and thus the material removal is also high. In the 2nd stage, the dielectric drains out through the hole which created in the 1st stage. This dielectric subsequently clears the debris from the machining zone. Thus, removal of debris from the machining zone makes machining more stabilized and increases the MRR. As in both of the stages the removal rate increases, the overall MRR of the process increases too.

As the peak current increases, the energy input also increases. That's why, the MRR also increases.

Fig.5 exhibits that, as the pulse-on-time increases from 10 μs to 15 μs, MRR increases sharply. As the pulse on time increases the discharge energy per pulse also increases and as the discharge energy increases the MRR increases. But, further as the pulse-on-time increases from 15 μs to 30 μs the MRR slightly decreases. As the discharge energy increases the size of the debris also increases.

These large sized debris are very difficult to flush out. Thus the debris, accumulated in the machining zone, retard the machining rate.

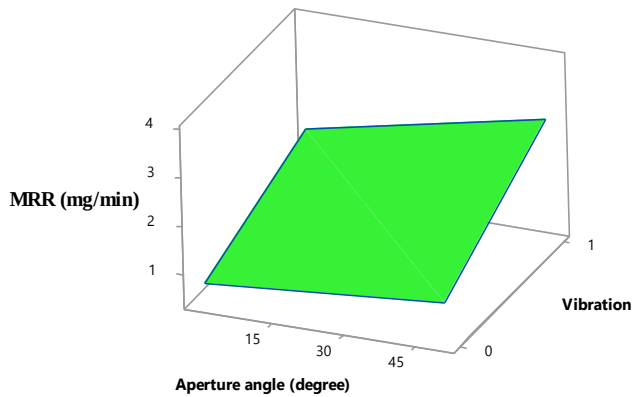


Figure 7. Surface Plot of MRR vs. aperture angle, vibration

The vibration and the aperture angle are the two parameters mainly emphasized in the research. That's why, the surface plot for these parameters has been shown in Fig.7. It is observed that, they don't have any significant interaction effect. The maximum MRR has been achieved when the tool is conical shaped and the workpiece have been vibrated.

4.2 Analysis of DOC

Table.4 shows the ANOVA table for DOC.

Table.4 Analysis of variance for DOC

Source	DF	Adj SS	Adj MS	F-Value	P-Value
f	1	87351	87351	2082	0.000
θ	1	6939	6939	165.45	0.000
I_p	1	6269	6269	149.48	0.000
T_{on}	2	12757	6378.5	152.07	0.000
f x θ	1	112	112	2.68	0.136
f x I_p	1	562	562	13.39	0.005
f x T_{on}	2	293	146.5	3.49	0.075
θ x I_p	1	1013	1013	24.14	0.001
θ x T_{on}	2	855	427.5	10.19	0.005
I_p x T_{on}	2	560	280	6.67	0.017
Error	9	377	41.9	—	—
Total	23	117088	—	—	—
R-sq=99.68% R-sq(adj)=99.18% R-sq(pred)=97.71%					

Table.4 shows that all the p-values, except in case of interaction in between vibration & aperture angle and interaction between vibration & pulse-on-time, are in well below permissible range which is 0.05. Work piece vibration has the maximum effect on DOC, as the F-value for vibration is the highest.

Fig.8 shows the mean effect of different process parameters on DOC

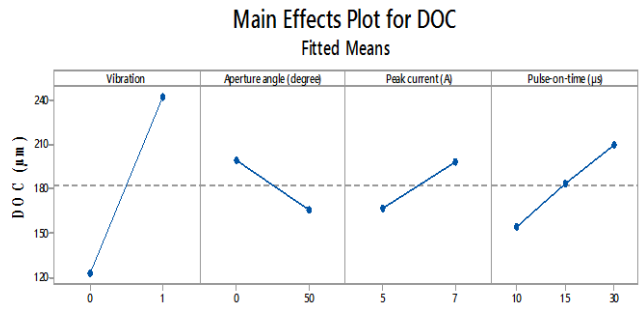


Figure 8. Main Effect Plot for DOC

From fig.8 it has been observed that as vibration increases DOC also increases. As shown in fig.9, there are two types of vibration, one is longitudinal which is desired and another is transverse which is not desired. Due to the erroneous inclusion of transverse vibration, the diameter of machined hole increases, which increases the DOC.

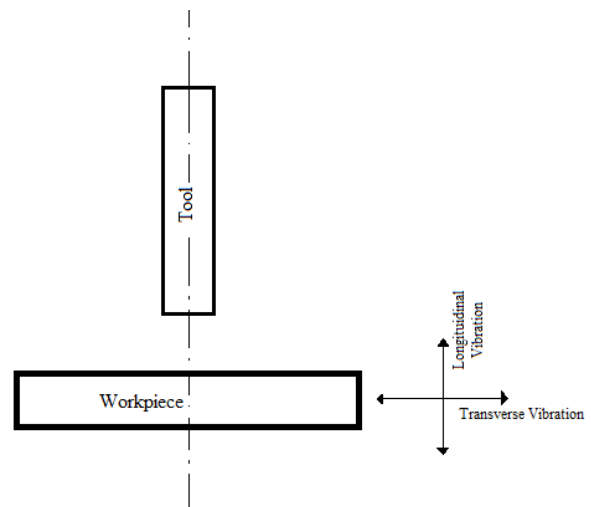


Figure 9. Direction of Vibration

Fig.8 shows DOC decreases due to the use of conical shaped tool. In case of cylindrical tool, there is a continuous interaction in between tool and final machined surface as shown in fig.6(a), but in case of conical shaped tool, the tool interacts with final machined surface only during 2nd stage which is very less than in case of cylindrical tool. That's why, in case of conical shaped tool, the final machined surface is exposed to side sparks for less time than cylindrical tool. Because of that, the DOC is less in case of conical shaped tool.

Fig.8 also shows as the peak current is increased, DOC also increases. As the peak current increases, the energy of the spark increases, simultaneously energy of side spark increases which ultimately increase the size of the hole and thus the DOC increases.

Also, the DOC increases as the pulse-on-time increases in a same way.

4.3 Machined Surface Analysis

Figure 10 & 11 shows the optical microscopic view of the machined surfaces at different parameter settings.

It has been observed from the Fig.10 that hole quality has been improved using the conical tool; as in case of cylindrical tool there is a continual interaction between the tool and machined hole, but in case of conical shaped tool, the tool interacts with final machined

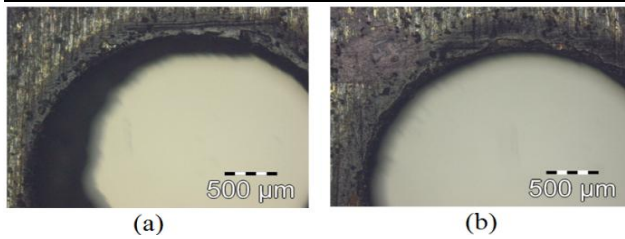


Figure 10. Microscopic view of machined surface for parametric setting $T_{ON}=10\mu s$, $I_p=5A$, without vibration
(a)Cylindrical tool
(b)Conical shaped tool

surface only during 2nd stage of machining as shown in Fig.6. It has also been observed from Fig.4 that in case of cylindrical tool the lower diameter is much lower than the upper diameter, i.e., the hole has a severe tapering action in case of cylindrical tool without vibration. It is also significant to observe that in both cases the hole has a substantial recast layer.

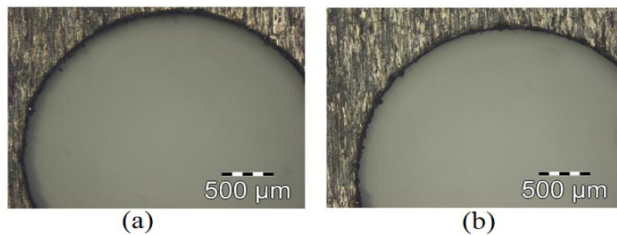


Figure 11. Microscopic view of machined surface for parametric setting $T_{ON}=10\mu s$, $I_p=5A$, with vibration
(a)Cylindrical tool
(b)Conical shaped tool

It is observed from the main effect plot of MRR that MRR has increased substantially using workpiece vibration, i.e., the machining time has been reduced. Because of that, the interaction time between tool and machined surface has also been reduced. Also due to workpiece vibration, the debris has been efficiently removed and thus the number of secondary sparks has been decreased. Because of this reason, it has been observed from Fig.11 that using vibration, the quality of hole has been improved a lot, both in case of cylindrical and conical shaped tool. Recast layer in this case almost has been diminished.

5. Conclusions

In the present research Ti6Al4V alloy, has been successfully machined. The effects of both, workpiece vibration and shape of the tool has been analyzed to achieve better machining rate and quality and from the study following conclusions have been drawn:

- The MRR almost has been doubled by the application of workpiece vibration,
- The MRR also has been substantially increased by using conical tool,
- It is also observed that peak current and vibration do not have any interaction effect on MRR. The maximum MRR has been achieved by using conical tool and vibrated workpiece,
- MRR has been increased with the increase of peak current,
- As pulse-on-time increases from $10\mu s$ to $15\mu s$ the MRR has been increased, but after that it has been decreased slightly,
- Workpiece vibration has a significant effect on DOC & it has been adversely increased by the application of work piece vibration because of error in vibration. Reduction in the error in vibration challenge to designing the work piece vibration device is to be undertaken.
- DOC has been decreased by using conical tool.
- It is observed that the DOC is minimum when no vibration has been applied and conical tool has been used.

- DOC has been increased with the increase of peak-current and pulse-on-time.
- It is observed that hole quality has improved slightly by using conical tool and the tapering of the machined hole also has been reduced by using conical tool.
- It is also observed that the recast layer almost has been removed by incorporating workpiece vibration.

Acknowledgement

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Improving the wear resistance of the meat comminutor knives by using the method of pulse-plasma hardening

Alexander Batrachenko¹, Nadiya Filimonova¹, Sergey Filimonov²
 Faculty of Computer-Aided Engineering and Design Technologies¹
 Faculty of Electronical Technologies and Robotics²
 Cherkassy State Technological University, Cherkassy, Ukraine
 avbatrachenko1980@gmail.com

Abstract: *The paper presents experimental results of hardening of the meat comminutor knives by using the pulse-plasma method. A search for existing methods for increasing the wear resistance of knives of meat-cutting machines has been carried out. The determination of the increase in wear resistance of the meat comminutor knives has been carried out according to the following stages: knives hardening; knives testing on the meat comminutor with the simultaneous execution of control prints; determination of the radius of blade curvature using an optical microscope and processing of research results. It is experimentally established that the use of the proposed method allows to increase the wear resistance of the meat comminutor knives by 4 times. Also, during the study, the optimal hardening modes of the meat comminutor knives are determined. The graphical dependence of the amount of knives wear on the presence and regime of hardening treatment is presented.*

KEYWORDS: MEAT COMMUNOTOR AND CUTTER KNIVES; INCREASE OF WEAR RESISTANCE, PULSE-PLASMA HARDENING

Introduction

Due to the widespread use of meat comminutors and cutters in meat processing, the considerable cost and insufficient durability of their knives, as well as their high metal consumption, the task of increasing their durability continues to be relevant. Numerous studies on the choice of the method of surface hardening of the cutting edges of meat comminutor and cutter knives are known, but they have a limitation on practical use, provide insufficient increase in durability and require significant investment or energy consumption. It is advisable to search for a more effective method of surface hardening of the cutting edges of knives of these meat-cutting machines [1-4].

A significant number of scientific papers [5] is devoted to the study of increasing the durability of meat comminutor and cutter knives. Chemical-thermal treatment is the most widely used in the study of increasing the durability of a meat-cutting tool. So, according to [5], to increase the durability of the cutting tool of meat-cutting machines, the chromium plating method, after processing by which the wear resistance of the cutter knives increases by 2-3 times, and that of the meat comminutor knives – up to 1.5 times, is recommended. Nitriding the cutting edges of the cutter knives leads to an increase in their wear resistance by 1.7 times. Insufficient increase in the durability of the meat-cutting tool can be considered the disadvantage of such methods of hardening.

Single-phase borating of the meat comminutor grids allows to increase their mean time between failures (MTBF) by 4-5 times. However, it should be noted that despite the advantages of chemical-thermal treatment (the simplicity of technical equipment), these methods have significant drawbacks – high energy and time costs. Also, as is known, borating leads to a significant increase in the fragility of the metal surface, which is not a significant drawback for meat comminutor grids, while for the cutting edges of the meat comminutor and cutter knives this leads to their increased chipping.

The effect of cryogenic reinforcement on the wear resistance of a cutting tool is investigated. An increase in durability of up to 2 times has been noted. However, the implementation of this method requires complex technical equipment, which has significant cost. Positive effect is not observed in all cases, which impedes the wide industrial use of the method.

Electrospark alloying of the surface layers of the cutting edge is another known method. Saturation of the knife material with alloying elements (W, Ti, Mo) allows to increase durability by 1.5-2 times [5, 6]. The disadvantages of this method include its insufficient effectiveness, which is caused by the absence of a complex effect (of heat treatment, surface plastic deformation, alloying).

A constructive method for increasing the durability of the meat comminutor knives, which consists in using the effect of selective transfer in a friction pair knife-grid due to the use of bronze inserts, is known [6]. Due to this, an increase in durability

up to 2.5 times is achieved. But it should be noted that for the application of such a solution it is necessary to manufacture special designs of knives, which creates a limitation in practical use.

An increase in durability of the cutter knives by 1.2-1.4 times is achieved after surface plastic deformation. Despite the simplicity of technical implementation of such an impact, an increase in durability up to 1.4 times cannot be considered significant.

Other methods of increasing wear resistance are also known [7-9].

Known technologies to increase the wear resistance of parts by pulse-plasma processing have been developed [10, 11]. The pulsed action is ensured by the use of explosives (gas) and the amplification of detonation waves by an electromagnetic field between symmetrically located electrode nodes. Also during processing, the surface alloying with metal electrode erosion products (molybdenum, tungsten) and gas (propane, nitrogen) occurs. As a result of this treatment, the wear resistance of machine parts increases by 3-5 times.

This technology has high efficiency (as with pulsed laser hardening), high productivity (0.5 m²/hour), significantly higher heating efficiency (0.8 versus 0.05), and an order of magnitude lower cost of technological equipment compared to laser hardening.

We can conclude that the known methods for increasing the durability of the meat comminutor and cutter knives have insufficient efficiency and high energy intensity. The application of the method of pulse-plasma hardening for this purpose is promising. However, in the well-known literature there are no quantitative data on increasing the wear resistance of knives of these meat-cutting machines after pulse-plasma processing.

The experiments results and their discussion

The aim of this work is to experimentally determine the increase in durability of the meat comminutor and cutter knives by means of hardening their cutting edges by pulse-plasma processing.

The determination of the increase in wear resistance of the meat comminutor knives was carried out according to the following stages: knives hardening; knives testing on the meat comminutor with the simultaneous execution of control prints; determination of the radius of blade curvature using an optical microscope and processing of research results.

For experimental studies, the WS-180 meat comminutor model was chosen. We have studied the wear resistance of four-blade single-sided knives with a right angle of sharpening of the cutting edge, which were made of steel 60C2 and passed the standard heat treatment for such knives.

Pulse-plasma hardening was carried out on the installation "IMPULSE" of the laboratory of the E. O. Paton Electric Welding Institute of the NAS of Ukraine. The operation diagram of the installation is shown in Fig. 1.

The detonation plasma generator consists of a detonation chamber 1, where the formation of a combustible gas mixture and

the initiation of its combustion in detonation mode are carried out; coaxial electrodes 2 and 3; power sources 4. In the process of accelerating the plasma formation, gas-dynamic and electromagnetic forces take part [7, 8]. As a result of detonation, partially ionized combustion products enter the interelectrode gap 5 from the detonation chamber and close the R–L–C circuit of the power source. The capacitor bank is discharging.

Between coaxial electrodes 2 and 3, a current flows through the leading volume of gas 6, the degree of ionization of which increases. The resulting plasma jet 7 acts on the treated surface 8. When the plasma pulse interacts with the surface of the product, the electric circuit between the central electrode and the surface of the product 8 closes, and in the contact zone, an area of shock-compressed plasma layer is formed.

The heat flux to the surface of the workpiece is controlled by the parameters of the R–L–C power source circuit, the distance H , and electrode recesses (Fig. 1). The recessing of the electrode mainly affects the diameter of the processing zone, thereby playing the role of focusing. This, in turn, allows to adjust the density of the heat flux at the same pulse energy. The maximum heat flux to the surface layers occurs when the product is an anode, and the minimum one – when the product is insulated. During pulse-plasma processing of an isolated product, a decrease in heat flow occurs.

Pulse-plasma processing allows to combine complex cyclic (1–10 Hz) pulsed ($t_{imp} = 0.2...0.6$ ms) effect on the surface of a solid: thermal (up to 10^6 W/cm²) and electromagnetic (current density up to 10 kA/cm², magnetic field strength up to $4 \cdot 10^5$ A/m) effects and plastic deformation. In this case, the plasma parameters are as follows: the plasma flow velocity is up to 6 km/s; the temperature is up to 20000 K.

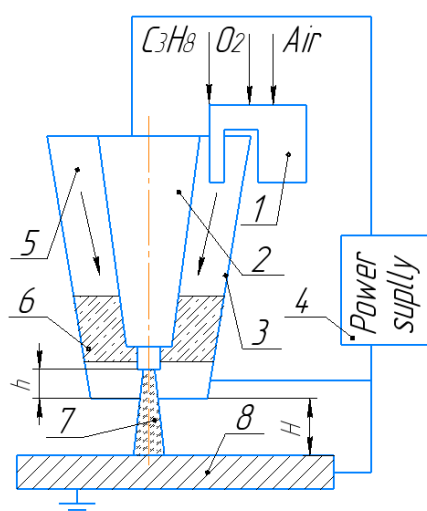


Fig. 1. The diagram of the installation "IMPULSE" for pulse-plasma processing

As a result of pulse-plasma treatment, fast heating (heating time is $10^{-3}...10^{-4}$ s) of the metal surface layer occurs, followed by its intensive cooling by removing heat into the metal volume. The high heating and cooling rate (up to 107 K/s) promotes phase hardening, the deformation of the surface layer and, as a consequence, the formation of a finely dispersed crystalline structure (for example, for carbon steel, the structure is represented by dispersed martensite needles of 160...300 nm), as well as high dislocation density ($\rho \sim 10^{12}$ cm⁻²). The resulting hardened layers have a characteristic size of up to 50 microns. It is also possible to introduce alloying elements (C, N, W, Mo, Cr, Ti, V, Al, etc.) into the plasma in the form of a vapor-droplet phase from a metal electrode (rod), fixed along the axis of the central electrode that erodes, and with the help of plasma-forming gas, which creates the conditions for chemical influence on the surface and plasma-chemical synthesis.

In this case, the hardening of the meat comminutor knives (Fig. 2) was carried out with the following parameters: the

capacitance of a capacitor bank of the discharge circuit $C = 800$ mF; voltage on the covers of the capacitor bank $U = 3.2$ kV; discharge circuit inductance $L = 30$ mF; pulse initiation frequency $\nu = 2.5$ Hz; the electrode material used is W. The duration of the interaction pulse was about 0.5 ms, and the heat flux density was $\sim 1.2 \cdot 10^5$ W/cm². In order to ensure the functioning of the hardened layer of the blade during the entire life of the knife, hardening was carried out with four-fold overlap on the front surface of the cutting edge, which during operation of the knife could not be re-sharpened (ensuring the effect of self-sharpening).

Three processing modes were used: No. 1 – 2 pulses per point, the part was grounded; No. 2 – 4 pulses per point, the part was grounded; No. 3 – 8 pulses per point, the part was grounded.

Fig. 2 shows a comparison of the bluntness of the cutting edge 1 and cutting edge 2, respectively, of the conventional and hardened meat comminutor knives of the WS-180 model, which are paired with a grid with an external diameter of 180 mm. It can be seen that the cutting edge 2 has a much less blunting.

After hardening, the knives were mounted on the meat comminutor and tested in operation before the first re-sharpening within 10 hours of machine time. Knives were tested at the production sites of the meat processing company LLC "Cherkassy Food Company". Meat raw materials for half-smoked sausages of the 1st grade were crushed; the meat comminutor of WS-180 model was used with a blade rotation speed of 5 s⁻¹.

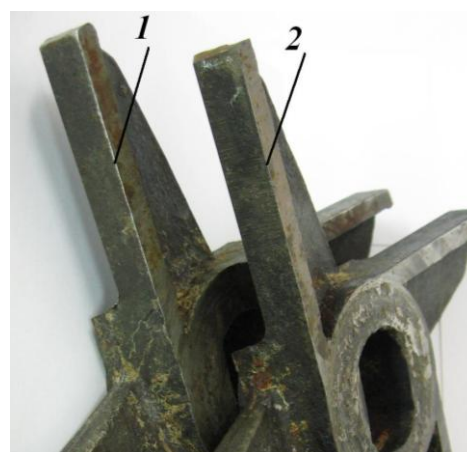


Fig. 2. The meat comminutor knives hardened by pulse-plasma processing (comparison of blunting of the cutting edge 1 of an ordinary meat comminutor knife and the cutting edge 2 of a hardened knife after 10 hours of use)

The determination of the amount of wear was carried out by determining the radius of curvature of the cutting edge of the blades. The radius of curvature was determined by the method of control prints [6]. To this end, during the operation of the knife, the imprints of the blades on lead washers were carried out. The point of measurement of the radius of curvature was chosen in the middle of the working length of the blade. An MBS-9 optical microscope with the magnification – $\times 56$, scale division value – 0.014 mm was used.

In Fig. 3 a graphical dependence of the amount of knives wear on the presence and modes of hardening treatment is shown.

It is established that pulse-plasma treatment of the meat comminutor knives has led to such an increase in their durability: knives hardened in mode 1 – 1.8 times; knives hardened in mode 2 – 3.2 times; knives hardened in mode 3 – 4 times.

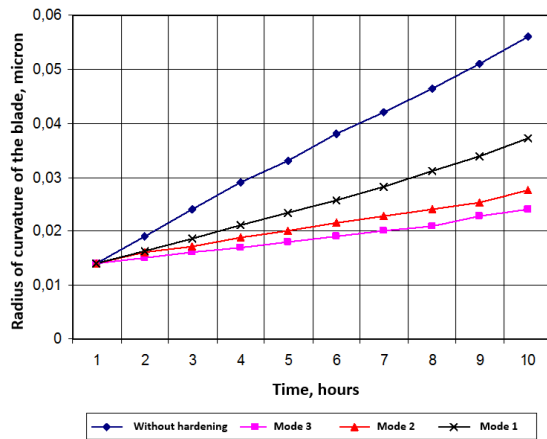


Fig. 3. Dependence of the amount of wear of the meat comminutor knives depending on the presence and modes of hardening treatment

Conclusion

The effect of pulse-plasma hardening on increasing the durability of knives of meat-cutting comminutors has been experimentally studied. It is established that when using the processing modes of the grounded part of 2, 4 and 8 pulses to the point, the increase in durability of the meat comminutor knives occurs 1.8, 3.2 and 4 times, respectively. Such a significant increase in the wear resistance of knives is due to the complex hardening effect of pulse-plasma treatment (thermal, electromagnetic effect and plastic deformation).

The experimental determination of structural changes in the material of knives as a result of pulse-plasma hardening with the aim of further optimization of processing conditions may be the direction of subsequent studies

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The importance of preventive thermographic inspections within periodic verifications of the quality of low-voltage electrical installations

Nedžad Hadziefendic¹, Jovan Trifunovic¹, Ivan Zarev², Nemanja Kostic¹, Marko Davidovic¹

School of Electrical Engineering, University of Belgrade, Belgrade, Serbia¹

Ministry of Interior, Government of the Republic of Serbia, Belgrade, Serbia²

E-mail: nedžad@etf.bg.ac.rs, jovan.trifunovic@etf.bg.ac.rs, ivan.zarev@mup.gov.rs, nmkostic@etf.bg.ac.rs, mdavidovic@etf.bg.ac.rs

Abstract: During the lifelong maintenance of low-voltage electrical installations in any facility special attention must be given to fire-causing failures, which cannot be detected by conventional protection devices (miniature circuit breakers, fuse-links, residual current devices, etc.). Such failures are most often caused by poor electrical contacts. International regulations and standards, which define periodic verification of the quality of low-voltage electrical installations, do not contain procedures by which a poor electrical contact would be detected at an early stage. However, one of the techniques used for this purpose today is performing preventive thermographic inspections (a standard covering this area is available only in the USA). By such inspections a poor electrical contact which creates prerequisites for the occurrence of an initial fire in a low-voltage electrical installation can easily and effectively be detected. Detected failures and irregularities can most frequently be eliminated by simple interventions of electricians or facility technical services. Experience from a large number of periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities, conducted by personnel of the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade, showed that many dangerous failures would not be detected without performing preventive thermographic inspections. Several practical examples of such failures, detected in low-voltage electrical installations in industrial and administrative facilities during preventive thermographic inspections, are presented and analysed. The procedure of performing preventive thermographic inspections within periodic verifications of the quality of low-voltage electrical installations, as well as the explanation for proper interpretation of the measurement results based on the ΔT and absolute temperature criteria, are also given in this paper.

Keywords: LOW-VOLTAGE ELECTRICAL INSTALLATION, POOR ELECTRICAL CONTACT, HOT SPOT, FIRE, INFRARED THERMOGRAPHY

1. Introduction

In order to prevent fire-causing failures of low-voltage electrical installations in a facility it is important to conduct periodic verifications of their quality using procedures defined in standards [1, 2]. However, there are some dangerous failures, such as poor electrical contact and series electrical arc, which cannot be detected either by conventional protection devices (miniature circuit breakers, fuse-links, residual current devices, etc.) or by inspection procedures defined in standards [3, 4]. In such cases, the application of infrared thermography for predictive/preventive maintenance of thermal defects of electrical components proved to be quite useful and efficient [5, 6]. A thermographic inspection, conducted using infrared thermal imager (infrared camera), enables the identification of "exceptions" – parts of electrical installations where the temperatures of the inspected electrical components deviate significantly from the expected operating ones [7]. Finding such exceptions allows targeted maintenance or elimination of problems before a fire and/or breakdown in an electrical system occurs. Therefore, it is recommended to include thermographic inspection in the procedure for conducting periodic verification of the quality of low-voltage electrical installations [8], although it is not included as a mandatory part of the procedure defined in standard [2] which is valid in almost all countries in Europe. Procedures given in standards covering this area in the USA [7, 9] should be taken into consideration.

2. Infrared thermography and its applications

All objects having a temperature greater than absolute zero (i.e. $T > 0K$) radiate heat (energy) in form of electromagnetic waves, in general case in continuous frequency spectrum. At room temperature most of that energy is radiated in the infrared spectrum, characterised by wavelengths longer than visible light (a typical human eye responds to electromagnetic waves the wavelengths of which are from about 380 nm to 740 nm). Therefore, that radiated energy cannot be perceived either by the human eye or standard cameras.

Although electromagnetic radiation in the infrared spectrum was investigated since 1800, the first infrared imaging device was

introduced in 1947 as a night vision camera for military purposes [10]. Such devices evolved into infrared thermal imagers – non-contact measurement equipment able to detect infrared radiations emitted from an object and, based on gathered information, give a thermal profile of the captured scene as an output.

Infrared thermography is an investigation technique involving thermal image acquiring using an infrared thermal imager followed by processing and analysing the obtained thermal data [10]. Due to the fast advance in the features of infrared thermal imagers, which has come together with their progressive cost reduction, the use of this technique has expanded to many industrial applications [11]. For example, it is used in civil engineering [12], mechanical engineering [13], manufacture of electrical [14] and mechanical [15] components, as well as in the detection of failures in electrical systems [16, 17] and assessment of the condition of electrical equipment [18, 19].

It is emphasised in [20] that poor electrical contact, loose connection, corrosion, rust, accumulation of dust, short circuit and overloading may lead to equipment failure and that most of those defects will generate excessive heat near the area of fault. Such thermal anomalies can easily be captured by an infrared thermal imager and by assessing the condition of the equipment any signs of failure can be identified [20].

3. Thermographic inspections – procedures and evaluation criteria defined in [7, 9]

3.1 Thermographic inspections – significance and procedure

As defined in [7], the purpose of a thermographic inspection is to identify and document exceptions in the electrical installation of the end-user (person or company requesting the thermographic inspection). Exceptions are usually caused by loose or deteriorated connections, short circuits, overloads, load imbalances or faulty, mismatched or improperly installed components. In order to successfully detect them, a thermographer (a person who is trained and qualified to use an infrared thermal imager) must have sufficient knowledge about the components, construction and theory of electrical systems to be able to understand the observed patterns

of the infrared radiation captured in a thermal image (thermogram). The obligation of the end-user is to provide (or help the development of) an inventory list of the equipment to be inspected in a logical and efficient route through the facility. In addition, the end-user must provide a qualified assistant (a person authorized by the end-user, who is familiar with the operation and history of the equipment to be inspected, as well as trained in all of the safety practices and rules of the end-user) who will accompany the thermographer during the thermographic inspection. The obligations of the qualified assistant are to obtain authorisation necessary to gain access to the equipment to be inspected, notify the operations personnel of the inspection activities, open and/or remove all necessary covers immediately before inspection by the thermographer, close and/or replace the cabinets and enclosure covers immediately after inspection by the thermographer, assure that the equipment to be inspected is under adequate load (ideally – normal operating load), create satisfactory loads when necessary, allow sufficient time for recently-energised equipment to produce stable thermal patterns, measure electric loads when requested by the thermographer, etc.

Thermographic inspections may be qualitative or quantitative in nature. Qualitative inspection implies gathering information about a structure, system, object or process by observing images of infrared radiation, and recording and presenting this information, while quantitative inspection implies precise measuring of temperatures of the observed patterns of infrared radiation. Whenever possible, measured temperatures of similar components under similar load should be compared to each other. Components exhibiting unusual thermal patterns or operating temperatures should be deemed as exceptions and documented with a thermal image and visible light image. If any exception is detected, its severity level should be evaluated, the cause of exception should be inspected and appropriate corrective actions should be taken as soon as possible.

3.2 Documentation for the performed thermographic inspections

The thermographer should provide appropriate documentation for all performed thermographic inspections. Written reports which will be given to the end-users should include the following information [7]:

- the name and any valid certification level(s) and number(s) of the thermographer,
- the name and address of the end-user,
- the name(s) of the qualified assistant(s) accompanying the thermographer during the inspection,
- the manufacturer, model and serial number of the infrared equipment used,
- a list of all the equipment inspected and notations of the equipment not inspected on the inventory list, and
- the date(s) of the inspection and when the report was prepared.

When a thermographer performs a qualitative thermographic inspection, the written reports which will be given to the end-users should include the following information for each exception identified [7]:

- the exact location of the exception,
- a description of the exception such as its significant nameplate data, phase or circuit number, rated voltage, amperage rating and/or rotation speed,
- when significant, the environmental conditions surrounding the exception including the air temperature, wind speed and direction, and the sky conditions,
- hardcopies of a thermal image and corresponding visible-light image of the exception,
- the field-of-view of the infrared imager lens,
- notation of any windows, filters or external optics used,
- if desired, a subjective evaluation rating provided by the qualified assistant and/or end-user representative, of the

importance of the exception to the safe and continuous operation of the system, and

- any other information or special conditions that may affect the results, repeatability or interpretation of the exception.

When a thermographer performs a quantitative thermographic inspection, the written reports which will be given to the end-users should include the following information for each exception identified [7]:

- the distance from the infrared imager to the exception,
- whenever possible, the maximum rated load of the exception and its measured load at the time of the inspection,
- the percentage load on the exception, calculated by dividing its measured load by the rated load,
- the emittance, reflected temperature and transmittance values used to calculate the temperature of the exception,
- when using ΔT (temperature difference) criteria, the surface temperature of the exception and of a defined reference and their temperature difference,
- when using absolute temperature criteria, the surface temperature of the exception and the standard temperature(s) referenced,
- if desired, an evaluation of the temperature severity of the exception, and
- if desired, a repair priority rating for the exception based on its subjective rating, temperature severity rating or an average of both.

3.3 ΔT criteria for electrical systems

To evaluate the severity level of a detected exception a thermographer may use the ΔT criteria given in Table 1 [7, 9]. Evaluations by ΔT criteria are based on the value of the measured temperature rise of the exception above the temperature of a defined reference, which is typically the ambient air temperature, a similar component under the same conditions or the maximum permissible temperature of the component. Recommended actions for each defined range of the measured temperature rise are also given in Table 1.

Table 1: Thermographic survey suggested actions based on the temperature rise (ΔT criteria) [7, 9]

Priority	Temperature difference (ΔT) based on comparisons between similar components under similar load	Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures	Recommended action
4	1°C–3°C	1°C–10°C	Possible deficiency; warrants investigation
3	4°C–15°C	11°C–20°C	Indicates probable deficiency; repair as time permits
2	-----	21°C–40°C	Monitor until corrective measures can be accomplished
1	>15°C	>40°C	Major discrepancy; repair immediately

3.4 Absolute temperature criteria for electrical systems

To evaluate the severity level of a detected exception the thermographer may also use the absolute temperature criteria defined in [7]. In that case, the thermographer uses the information about the defined maximum permissible temperatures for the inspected electrical components, which are given in various relevant standards. Reference [7] contains a list of relevant ANSI, IEEE and

NEMA standards, as well as relevant information ($T_{amb.}$ – rated ambient temperature, $T_{rated\ rise}$ – rated permissible temperature rise and $T_{max.}$ – maximum permissible temperature, all in °C (Eq. 1 applies)) taken from those standards for the most commonly used electrical components.

$$T_{amb.} + T_{rated\ rise} = T_{max.} \quad (1)$$

As an illustration, values $T_{amb.}$, $T_{rated\ rise}$ and $T_{max.}$ are given in Table 2 for some electrical components.

Table 2: Values $T_{amb.}$, $T_{rated\ rise}$ and $T_{max.}$ for some electrical components [7]

Electrical component	$T_{amb.}$	$T_{rated\ rise.}$	$T_{max.}$
THW (PVC), polyethylene, XHHW or RH-RW conductor insulation	30°C	45°C	75°C
Silicone rubber conductor insulation	30°C	95°C	125°C
Connectors and terminations (copper, copper alloy or aluminum)	40°C	50°C	90°C
Disconnects and switches	40°C	30°C	70°C
Miniature circuit breakers	40°C	30°C	70°C
Fuses with fuse links	40°C	30°C	70°C
Coils and relays (Class 90)	40°C	50°C	90°C

The thermographer measures temperatures across a given surface and compares measured temperature values of electrical components to the temperature values given in Table 2 (as well as to other relevant temperature values given in [7] and other relevant standards) and after detecting an exception evaluates the severity of its level and recommends corrective action. When the detected exception is composed of several adjacent components, the evaluation should be based on the $T_{amb.}$, $T_{rated\ rise}$ and $T_{max.}$ values of the component for which those values are the lowest. In addition, when several different $T_{amb.}$, $T_{rated\ rise}$ and $T_{max.}$ values for similar equipment are given in the relevant standards, the lowest temperatures (most conservative) should be used for the evaluation. In cases when the thermographer is unable to determine the class of insulation or equipment being inspected, the lowest $T_{amb.}$, $T_{rated\ rise}$ and $T_{max.}$ values (most conservative) within the component group should be used for the evaluation.

Unless noted otherwise, $T_{rated\ rise}$ and $T_{max.}$ values are valid for equipment operating at the stated $T_{amb.}$ and at 100% of their rated load (I_{rated} , in A). In many cases when the thermographer performs infrared inspections the ambient temperatures are lower than the stated $T_{amb.}$ and equipment operates at less than 100% I_{rated} , which is why the electrical component that possesses a potential problem that may cause its overheating does not reach the actual operating temperature (which would be reached at the stated $T_{amb.}$ and at 100% I_{rated}) during thermographic inspection. In such cases, the comparison of the measured temperature values of electrical components to the stated $T_{max.}$ values can mislead the thermographer to a conclusion that a potential problem does not exist and that corrective actions are not required. Therefore, in such cases it is necessary to compare the measured temperature values of electrical components to the corrected maximum permissible temperature ($T_{max. corr.}$) in order to detect an exception, evaluate the severity of its level and recommend appropriate corrective action. Value $T_{max. corr.}$ for the measured reduced operating load ($I_{meas.}$, in A) of the inspected electrical component and measured actual ambient temperature ($T_{amb. meas.}$, in °C, lower than stated $T_{amb.}$) can be calculated using Eq. 2 [7]:

$$T_{max. corr.} = \left(\left(\frac{I_{meas.}}{I_{rated}} \right)^2 + T_{rated\ rise} \right) + T_{amb. meas.} \quad (2)$$

4. Results and discussion

Experience from a large number of periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities, conducted by the personnel of the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade, showed that many dangerous failures would not be detected without performing preventive thermographic inspections [21]. Five practical examples of such failures, detected in low-voltage electrical installations in industrial and administrative facilities during preventive thermographic inspections, are presented and analysed. In each of them the measured temperatures of the electrical components showed that according to ΔT criteria given in Table 1 priority for corrective action was the highest (1), major discrepancy was ascertained and immediate repair was recommended because in each of them the temperature difference between similar components under similar load was far above 15°C and the temperature difference between the component and ambient air temperatures was far above 40°C. In addition, in each of the presented examples the measured temperatures of electrical components were far above $T_{max.}$ values defined for those components by the absolute temperature criteria. In some cases, danger can be eliminated by tightening the screws on the terminals of electrical components. However, in all of the presented cases poor electrical contact could not be eliminated this way, so the old components with permanently damaged contacts had to be replaced with new ones.

4.1 Practical example No. 1

This practical example represents the result of a thermographic inspection of a main switch of a switchboard feeding three floodlights, each with the rated power of 1200 W (Fig. 1).



Fig. 1 Thermal image (left) and corresponding visible-light image (right) of the detected exception (hot spot on one of the active phase terminals). [21, 22]

The detected exception (hot spot on one of the active phase terminals) can clearly be seen (the maximum temperature measured during thermographic inspection was 107°C). According to the measured temperature of the terminal, using ΔT criteria given in Table 1, it was concluded that the priority for corrective action was the highest (1), major discrepancy was ascertained and immediate repair was recommended, because temperatures of adjacent terminals did not reach more than 30°C (the temperature difference between similar components under similar load was more than 77°C – far above 15°C) and ambient air temperature did not reach more than 25°C (the temperature difference between the component and ambient air temperature was more than 82°C – far above 40°C). A similar conclusion was obtained using the absolute temperature criteria because the maximum temperature of the terminal measured during the thermographic inspection was 107°C, which was significantly above $T_{max.}$ value defined for connectors and terminations in Table 2 (90°C) and far above $T_{max.}$ value defined for

PVC conductor insulation in Table 2 (75°C). However, in standard [23] it is stated that the maximum allowed the temperature for PVC insulation is 70°C, and therefore, following the rules that when the detected exception is composed of several adjacent components, evaluation should be based on the T_{max} values of the component for which those values are lowest and when several different T_{max} values for similar equipment are given in the relevant standards, the lowest temperatures (most conservative) should be used for the evaluation, in this case $T_{max} = 70^\circ\text{C}$ is used, which is far below measured 107°C. By functional check of the condition of the terminal, it was found that it was mechanically damaged, so it had to be replaced with the new one.

4.2 Practical example No. 2

During a thermographic inspection of the switchboard from which the ovens were fed in a bakery, overheating of the contacts on the main switch was detected (Fig. 2). The maximum temperature measured during the inspection was 114°C. The interpretation of the measurement results based on the ΔT and absolute temperature criteria is the same as the one given for the practical example No. 1.

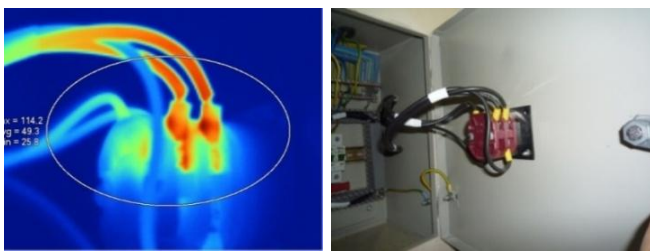


Fig. 2 Thermal image (left) and corresponding visible-light image (right) of the detected exception (overheating of the contacts on the main switch). [21, 22]

4.3 Practical example No. 3

This example was observed during a thermographic inspection of a ventilation cabinet in a heating substation. The contact temperature of one of the contactors in the cabinet was found to reach 107°C (Fig. 3). It was established that the contactors were very old and worn out. As the situation did not significantly change after the contacts were tightened, the replacement of the worn-out contactor with a suitable new one was recommended.



Fig. 3 Thermal image (left) and corresponding visible-light image (right) of the detected exception (poor contacts of worn contactors). [21, 22]

4.4 Practical example No. 4

A dangerous hot spot of temperature over 100°C was detected inside a distribution cabinet containing a poor electrical contact on the phase conductor terminal block (Fig. 4). The thermally damaged terminal block was immediately replaced.

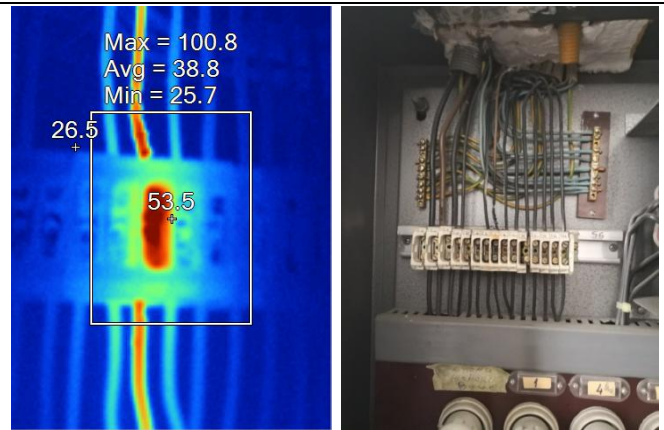


Fig. 4 Thermal image (left) and corresponding visible-light image (right) of the detected exception (hot spot on the phase conductor terminal block). [21]

4.5 Practical example No. 5

This is an example where a defective lamp was detected. The thermographic inspection showed that the lamp electromagnetic ballasts had temperatures exceeding 106°C (see Fig. 5). According to the information given in Table 2, T_{max} value for class 90 coils is 90°C. Also, according to [24] the maximum ballast case operating temperature specified by standards is 90°C.

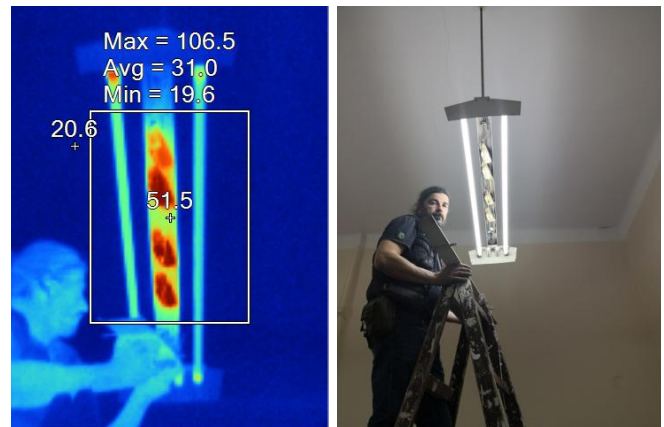


Fig. 5 Thermal image (left) and corresponding visible-light image (right) of the detected exception (overheated electromagnetic ballasts). [21]

5. Conclusion

Experience from a large number of periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities, conducted by the personnel of the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade, showed that many dangerous failures would not be detected without performing preventive thermographic inspections. In order to successfully detect them, a thermographer must have sufficient knowledge about the components, construction and theory of electrical systems to be able to understand the observed patterns captured in a thermal image. Finding such failures allows targeted maintenance or elimination of problems before a fire and/or breakdown in an electrical system occurs. Therefore, it is recommended to include thermographic inspection in the procedure for conducting periodic verification of the quality of low-voltage electrical installations, although it is not included in standards valid in countries in Europe. The procedure of performing thermographic inspections, as well as the explanation for proper interpretation of measurement results based on the ΔT and absolute temperature criteria, defined in standards covering this area in the USA, are also given in this paper.

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Estimation of structural similarity between plant-derived phenolic compounds and drug molecules by virtual screening of DrugBank

Merilin Al Sharif, Petko Alov, Ivanka Tsakovska, Tania Pencheva, Ilza Pajeva

Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences, Sofia, Bulgaria
merilin.al@biomed.bas.bg, petko@biophys.bas.bg

Abstract: Phenols are widely distributed in various plants and plant-derived foods. Currently, there is an increasing interest in their application as food supplements. In this study we performed a virtual screening to identify potential molecular targets of phenolic compounds derived from medicinal plants known for their antioxidant and anticancer effects. A dataset of 75 phenols, reported in the literature and a virtual library of 7770 unique drug compounds, extracted from the DrugBank database (<https://www.drugbank.ca/>) were used. Multi-conformer structure databases were created using OpenEye OMEGA, shape- and chemical-based overlays of the conformers were performed in OpenEye ROCS (<https://www.eyesopen.com/>). As a result of the virtual screening, followed by data filtration and analysis, two bacterial enzymes, responsible for DNA replication, were suggested as potential novel targets of a plant-derived hydroxyanthraquinone. This research allows outlining the potential receptor-mediated pharmacological mechanisms of phenolic compounds and aims to be a first step in the development of *in silico* protocol for their prioritisation as healthy dietary supplements.

Keywords: PHENOLS, DRUGS, VIRTUAL SCREENING, TARGET IDENTIFICATION, FOOD/FEED SUPPLEMENTS

1. Introduction

Recently, the therapeutic applications of phenolic compounds found in traditional medicinal plants, foods, nutraceuticals and species have gained an increased scientific interest [1-4]. The generally accepted concept for their antioxidant activity as a mechanism driving their beneficial actions has been enriched with increasing evidence for modulation of variety of molecular targets resulted in therapeutic effects on cancer, diabetes, cardiovascular and neurological diseases [5].

In silico screening approaches have proved their efficiency at early stage identification of putative targets of phenols [6-8]. DrugBank database [9] represents a useful source of structural and experimental data in virtual screening projects. The latter includes discovery of new retinoid X receptor alpha modulators [10], as well as identification of novel inhibitors of putrescine uptake in *Trypanosoma cruzi* [11] and of the breast cancer resistance protein [12].

In the current study, an application of a virtual protocol for target-fishing is reported. It involves estimating the shape and chemical similarity between the structures of 75 naturally-derived phenols, reported in the literature [13] and known drugs, deposited in the DrugBank database [9].

2. Data and methods

Two datasets were used in the study, including: (i) 75 phenols and (ii) 7770 drug molecules. The first dataset is comprised of structurally diverse antioxidant compounds used in the traditional Chinese medicine for anticancer therapy [13]. It includes flavonoids, stilbenes, coumarins, curcuminoids, lignans, quinones and phenolic acids. The information about drug structures and related molecular targets and actions were extracted from the DrugBank database, along with data on the status of the deposited medicines [9].

Preparation of the three-dimensional (3D) structures and the virtual screening were performed using programs of the OpenEye Scientific Software (<https://www.eyesopen.com/>). Multi-conformer structural databases were created using OMEGA v.3.1.1.2. [14], and the shape- and chemical-based overlays of the representative conformers were performed in ROCS v.3.3.1.2 [15].

3. Results and discussion

Here we present the application of a protocol for target identification in three main steps: (1) similarity-based searching of chemical structures; (2) ranking and filtration of the output data based on the obtained shape and chemical similarity scores; and (3) data curation by visual analysis of the overlays of phenols and DrugBank hits.

Step 1: At this step the flexibility of the molecules was taken into account by conformer generation in OMEGA, while the conformers' alignment was performed and ranked using the ROCS TanimotoCombo score (ranging from 0 to 2). The latter is a cumulative estimation of both the shape overlap of the conformers in the space plus the spatial alignment of chemically similar functional groups (e.g. hydrogen bond donor, hydrogen bond acceptor, cationic, anionic, hydrophobic and ring). As a result, 75 databases, one per each query phenolic structure, were generated. Each database was comprised of 500 top-scored paired overlays of phenolic and drug conformer, the latter designated as a hit.

Step 2: The highly scored hits were further filtered based on the drug status reported in the DrugBank database. Drug hits with status "withdrawn" were not included in the final set. By excluding drugs with status "investigational" or "experimental" the focus was placed only on hits with full documentation regarding the mechanism of action and the molecular target. Thus, only approved drugs with indication for oral administration were selected.

At this stage, a major problem arose, stemming from the significant number of plant phenolic derivatives among the known therapeutics. These drugs were identical or very similar in structure with many of our query phenols, therefore an exclusion of such "hits" was necessary to enrich the output with drugs which could potentially outline some new molecular targets. This dataset filtering procedure was performed by ranking based on the aforementioned overlay estimates. In particular, only matches with TanimotoCombo scores equal to or lower than 1.5 were considered with sub-optimal estimations of shape and chemical overlaps ranging between 50 and 80%. Duplicates of phenolic compounds or drugs were cleared up in the final compound library of query-hit pairs by preserving the lower scored matches for each phenolic query and the lower scored matches for each DrugBank hit.

Step 3: Analysis of the 3D representations of the overlays supporting the relevance of resveratrol derivatives [22], vitexin

Table 1: Estimations of shape and chemical similarity between the DrugBank hits and phenolic queries

No	DrugBank ID	Drug name	Phenol name	TanimotoCombo score
1	DB00292	Etomidate	5-methoxyfuranocoumarin	1.1
2	DB00890	Dienestrol	Daidzein	1.3
3	DB06292	Dapagliflozin	Daidzin	1.2
4	DB00655	Estrone	Naringenin	1.3
5	DB01044	Gatifloxacin	Pseudopurpurin	1.3
6	DB00783	Estradiol	Resveratrol	1.3
7	DB09038	Empagliflozin	Resveratrol-3-glucoside	1.1
8	DB08907	Canagliflozin	Vitexin	1.0

allowed for further data curation. Alignments based on matching of carbohydrate moieties only without alignment of aglycone substructures were considered irrelevant. Additionally, we considered a structural diversity in the query-drug pairs as a suggested prerequisite for discovery of new pharmacological targets. Thus, we selected combinations of 8 drugs with 8 phenolic compounds (Table 1), with TanimotoCombo scores ranging between 1.0 and 1.3.

The DrugBank records for the selected query-hit pairs were analysed in details. By filtering out matches with incomplete records, only pairs with full data regarding molecular actions were summarised in Table 2. The outlined drug hits have agonistic action on the human estrogen receptors, alpha-2B adrenergic receptor, gamma-aminobutyric acid receptor; antagonistic and/or inhibitory action on human sodium/glucose cotransporter 2; bacterial DNA replication inhibitory effect; positive allosteric regulatory role regarding human gamma-aminobutyric acid receptor and capacity of binding the human estrogen-related receptor gamma.

The related pathological conditions vary depending on the targets. Modulation of the estrogen receptors and the estrogen-related receptor were relevant to cancer, osteoporosis, genital disorders, and hypoestrogenism. By the similarity-based virtual screening we predicted putative relation to the discussed pathological conditions of the following phenols: naringenin, daidzein, and resveratrol. We outlined the sodium/glucose cotransporter 2, associated with type 2 diabetes treatment, as possible target of phenolic compounds like vitexin, daidzin, and resveratrol-3-glucoside. A group of drugs, used in conjunction to general anaesthesia, were paired with 5-methoxyfuranocoumarin thus linking this compound to the putative modulation of the alpha-2B adrenergic and the gamma-aminobutyric acid receptors. While the aforementioned conditions were related to human molecular targets, the estimated similarity between one natural hydroxyanthraquinone and synthetic suppressor of bacterial DNA replication was related to molecular targets in a pathogenic organism.

The established phenol-target relationships were evaluated by searching experimental evidence in the literature. In our analysis, predicted targets with supportive experimental data linking them to the corresponding phenol were out of the focus, since the priority was outlining novel targets. Therefore, the estrogen receptor-related activities of naringenin [16, 17], resveratrol and daidzein [18, 19] were excluded. Furanocoumarins have been discussed in the literature as modulators of the alpha-adrenergic [20] and the gamma-aminobutyric acid receptors [21], as well. Evidence

[23], daidzin [24], and esculin [25] to the sodium/glucose cotransporter 2 were also found. Two bacterial enzymes (Table 2, No 5), however, were outlined as putative new targets of a hydroxyanthraquinone from *Rubia cordifolia* L. [13]. The alignment of this phenolic compound and the corresponding DrugBank hit (ID: DB01044) received a TanimotoCombo score = 1.3, with 80% shape similarity between the structures and 50% matching between their characteristic functional groups. The good alignment of the novel phenol-drug pair is presented in Fig. 1.



Fig. 1 Overlay of hit (magenta) over query (cyan) structure.

The outlined drug hit represents a synthetic broad-spectrum antibiotic agent. The related pharmacological mechanism of prevention/treatment of bacterial infections in the respiratory tract involve suppression of DNA replication in Gram-positive and Gram-negative bacteria. Importantly, the phytochemicals from the chemical class of the anthraquinones have been known for their anti-bacterial effects [26]. In particular, biological activities against *S. aureus* and *B. subtilis* have been reported for the water extract of the medicinal plant *R. cordifolia* [27]. However, in our searches, no data was found for investigations on activity of *R. cordifolia* or the studied phenol against this Gram-positive bacteria.

The design of a food or feed supplement based on molecular scaffolds derived from medicinal plants requires comprehensive experimental analyses. Therefore, more studies are necessary to estimate the ability of the outlined phytochemical to bind and modulate the activity of the predicted bacterial targets without being harmful for the host organism, as well as to assess its bioavailability in mammals.

Table 2: Related molecular targets based on estimated similarity within phenolic compound-drug pairs.

No	Target	Phenol name	Drug name
1	Alpha-2B adrenergic receptor and Gamma-aminobutyric acid receptor	5-methoxyfuranocoumarin	Etomidate
2	Estrogen receptor alpha	Daidzein	Dienestrol
3	Sodium/glucose cotransporter 2	Daidzin	Dapagliflozin
4	Estrogen receptor alpha	Naringenin	Estrone
5	DNA gyrase and DNA topoisomerase IV	Pseudopurpurin	Gatifloxacin
6	Estrogen receptors (alpha, beta) and Estrogen-related receptor gamma	Resveratrol	Estradiol
7	Sodium/glucose cotransporter 2	Resveratrol-3-glucoside	Empagliflozin
8	Sodium/glucose cotransporter 2	Vitexin	Canagliflozin

By searching the predicted novel molecular targets among the Protein Data Bank (<http://www.rcsb.org/>) resources we found significant number of relevant crystallographic 3D structures of the proteins bound to their chemical ligands. Thus, our results present opportunity for further *in silico* studies of protein-ligand interactions. As a next step, virtual screening based on estimation of structural similarity and data mining techniques are foreseen to support the identification of the studied hydroxyanthraquinone among local ethnopharmacological sources or food ingredients.

4. Conclusion

In summary, our investigation underlined the combination of similarity-based virtual screening with data processing techniques as a promising multi-staged protocol for identification of novel targets even for well-studied molecules possessing wide range of biological activities and related molecular targets.

We predicted potential anti-bacterial molecular mechanism of a hydroxyanthraquinone from natural origin particularly leading to suppression of bacterial DNA replication. The proposed novel phenolic compound-molecular target pairs could direct the scientific efforts to development of healthy food or feed supplements with possible preventative/ therapeutic action on bacterial infections.

Overall, our study led to the estimation of potential receptor-mediated modes of action and presents a first step in the design of an *in silico* screening workflow for the discovery of lead structures bearing phenolic molecular scaffolds.

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Synthesis and investigation of BiTeSe single crystal doped with As obtained using bridgman method

Saša Marjanović¹, Emina Požega², Dragoslav Gusković¹, Danijela Simonović², Zdenka Stanojević Šimšić², Slavica Miletić², Milijana Mitrović¹

Technical Faculty Bor, University of Belgrade, V.J. 12, 19210 Bor, Serbia¹
Mining and Metallurgy Institute Bor, Zeleni bulevar 35, 19210 Bor, Serbia²
smarjanovic@tfbor.bg.ac.rs

Abstract: Researches in this paper included synthesis and characterization of bismuth telluride single crystal doped with arsenic, obtained using Bridgman method. Compounds based on bismuth telluride are very important materials for thermoelectric refrigerators and devices for electricity production. For the monocrystal characterization, SEM - EDS, Hall and Van der Pauw method were used. The results presented in paper show the synthesis of monocrystal ingot, BiTeSe doped with arsenic. An analysis of energy dispersive spectrometry (EDS) was used to determine the chemical composition of the samples studied, as well as checking and confirming the homogeneity of the samples. Measurements of X-ray diffraction (XRD) showed that the resulting crystalline ingot represent a single crystal and confirm the compound of Bi₂Te₃ type. Mobility, concentration, resistivity/conductivity, of majority of charge bearers and Hall coefficient of single crystal, were determined using a Hall Effect measurement system based on the Van der Pauw method. For the sample of BiTeSe doped with arsenic Hall effect was measured at room temperature with an applied magnetic field strength of 0.37 T at different current intensities. Further characterization of the BiTeSe sample doped with arsenic was not performed, because the expected improvement in the mobility of this sample in comparison with the theoretical value of the n type Bi₂Te₃, was not obtained.

Keywords: BISMUTH AND TELLURIUM SINGLE CRYSTAL, SEMICONDUCTOR, BRIDGEMANN METHOD, DOPING, SEM - EDS, HALL AND VAN DER PAUW METHOD

1. Introduction

Thermoelectric transport properties of doped Bi₂Te₃ have been examined for a long time [1 - 7].

Special attention has been paid to increase the thermoelectric figure of merit (ZT) for enabling the widespread use of this method for directly converting heat into electricity [8 - 12].

A parameter that evaluates the quality of thermoelectric materials, thermoelectric figure of merit, Z, is determined by the dimensionless value, ZT, [13 -15] which is defined as:

$$ZT = \frac{S^2 \cdot \sigma \cdot T}{k} = \frac{S^2 \cdot T}{k \cdot \rho} = \frac{S^2 \cdot T}{(k_e + k_l) \cdot \rho}$$

where: S - Seebeck coefficient, σ - electrical conductivity, k - thermal conductivity, T - absolute temperature, ρ - electrical resistance.

Thermal conductivity has two components: electronic conductivity, k_e , and lattice conductivity, k_l . The ratio $\frac{S^2}{\rho}$ is defined as the power factor and determines the electrical properties. Combinations of material properties required for thermoelectric materials to have quality and usable properties are also a challenge for scientists.

2. Experimental

Single crystal ingot of Bi₂Te₃ doped with arsenic was synthesized using the Bridgman method at the maximum temperature of about 600°C. High purity elements (5 N) were used as the source material. Tellurium (Sigma – Aldrich, 99.999%), bismuth (Sigma – Aldrich, 99.999%), selenium (Alfa Aesar, 99.999%) and arsenic (Koch-Light Laboratories Ltd Colnbrook Bucks England, 99.999%) were taken in a certain proportion.

The temperature gradient was 2°C/mm in the zone of heating and 5°C/mm in the zone of cooling. The ingot was grown at the speed of 2.2 mm/h.

The content of Bi, Te, Se and As in sample was obtained using Energy Dispersive X-ray Spectroscopy (EDS) analysis on a JEOL JSM 6610LV device equipped, which uses W wire or LaB₆ as the electron source and has Se, BSE, CL i EDS detectors. Measurements were made in the middle of the sample.

Hall effect measurements were conducted using the Hall Effect Measurement System Ecopia HMS-3000 at the Faculty of Technical Sciences, Novi Sad, Serbia.

3. Results and Discussion

The sample tested by the EDS method was cut from the ingot normal to the crystallization direction ($\perp$). In the following, this pattern will be referred to as 5/3 ($\perp$). The same sample was also used for the Hall and Van der Pauw measurements.



Figure 1. Schematic representation of the location from which the 5/3 ($\perp$) sample was cut from the ingot

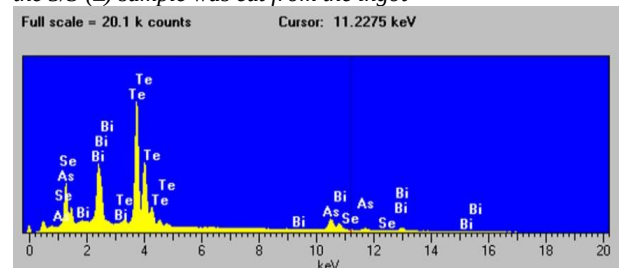


Figure 2. EDS picture of sample 5/3 ($\perp$)

Concentrations of elements in studied point are function of the peak areas at EDS diagram (figure 2.).

The experimental results of EDS chemical analysis of sample 5/3 ($\perp$) are shown in Table 1. The table shows that Se was not detected.

Table 1. Results of EDS analysis of sample 5/3 ($\perp$)

Element	Measurement values (atomic%)							Average value
Bi	16.39	20.06	17.82	21.46	23.06	20.02	17.45	19.46571
Te	68.74	62.71	63.7	62.88	62.36	62.94	62.59	63.70286
As	18.89	19.63	21.28	17.82	16.36	19.56	22.72	19.46571
Se	None							

The samples used for measurements were prepared to be in the form of thin disc (Figure 3.) cut perpendicular to the long axis of a single crystal ingot. All samples were carefully inspected for cavities and scratches and polished if necessary. All measurements were carried out at room temperature ($T = 300$ K). The source of magnetic field applied perpendicular to the Hall element was a permanent magnet of 0.37 T. Hall effect measurements were done to obtain transport properties.

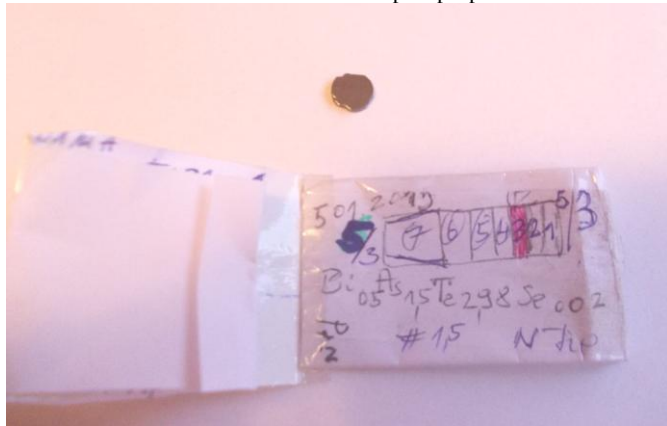


Figure 3. Cross-sectional view of a circular sample 5/3 (⊥), cut from the ingot

Table 2. The results of the Hall and Van der Pauw method for the sample 5/3 (⊥)

Current intensity I [mA]	Specific conductivity σ [$1/\Omega\text{cm}$]	Specific resistivity ρ [Ωcm]	Bulk carrier concentration n_b [cm^{-3}]	Sheet carrier concentration n_s [cm^{-2}]	Mobility μ [cm^2/Vs]	Average Hall coefficient R_H [cm^3/C]
0.1	$2.447 \cdot 10^1$	$4.086 \cdot 10^{-2}$	$-3.033 \cdot 10^{18}$	$-4.550 \cdot 10^{17}$	$5.036 \cdot 10^1$	$-2.058 \cdot 10^0$
0.5	$2.900 \cdot 10^1$	$3.448 \cdot 10^{-2}$	$-2.575 \cdot 10^{18}$	$-3.862 \cdot 10^{17}$	$7.030 \cdot 10^1$	$-2.424 \cdot 10^0$
1	$2.881 \cdot 10^1$	$3.471 \cdot 10^{-2}$	$-3.044 \cdot 10^{19}$	$-4.566 \cdot 10^{18}$	$5.908 \cdot 10^0$	$-2.051 \cdot 10^{-1}$
5	$2.914 \cdot 10^1$	$3.432 \cdot 10^{-2}$	$-2.442 \cdot 10^{19}$	$-3.662 \cdot 10^{18}$	$7.450 \cdot 10^0$	$-2.557 \cdot 10^{-1}$

The sample 5/6 (⊥) of circular cross-section is 1.55 mm thick.

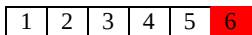


Figure 4. Schematic representation of the location from which the 5/6 (⊥) sample was cut from the ingot

Table 3. The results of the Hall and Van der Pauw method for the sample 5/6 (⊥)

Current intensity I [mA]	Specific conductivity σ [$1/\Omega\text{cm}$]	Specific resistivity ρ [Ωcm]	Bulk carrier concentration n_b [cm^{-3}]	Sheet carrier concentration n_s [cm^{-2}]	Mobility μ [cm^2/Vs]	Average Hall coefficient R_H [cm^3/C]
0.1	$1.484 \cdot 10^2$	$6.738 \cdot 10^{-3}$	$-1.499 \cdot 10^{18}$	$-2.324 \cdot 10^{17}$	$6.180 \cdot 10^2$	$-4.164 \cdot 10^0$
0.5	$2.401 \cdot 10^2$	$4.165 \cdot 10^{-3}$	$-5.412 \cdot 10^{18}$	$-8.388 \cdot 10^{17}$	$2.770 \cdot 10^2$	$-1.153 \cdot 10^0$
1	$2.974 \cdot 10^2$	$3.363 \cdot 10^{-3}$	$-2.321 \cdot 10^{19}$	$-3.597 \cdot 10^{18}$	$7.999 \cdot 10^1$	$-2.690 \cdot 10^{-1}$
5	$3.620 \cdot 10^2$	$2.762 \cdot 10^{-3}$	$-5.342 \cdot 10^{19}$	$-8.280 \cdot 10^{18}$	$4.230 \cdot 10^1$	$-1.168 \cdot 10^{-1}$

4. Conclusion

This paper was the result of testing the properties of an arsenic-doped bismuth telluride semiconductor monocrystalline compound. SEM-EDX, Hall's and Van der Pauw's methods were used for material characterization.

An arsenic-doped bismuth telluride monocrystal was synthesized. The electrical properties of this crystal were measured and the mobility and concentration of the majority charge carriers were observed. On the basis of the Hall coefficient, it was determined that in the monocrystal the majority carriers are electrons. The measured electrons mobility was significantly less than the electron mobility in pure bismuth telluride.

The results of these studies show that the arsenic-doped bismuth and tellurium monocrystal was successfully synthesized by the Bridgman method, and significantly complement existing knowledge of bismuth telluride single crystals.

The samples tested by the Hall and Van der Pauw methods were cut from different parts of the ingot normally to the crystallization direction (⊥). In the following, these samples will be referred to as 5/3 (⊥) and 5/6 (⊥), respectively.

The sample 5/3 (⊥) of circular cross-section is 1.5 mm thick

The concentration of the carriers and the mobility of the charge carriers for the studied samples 5/3 (⊥) and 5/6 (⊥) are given in Table 2. and Table 3.

Measurements were made at currents of: 0.1; 0.5; 1; and 5 mA. The concentration of charge carriers of both samples ranges from 10^{18} to 10^{19} cm^{-3} . The values of the Hall coefficient are negative, indicating that the samples are n-type and that the majority of charge carriers are electrons. The fact that the samples are n type is also confirmed by the hot spot method. The mobility of the majority charge carriers μ is less than the value of the mobility of bismuth telluride n type which is $1200 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ [16]. A large dependence of the mobility of majority charge carriers is observed on the change in current intensity, so that the mobility decreases with increasing current intensity. The samples are n type and the transport parameters refer to electrons as majority carriers.

Acknowledgement

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Thermal conductivity of the ceramic beehives

Lepkova, Todorka¹, Lakov, Lyuben², Martinova, Ivanka³, Martinova, Gergana⁴, Toncheva, Krasimira⁵
^{1,2,5} Institute of Metal Science, Equipment, and Technologies with Center for Hydro- and Aerodynamics "Acad. A. Balevski"
 Bulgarian Academy of Sciences, Bulgaria
^{3,4} Inovationtech Ltd, Bulgaria

Abstract: Beehive made of ceramic is a relatively novel concept in the feed of the beekeeping industry. One of the reasons behind the idea of changing the classical construction material of the beehives is the relatively better thermal conductivity of the ceramic material in comparison with the wooden. Previous field observations show that in wintertime the temperature in the ceramic beehive is with 1°C to 2°C warmer than the temperature measured in a wooden beehive from the same field. The present study aims to examine the thermographic characteristics of a ceramic beehive and to compare them with the most spread wooden type of hives. For the purpose, it was conducted a thermographic diagnostic of three beehives (two ceramic and one wooden) from the same field. The measurement is conducted with a thermal imaging infrared camera. For the analysis is used a licensed software FLIR Reporter Pro. The results of the comparative analysis show that in terms of balanced thermal distribution and creating a better internal environment, the ceramic beehives outperform the wooden one. What is more, the higher porosity of the ceramic material is proved to be a factor in the provision of a balanced thermal environment for the bee family.

KEYWORDS: CERAMIC BEEHIVE, THERMAL BALANCE, THERMAL DISTRIBUTION, BEEKEEPING

INTRODUCTION

The idea for a beehive made of ceramics starts its development in 2012 with the first theoretical research and expert evaluation. In 2014 the prototypes of the beehive are produced and inhabited. The results from the initial experiments have been published in 2019 [1]. This idea inspired by the ancient ways of beekeeping is reasoned with the comparatively better characteristics of the constructional ceramics over the wood. Until they are well known and already proven in the scientific literature, there are still no publications that examine the real living environment which the ceramic tiles structure creates within the beehive. There are several indicators by which it can be evaluated such as temperature and humidity [2].

GENERAL OVERVIEW OF THE PROBLEM

The temperature within the hive is an extremely important factor for the survival of the bees but also for the quality of the bee products. The researches show that the optimal temperature in the breed is around 35-36°C [3]. Higher temperatures can cause the death of the family. Lower temperatures especially temperatures below 0°C will lead to protective diapause behaviour or will have a lethal effect. The extreme temperatures affect the bee products as well. Overheating causes wax melting and too-quick dehydration of the honey [4] while the low temperatures slow down the dehydration of the nectar which causes problems in the production of the honey. The bees have own regulation mechanisms to maintain the healthy temperature of the hive. Whenever the weather is too hot, they start fanning the hot air out or use evaporative cooling mechanisms. If the temperature gets too low they start generating metabolic heat by contracting their flight muscles [5]. Both these mechanisms consume high energy of the bees and increase their need for food.

The specific physics and mechanical parameters of the ceramic material make it more preferable for construction purposes in comparison with the wood. Such are the better isolation properties; the pore "breathing" structure; the homogeneous clay mix which assures equal physical properties at each part of the tile; and the lower percentage of water absorption. This leads us to the assumption that the ceramic material would be a better option for ensuring a more balanced internal environment of the breed. To test this hypothesis, we have conducted a thermographic diagnosis of both ceramic and wooden beehives and compared the results.

METHODOLOGY

For thermographic diagnosis are presented three different beehives – two ceramic and one wooden. The ceramic breeds are 10-frames Dadant-Blatt type of hives. The four walls of the brood box are four ceramic tiles with a high cavity (>66%) which are connected with construction glue on cement basis with fiber

filaments. There are some constructional differences between both ceramic samples and the wooden hive. For the purpose of the present study they are labelled respectively Type 1, 2 and 3:

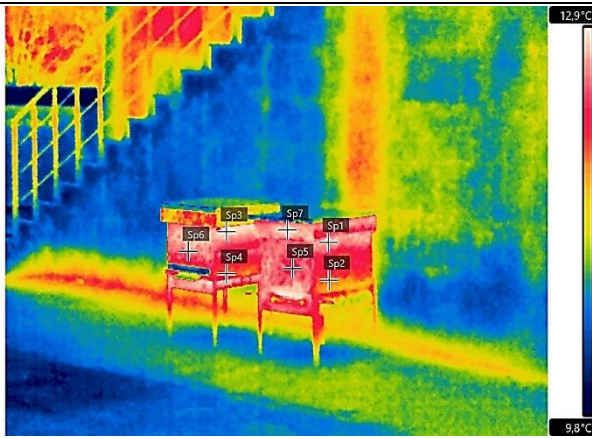
Table 1 Test models

	Brood box	Feeder	Roof	Floor	Stand
Type 1	Ceramics, high bottom	Wood	Wood covered with galvanized metal layer	Net, no thermal insulation	Metal
Type 2	Ceramics, deep bottom	PVC	Wood covered with galvanized metal layer	Net, 2 cm thermal insulation from expanded polystyrene	Metal
Type 3	Wood	Wood	Wood covered with galvanized metal layer	Net, no thermal insulation	Wood

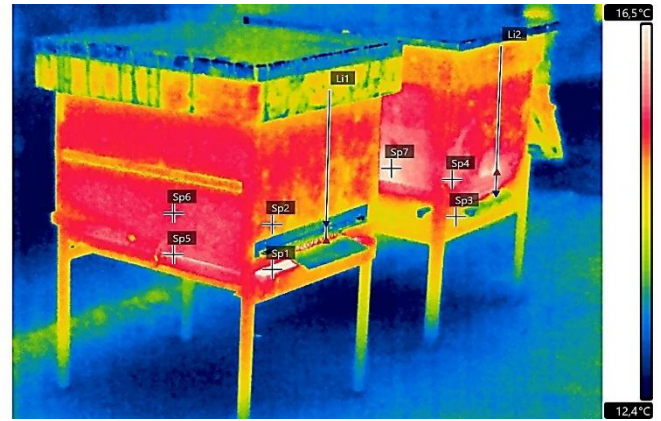
The measurement is conducted with a thermal imaging infrared camera. For the analysis is used a licensed software FLIR Reporter Pro. The measurement is conducted on November 13, 2019, in Chernoochene Village, Haskovo Municipality. The temperature outside is measured three times with Relative Humidity respectively: t= 9°C, RH= 96%; t=10 °C, RH= 95%; t= 11 °C, RH= 94%. The results from the capturing are colour images where the brighter tones stand for higher temperatures. For the purpose of the thermal diagnostics at the second stage of the measurement in each hive has been put a heat source (a bottle of hot water) in order to be observed the heat leakage and the heat distribution on the walls. The last stage of the diagnostics is capturing ceramic and wooden hives which are already inhabited with bees on the beekeeping field. The results obtained for all examined hives are compared.

RESULTS AND DISCUSSION

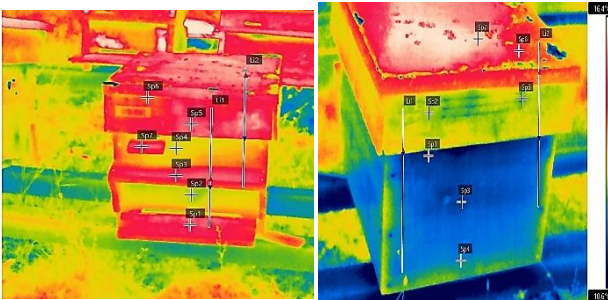
The beehives were first captured in their normal condition without bees inside.



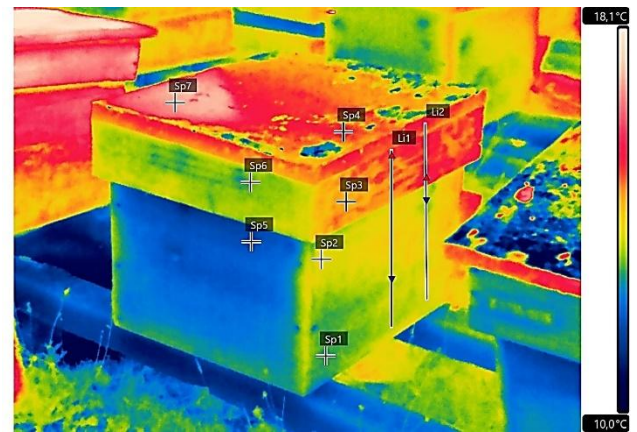
Picture 2 Ceramic beehives: Type one (left) and Type 2 (right)



Picture 3 Ceramic beehives with a heat source inside



Picture 3 Wooden beehive Type 3, Front(left and back)



Picture 4 Wooden beehive with a heat source inside

Table 2 Measured temperature in normal conditions

	Picture 1 [°C]	Picture 2[°C]	
		Front (T3)	Back (T3)
Sp1	12,7 (T2)	14,4	11,2
Sp2	12,0 (T2)	12,0	12,9
Sp3	13,0 (T1)	14,6	11,5
Sp4	12,1 (T1)	12,4	12,3
Sp5	12,3 (T2)	14,7	12,5
Sp6	12,7 (T1)	13,5	14,7
Sp7	12,8 (T2)	14,7	16,0

What can be observed from pictures 1 and 2 and the table with the measured temperature of the external walls leads us to the conclusion that the temperature of on the surface of the ceramic hive is distributed more balanced. The measured temperature in the different points of each ceramic hive have relatively the same values with a very small deviation. Differences are observed in the measured points where the element is made of wood. The entrance reducer of Type 1 is made of metal and this explains the lower temperature measured there. This information can be used for constructional improvements in the future. What we see in picture 2 is that the heat is not equally distributed in the front $Dt(Sp1-Sp2)=2,4^{\circ}C$, $Dt2(Sp3-Sp4)=2,2^{\circ}C$, $Dt3(Sp5-Sp6)=1,2^{\circ}C$ and back. The horizontal planes are heated more than the vertical (the walls) which we can say is due to more accumulated sun heat. The temperature differences could be explained with the wood's higher moisture absorption which accumulates different heat from the air. The higher measured temperature on the walls of the beehive can be due to sun exposure at the time the pictures have been taken. Considering the results for the temperature on the plane back of the wooden hive, it is obvious that although in one plane, the temperature in the different points is different which can lead us to the idea that there is moisture in the walls.

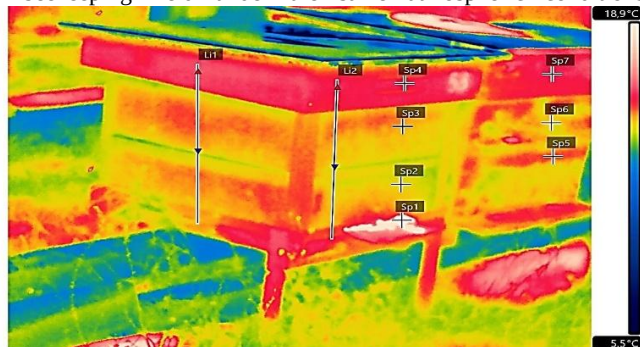
At the next stage at each of the beehives was put a heat source with the temperature of $39,9^{\circ}C$. The results after that are presented in Pictures 3 and 4 and Table 3.

Table 2 Measured temperatures when a heat source is put in the hive

	Picture 3 [°C]	Picture 4 [°C]
Sp1	17,3	13,0
Sp2	15,2	13,9
Sp3	14,6	14,5
Sp4	15,9	15,2
Sp5	16,3	11,9
Sp6	15,5	13,2
Sp7	16,6	17,0

Immediately before picture 3 was captured the heat source was moved from Type 1 to Type 2. The heat is moving from the internal walls to the internal cavity of the tiles where it heats the air and from there it moves to the external side of the tile. The heat in the two ceramic hives is distributed relatively balanced. The difference in Sp7 (Picture 3) is due to direct contact of the heat source to the hive's wall. The only imbalance is observed in the roof area which is made of wood. There is high contrast at Sp 1 (Pic.3) which is due to the exfiltration of hot air through the entrance reducer because it is not well compacted. The thermal decline drops significantly. Considering Picture 4, we see that the heat source leads to an increase in the temperature of those zones of the walls which are dryer. The backside of the wooden hive remains relatively cold ($Sp5=11,9^{\circ}C$). At this stage of the analysis, we can conclude that for the ceramic hives in both conditions (with and without a heat source) the heat distributes in even pace to all ceramic parts of the hive. On the other hand, the moisture in the wooden brood prevents this to be observed there. The temperature differences in the different parts of a same wall of the wooden hive make the air move which can cause swirling inside the brood. Such would create a disturbance of the bee family.

The last stage of the diagnostics is the comparison between inhabited ceramic and wooden broods. Both of them are on a beekeeping field under the same atmospheric conditions.



Picture 5: Inhabited hives: Ceramic (Left) and Wooden (Right)

Table 3: Measured temperatures in inhabited ceramic (left) and wooden (right) hives

	Picture 5[°C]
Sp1	22,4
Sp2	14,6
Sp3	14,9
Sp4	15,9
Sp5	15,4
Sp6	14,7
Sp7	16,0

The highest measured temperature is at point Sp1 which is due to the presence of bees there which have their own temperature so this point will be neglected during the analysis. The picture is taken at 10:58 when the temperature of the air is 9°C, RH=96%, wind <2m/s. The ground of the field is wet because of rain. Despite the high humidity of the air we can see that the heat distribution on the ceramic walls is relatively balanced. For the wooden hive, we see more clearly a difference in the different points of measurement. This can be explained with the accumulated moisture at some parts of the wooden walls and changes the thermal properties of the material. At the image, we observe that the wooden walls are not tempered evenly and homogeneously which is visible from the high contrast zones. Here should be considered the dynamic nature of the evaluated hives. The captures have been done at a given moment which is part of a continuous movement of energy streams which characterizes the energy exchange and interchange of the brood. In the picture, we see that some parts of the wooden hive, as well as the periphery of both roofs are coloured in contrasting red. We can explain this with the moisture which the wood keeps as the water has higher thermal capacity and stores the accumulated heat for a longer period in comparison with the dry wood. In the conditions of thermal transition when a process of heat exfiltration takes place, it is normal for the wet zones to appear warmer than the dry zones. When the walls are ceramic, the thermal transition waste is lower which decreases the need for the bee family to self-produce an additional quantity of heat.

CONCLUSION

The results from the present study show that if the classical wooden walls of the brood structure are changed with ceramic tiles with a high cavity, this would increase the thermal comfort of the bee family because it will ensure a balanced environment in the brood. This statement is derived from the fact that the surface heat of the examined ceramic hives is distributed evenly on each tile. The wood and the ceramics have different porosity and they absorb different quantity moisture from the air. The higher moisture resistance of the ceramic walls improves the living environment and decreases the risks of development of different harmful microorganisms. This may reflect also to the quality of the bee products. At the same time, the unbalanced moisture storage of the wooden walls leads to a change of the thermal coefficient of some zones of the walls. Evidence for this are the contrast zones displayed on image 4. The absorbed water changes the thermal properties of the wood and when in the brood is put a heat source, and a thermal difference between both sides of the wall is created, some zones of it remain colder. When the source is removed, we observe that the wet zones become warmer than the dry zones. When it comes to the ceramic hives such events are not observed.

Considering the results of the study we can conclude that for the examined hives, the ceramic ones have better and even heat distribution while the moisture absorption is relatively low. Both factors result in a better living environment for the bees, creating conditions for lower energy waste of the family.

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Peculiarities of the technological process in the preparation of metal powders

Ivanka Miteva

Technical University Gabrovo, 4. "H. Dimitar" Str., 5300 Gabrovo, Bulgaria
idmiteva_prestij@abv.bg

Abstract: This publication traces the peculiarities of metal powder production for powder metallurgy. Of the variety of methods, particular attention is paid to those that are most widely used in practice - reduction and powdering methods. Metallurgical photo of iron powders obtained by different technological processes are presented, as well as tables with the basic technological properties of iron powders obtained by reduction and powdering.

Keywords: POWDER MATERIALS, IRON POWDERS, POWDERING, REDUCTION, TECHNOLOGICAL PROPERTIES

1. Introduction

Since the beginning of the industrial application of metal powders in powder metallurgy, that is, since about 1930, a number of methods for their production have emerged. For various technical or economic reasons, some of these methods have not been industrialized at all and others have been used for a short time. Among the relatively short-lived methods used, however, which are an important step in the development of these processes, the Hammetag method and the electrolysis method should be mentioned. The Hammetag process is the grinding of soft metal wire to powder. It was used during the Second World War in Germany. The metal powder electrolysis process was developed in the mid-1940s in Sweden and England and has been applied for about 20 years. The iron powder obtained is characterized by high purity and very good compressibility.[3,5]

In this study, we traced the peculiarities of the technological processes for the production of iron powders by powdering and reduction, and also identified the main technological characteristics of the most common brands of powders.

2. Exposition

Of the many iron powder production methods, only two have lasted their technical and economic benefits: [3]

- ✚ the method of reduction;
- ✚ the powdering method.

The two methods have different modifications. In the reduction method, the modifications relate to the raw material used and to the completion of the reduction process. The raw material used is iron ore or slag, and the reduction process is carried out in one or two steps.

In a one-step process, the iron oxide is usually reduced with hydrogen in a belt furnace.

In the two-step process, also known as the Hoganes method, the iron ore (or slag) is first reduced by hard carbon in tunnel furnaces to sponge iron, which is then crushed and milled, and the resulting powder is thermally treated in a reducing medium and this leads to the final product.

The Hoganes method has been widely used in industry, using iron ore as a feedstock.

The method of producing iron powder by smelting melt was developed in World War II as the cheapest alternative to the Hammetag method. Initially, the jet of liquid metal was dispersed from a rotating water-cooled disc.

Subsequently, the use of kinetic energy of air, steam or water to convert the liquid metal to powder began - powdering. Today, the following modifications to this process are being applied in industry:[1,2]

- ✚ Air sputtering of molten cast iron - $C > 4\%$, followed by thermal treatment to decarbonise the material and reduce oxygen to the surface of the particles - the process is known as the RZ process;

- ✚ Granulation or powdering of high-purity cast iron melt to relatively coarse particles which, after milling in ball mills, are subjected to reduction-heat treatment to remove carbon and oxygen;
- ✚ Direct water spray melt of steel to powder with desired particle size, subjected to temperature treatment in furnaces with reducing medium. The production of iron and steel powders by this state-of-the-art method began in 1965 year in USA. Shortly thereafter, the same method began to be used at Hoganes (Sweden), Manesman-Pulvermetal (FRG) and Kobe Style (Japan). A variant of this method is the process developed by Sumitomo (Japan) to powdering with oil melt.

Of the elements of the first group, carbon is of greatest importance. High quality iron powders typically contain less than 0.02% carbon. The content of the other elements is also very low and depends on the type and quality of the starting materials used in the production of the iron powder. All iron powders contain certain non-metallic inclusions, but their amount is significantly lower in the powders obtained by powdering.

Table 1 shows the experimental results of the study of impurities in two of the most characteristic iron powders obtained by reduction and powdering.

Table 1: Experimental results for impurities in iron powders

Compounds, %	Iron powder type	
	NC100.24	ASC100.29
C	0,008	0,005
Mn	0,030	0,200
Si	-	0,020
Cr	0,002	0,080
Ni	0,020	0,040
Mo	0,0001	0,005
Cu	0,003	0,060
Sn	0,0003	0,006
SiO ₂	0,140	0,010
Al ₂ O ₃	0,190	0,010
TiO ₂	0,140	0,002
MgO	0,240	0,006
CaO	0,030	0,003

Several decades ago, there were only a few brands of iron powder for use in powder metallurgy. Today, more than 50 special types are available. This requires that the properties of the powders are very well known in order to select the most appropriate type for each case.

Pressability is undoubtedly one of the most important properties to consider when selecting the type of iron powder, as it determines the density that can be obtained when pressed, and hence the physical and mechanical properties of the product.[4] When we talk about pressability, we have in mind both sides - compactability and moldability. Tables 2 show the experimental results for the moldability of iron powders by pulverizing and reducing.

It is determined by the crude strength of specimens with a density of $6,5 \cdot 10^3 \text{ kg/m}^3$.

Table 2: Experimental results for the moldability of iron powders with a density of $6,5 \cdot 10^3 \text{ kg/m}^3$

№	Brand of powder	Method of preparation	Rm, MN/m ³
1.	MH 65.17	reduction	36
2.	MH 80.23	reduction	20
3.	NC 100.24	reduction	12
4.	EC 100.24	reduction	10
5.	SC 100.26	reduction	8
6.	AHC 100.29	powdering	6
7.	ASC 100.29	powdering	5

The crude strength depends on the particle structure and the compression pressure. This is primarily a technological feature related to the pressing operation. Pressed articles must be able to withstand the forces that they exert upon release from the pressing tools and must not be dipped when transported to the kiln. For all powders intended for the manufacture of low density products, the crude strength is a basic characteristic. Therefore, the ratio between the crude strength (the formability of the powder) and the compactness must be selected on a case-by-case basis.

It is known that the physic-mechanical properties of powder metallurgical products depend to a great extent on their porosity. It can also be assumed that impurities have the same effect on mechanical properties as pores. Spongy powders typically contain about 0,8% (by weight) impurities,

which roughly corresponds to 1,5% (by volume). High quality powdered material generally have less impurities. This means that in the manufacture of structural products by conventional methods, ie. with single and double pressing, the impurities have a negligible effect on the mechanical properties and the reducing and dusting powders can be used equally. However, where the aim is to obtain products with a very low porosity, or example below 3%, as in the hot forging method, the influence of impurities is harmful and dusts with a minimum of such content should be selected. Impurities are also undesirable when the products must have special physical properties - for example, magnetic materials. Then, high quality powders obtained by the water spray method are worked.

In tables 3 and 4 we have defined the main technological properties of the most used brands of iron powders.

Powder brands offered by different companies are in many cases comparable in their qualities, but very rarely could be completely replaced. This applies in particular to powders obtained by the melt powdering method. The production of quality powders by the reduction method is the exclusive monopoly of the Swedish company Hoganes, which uses high quality ore from a large field in northern Sweden as raw material. Reducing powders produced in the USA and Canada are also based on Swedish ore.

There is no generally accepted classification of iron powder brands. Each company uses its own designations. The letters of the Hoganes company indicate the method of manufacture (M, N and S - reduction, A - powdering).

Table 3: Experimental results for technological properties of reducing iron powders

Powder mark	Max. particle size, μm	Bulk density, $\cdot 10^3 \text{ kg/m}^3$	Max. flowability, s	Max. compaction at 420MPa, $\cdot 10^3 \text{ kg/m}^3$	Max. O ₂ , %	Max. C, %
MH 40.24	420	2,40	35	6,20	0,45	0,04
MH 40.28	420	2,80	33	6,35	0,35	0,04
MH 65.17	210	1,70	-	-	0,45	0,03
MH 80.23	180	2,30	35	6,19	0,55	0,10
NC100.24	155	2,45	32	6,40	0,30	0,02
SC100.26	150	2,65	30	6,63	0,15	0,01
MH 100.28	150	2,80	30	6,45	0,30	0,02
MH 300.25	50	2,80	-	-	0,35	0,02

Table 4: Experimental results for technological properties of powdering iron powders

Powder mark	Max. particle size, μm	Bulk density, $\cdot 10^3 \text{ kg/m}^3$	Max. flowability, s	Max. compaction at 420MPa, $\cdot 10^3 \text{ kg/m}^3$	Max. O ₂ , %	Max. C, %
AHC100.29	169	2,95	25	6,69	0,10÷0,20	0,01÷0,02
ASC100.29	170	2,95	25	6,82	0,10÷0,15	0,01÷0,02
WP150	200	2,80÷3,10	26	6,65	0,20	0,02
WP150HD	210	2,90÷3,20	30	6,81	0,15	0,01
WP400	400	3,00÷3,30	30	6,65	0,20	0,02
WPL200	200	2,50÷2,70	33	6,61	0,21	0,02
KIP260A	250	2,55÷2,75	35	6,60	0,20	0,02
KIP280A	200	2,70÷2,90	30	6,62	0,19	0,02
KIP300A	205	2,80÷3,10	30	6,70	0,20	0,02
KIP300AS	200	2,80÷3,10	30	6,78	0,20	0,02
300M	220	2,852÷3,10	30	6,64	0,25	0,02
500M	250	2,85÷3,10	30	6,65	0,25	0,02

The first group of digits is the particle size of the dust particles and the second group of digits is the bulk density. The letters of the company Manesman (Germany) also give information about the method of producing the powder (WP - water powdering), and the figures determine only the largest particle size in μm .

Of the reducing sponge iron powders manufactured by Hoganes (Sweden), the most widely used powder brand is NC 100.24. The powder compaction is very good. Due to its spongy structure, its formability is particularly high. Iron powder SC 100.26 has a very high density after single pressing and sintering. It is recommended to produce parts that will undergo chemical-thermal treatment. Unlike NC 100.24, the iron powder MH 100.28 has a high density. Thanks to it - $2,8,10^3 \text{ kg/m}^3$, it is preferable for the production of long and thin details in order to obtain a smaller bulk height. To adjust the bulk density of mixtures, MH 100.28 is often added to other grades of iron powder. At equal pressure, MH 100.28 gives a slightly higher product density than NC100.24. MH 80.23 is a specially created brand for the production of self-lubricating bearings. It has excellent formability. The crude strength of the pressed powder is 50% better than that of NC100.24. MH40.24 and MH40.28 are more coarse-grained than NC 100.24 and MH 100.28 and can be used when high requirements for the smoothness of the surfaces of the pressed products are not met. However, their crude strength is not as high as that of NC100.24. MH300.25 iron powder is often used as an additive to NC100.24 in the manufacture of structural parts when particularly demanding surface smoothness requirements are imposed. Such an additive is also useful when dust specimens are required. MH65.17 has very high formability - the crude strength of the pressed specimens is almost twice that of NC 100.24. It is mainly used in the production of friction materials.

The most common brand of iron powder obtained by the spray method is ASC 100.29. It is the highest quality iron powder brand. With its very high purity, it has excellent compaction, which allows a density of $7,2 \div 7,3 \cdot 10^3 \text{ kg/m}^3$ to be reached with a single pressing. It is especially suitable for the manufacture of high-density structural products, as well as for products with certain magnetic characteristics. Its use has a beneficial effect on the durability of the press tools. The AHS 100.29 iron powder has a very good seal. Its use is similar to SC100.26. WPL 200 is a high quality iron powder. It is characterized by high purity, very good sealability (at a pressure of 600 MPa a density of $7,0 \cdot 10^3 \text{ kg/m}^3$ is reached) and formability. WP150 and WP150HD are powders with very good sealability and purity. In terms of these characteristics, they are similar to the AHC100.29 and ASC 100.29 respectively. Their formability is worse than the WPL 200. The WP 400 iron powder has a larger particle size and is suitable for large parts. The KIP 260A iron powder has good formability and sealability. Its properties are similar to those of the WPL 200. The KIP 280A and KIP 300A powders are highly compacted. They are comparable to the WP150 brand. The KIP 300AS iron powder has high compaction and purity. It is particularly suitable for magnetic materials, is comparable to the WP 150HD and is close to the ASC100.29.

3. Conclusion

From the researches made about the dependence of the technological properties of iron powders on the way of their production, the following generalizations can be made for the choice of the type of iron powder in the manufacture of structural parts:

- ✚ Reducing spongy and iron powders are particularly applicable where particularly high density (eg anti-friction products) is required. Their use is obligatory when the product has to have high raw strength, as with some friction materials, with long and thin details, etc.;
- ✚ Medium-density products can be made with either sponge or powder. The choice for each case is made by technical and economic considerations;
- ✚ In the manufacture of high density articles, powdered iron powder with high compaction and purity is used. Powdered iron powder is also used in the manufacture of magneto-mechanical and hot-rolled products, since it contains less impurities.

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