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VEDECKÉ ČLÁNKY

MODELOVANIE PROCESU PRIEBEHU TECHNOLOGICKÝCH BRÁZD AKO NÁSLEDOK POHYBU LESNÝCH STROJOV

MODELING OF THE TECHNOLOGY RUTTING PROCESS DUE FOREST MACHINE MOVEMENT

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ABSTRACT: The soil is seen as a complex rheological system with the plastic deformation and abnormal viscous fluidity intense properties. Theoretical foundations of the soil compaction process modeling, due to iterative loading from the technological transport effects, are presented. These results are compared with field measurements data.

Key words: energy approach, rutting

ABSTRAKT: Pôda je považovaná za komplexný reologický systém s plastickou deformáciou a abnormálnymi viskóznymi vlastnosťami. V článku sú prezentované teoretické základy modelovania procesu zhutňovania pôdy v dôsledku interaktívneho zaťaženia technologickými dopravnými prístrojmi. Tieto výsledky sa porovnávajú s dátami merania v teréne.

Kľúčové slová: energetický PRÍSTUP, brazdy

INTRODUCTION

The mechanical behavior of soils is an extremely complex and multifaceted problem. The soil, as a solid deformable medium, is characterized by a considerable set of rheological properties. Depending on the conditions of the external force influence, the soil reveals, in particular: elastic deformation properties; sealing ability associated with phase composition's change; plastic deformation; viscous flow; the ability to degradation processes associated with wear, chipping, cutting of surface or internal masses (Danko&Křilek, 2015; Dvořák et al. 2011; Mikleš et al. 2012; Goldshtain 1971; Tsytoich 1983).

The study of the interaction of technological transport thrusters with ground surfaces of motion is due to works Byblyuk (2004); Styranivsky& Styranivsky (2010); Pytka, (2013). However, the process of such research is far from complete. Attempts to determine the real parameters of the interaction of the thruster with the soil, taking into account the

phenomena of creep and relaxation, are accompanied by significant methodological and technical difficulties (Fedorenchik et al. 2000). In this paper, the use of the energy approach (Yakhno& Machuga 2016) to obtaining engineering estimates of the process of formation of irreversible residual deformations in the soil is proposed.

MATERIAL AND METHODS

Consider the equilibrium state of a mechanical object, which in the ideal case is the combination of linear-elastic solids or non-inhomogeneous liquids; the contact between them is ideal, the mixing of individual components is not considered. It is generally known that the state of such a body is described by the variational equation:

$$\delta \dot{I} = 0 \quad (1)$$

where \dot{I} – the potential energy. Equation (1) is crucial for calculating the components of stress tensors, deformations and velocities of deformations and displacement vectors in each of the points of the body.

As you know, the potential energy \dot{I} is determined precisely to some constant U_0 – the internal energy of the body. The value of total mechanical energy of the body U is introduced as follows:

$$U = U_0 + \dot{I} \quad (2)$$

From equations (1) and (2), taking into account what U_0 is constant for ideal bodies, follows:

$$\delta U = 0. \quad (3)$$

Using the structuring of energy U as the sum of exergy Ex and anergy An (Yakhno& Machuga 2016), from (3) we obtain:

$$\delta (Ex + An) = 0 \quad (4)$$

It is proposed to modify equation (4) for the possibility of analysis of irreversible behavior of the body. The irreversibility is, that any deviation of the body from the position of the energy equilibrium, including virtual, is accompanied by a dissipative transformation of the part of the mechanical energy into the heat due to the occurrence of viscous and elastic-plastic processes in the body's volume. Energy transformations during arbitrary, including virtual, deviations of the body from the equilibrium position, cause an increase in energy relative to its initial value. In virtual processes

$$\delta An \geq 0. \quad (5)$$

By virtue of the law of conservation of energy, the exergy in such a virtual process decreases:

$$\delta Ex \leq 0. \quad (6)$$

By combining (5) and (6) we can obtain a generalized variational inequality for the body as a whole:

$$\delta(Ex - An) \leq 0, \quad (7)$$

where Ex_i , An_i – respectively, the exergy and anergy of all components.

Ratio (7) can be decisive in the study of mechanical processes and states of rheological bodies with substantial dissipative properties. Mathematical expressions of exergy and anergy should be formulated in each particular case of configuration, rheological properties and type of load of the objects under consideration.

The proposed approach is intended, in particular, for the interaction of the vehicle's thruster and the soil surface, taking into account the soil's fluidity. The interaction of a wheeled or crawler thruster with a movement's supporting surface – the soil, refers to rather difficult problems that arise in real conditions. As a result of such interaction – single or multiple – soil damages occur, which, as a rule, lead to formation of a track and other related negative consequences.

Let's consider the rolling process of a thruster on the soil surface (Figure 1), taking into account the various mechanisms of the rheological behavior of the soils listed above. The vehicle's thruster acts with force on a contact pad with a characteristic size $2R$ and area $S_{\hat{e}}$. As a result of this action, the supporting surface deforms by magnitude Δh . After removing the external load, the elastic deformations $\Delta h_{f,\delta}$ disappear, and the residual deformations $\Delta h_{\hat{c}\hat{a}\hat{e}}$ caused by different rheological processes remain. Among the residual deformations we select the following:

$$\Delta h_{\hat{c}\hat{a}\hat{e}} = \Delta h_{\sigma T} + \Delta h_{\mu} + \Delta h_{\hat{n}\hat{e}} + \Delta h_{\hat{c}\hat{o}} + \Delta h_{\hat{e}\hat{i}\hat{a}\hat{c}} + \Delta h_{\hat{a}\hat{i}\hat{e}\hat{e}\hat{i}\hat{a}\hat{c}}, \quad (8)$$

where $\Delta h_{\sigma T}$ – residual deformations caused by plastic deformation of soil masses, Δh_{μ} – residual deformations due to viscous flow of soil masses, $\Delta h_{\hat{n}\hat{e}}$, $\Delta h_{\hat{c}\hat{o}}$, $\Delta h_{\hat{e}\hat{i}\hat{a}\hat{c}}$, $\Delta h_{\hat{a}\hat{i}\hat{e}\hat{e}\hat{i}\hat{a}\hat{c}}$ – residual deformations caused by the processes of chipping, cutting, wear due to longitudinal and lateral sliding of the thruster. All these processes can be modeled in the framework of the energy approach, but the complete analysis of such a problem may become the subject of a separate study. In this section of the article, an engineering approach to building the characteristics of the process of rutting, taking into account the plastic and viscous properties of the soil, is illustrated.

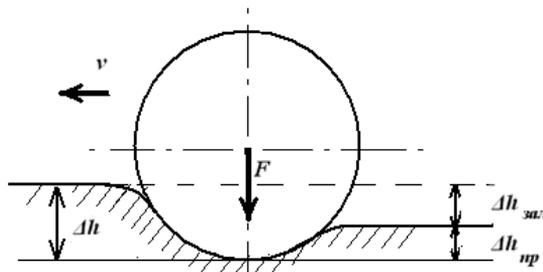


Fig. 1 General view.
Obr. 1 Všeobecný pohľad

Following (Tsytovich 1983), we will use the results of solving the classical Businets problem with respect to the influence of the distributed force on the elastic half-space [8]. In this case, the distribution of stresses will have a look, graphically represented in Figure 2 in the form of lines of identical stresses.

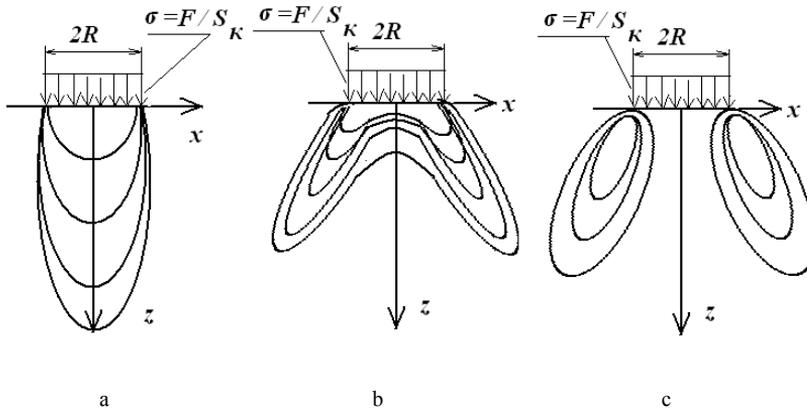


Fig. 2 Lines of the same stresses for the solution of the Businets problem a - vertical stresses σ_z , b - expansion stresses σ_x , c - shear stresses τ_{xz}

Obr. 2 Priebehy rovnakého napätia pre riešenie Businetskeho problému, a) vertikálne napätia σ_z , b) ťahové napätia σ_x , c) šmykové napätia τ_{xz}

Mathematical expressions of these values are given in Bozhydarnyk & Sulym (2012), in particular. From the analysis of the general type of stresses, it follows, that the growth of the external load over some limit leads to formation of the vertical consolidation of the plastic type directly under the thruster. The dimensions of this area depend on the contact area and the external force. Similarly, areas of horizontal consolidation and viscous flow are formed. According to the shapes of curves shown in Figure 2, it is proposed to model these areas approximately in the form of corresponding cylinder (σ_z) and torus (σ_x, τ_{xz}). Mathematical notation of the solution of this problem is rather complicated. To construct simplified expressions of exergy and energy of the investigated hydromechanical system, it is proposed to consider the deformed soil mass as an elastic cylinder of height H , compressed by vertical forces F and corresponding horizontal all-round pressure $\sigma = \frac{F}{S_\delta}$.

Potential energy of elastic deformation of such an object, which coincides with its exergy, taking into account the solution of cylinder's hydrostatic compression problem (Birger 1986, p. 476), we write down in the following way:

$$E_{i\delta} = Ex = \frac{F^2}{2S_\delta} \cdot \frac{2-\nu^2}{E} H \quad , \quad (9)$$

where E, ν – Jung's modulus and the Poisson factor of the soil environment, H – depth of the soil, on which the essential are the elastic deformations due to the force F action. By performing elementary transformations for the case of elastic deformation, we express

the external load F through the vertical displacement w of the point of application of force F :

$$F = w \frac{ES_{\dot{\epsilon}}}{H} \quad (10)$$

Taking into account (10) the expression (9) we write as follows:

$$E_{\dot{\epsilon}} = Ex = w^2 \cdot \frac{E \cdot S_{\dot{\epsilon}}}{H} \cdot \frac{2 - \nu^2}{2} \quad (11)$$

Applying the simplified configurations of areas of plastic deformation in the form of a corresponding cylinder and torus, we write the expressions of an energy for the considered dissipative processes. For a cylindrical area of plastic deformation in a vertical direction:

$$E_{\sigma T} = \sigma_T w S_{\dot{\epsilon}} \quad (12)$$

For a torus-like area of plastic deformation in a horizontal plane, taking into account the expression for the volume of the torus (Bronshtein & Semendiajev 1981):

$$E_{\sigma P} = \sigma_T \frac{w}{H} \cdot \frac{8k_1^2}{\sqrt{\pi}} S_{\dot{\epsilon}}^{3/2} \quad (13)$$

For a torus-like area of viscous flow:

$$E_{\mu} = \mu \pi \frac{w^2}{S_{\dot{\epsilon}} \cdot t} \cdot \frac{8k_2^2}{\sqrt{\pi}} S_{\dot{\epsilon}}^{3/2} \quad (14)$$

where σ_T – boundary of soil fluidity, μ – dynamic viscosity, k_1, k_2 – correction factors that take into account the deviation of the real volume of viscous or plastic deformation from the torus.

The expression of the energy for the case under consideration will be:

$$An = E_{\sigma T} + E_{\sigma P} + E_{\mu} \quad (15)$$

Using (11) – (15) in the variational inequality (7), in the case of progressive deformations of the contact surface we obtain:

$$w \leq \frac{\sigma_T \cdot S_{\dot{\epsilon}} \left(1 + \frac{8k_1^2}{\sqrt{\pi}} \cdot \frac{\sqrt{S_{\dot{\epsilon}}}}{H} \right)}{\frac{E \cdot S_{\dot{\epsilon}}}{H} (2 - \nu^2) - \frac{2\pi\mu}{S_{\dot{\epsilon}} \cdot t} \cdot \frac{8k_2^2}{\sqrt{\pi}} \cdot \frac{\sqrt{S_{\dot{\epsilon}}}}{H}} \quad (16)$$

where t – operation time.

Analyzing expression (16), we note the dependence of the motion surface deflection's deformation on the time, which is declining (Figure 3), that may indicate a consolidation of the soil mass.

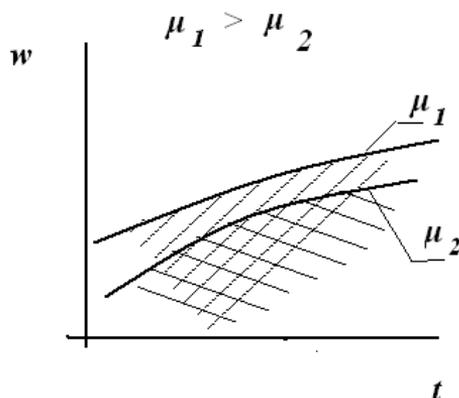


Fig. 3 Dependence of the motion surface points deformations on time for different values of soil viscosity μ

Obr. 3 Závislosť deformácií pohybových plôch v čase na rôznych hodnotách viskozity pôdy μ

The residual deformation is influenced significantly by the viscosity μ and yield strength σ_T , as follows from (16). The ratio (16) may, within certain limits, be used for theoretical and experimental studies of contact interaction of technological transport thrusters interacting with the reference surface – the soil.

DISCUSSION

Autors Ozgoz et al. 2006 reported that the increase in penetration resistance at 10-15 cm with increasing number of passes was 35.7% at the first pass, 39.85% at the third passes, and 8.6% at the fifth passes. Several researchers reported that relative increases in penetration resistance were at maximum after the first pass, whereas the second and further passes resulted in smaller increases in penetration resistance. (Ozgoz et al. 2006)

On dry soils with high bearing capacity, ruts remain shallow and the proportion of deep ruts is low. Furthermore, a high amount of logging residue decreases rut formation. (Sirén et al. 2013)

On wet harvesting sites with deep soils (gleys or peats), timber extraction is sometimes impossible due to low soil bearing capacity and increased machine sinkage, which impede mobility; hence, machine productivity is diminished (Horvat & Poršinsky 2001, Tiernan et al. 2003). Effective management of machine mobility, control of site disturbance, and moderation of potential soil damage due to wood harvesting and extraction machinery traffic requires characterization of the effects of the soil-machine interaction (Poršinsky et al. 2006). This interaction should take into account the influence of machine variables on a range of forest terrains that may be encountered (Nugent et al. 2003).

The residual deformation is influenced significantly by the viscosity and yield strength. The ratio may, within certain limits, be used for theoretical and experimental studies of contact interaction of technological transport thrusters interacting with the reference surface – the soil.

Another important issue is that, in practice, roads are planned by the machine operators. They try to avoid causing ruts, since ruts are considered to be a negative impact on soil and have undesired effects on forwarding operation. Consequently, operators actively choose to locate roads in areas that they perceive as having sufficient bearing capacity where passage is unavoidable, and try to reinforce the road surface. In other words, they are motivated to select appropriate road locations and reinforce them if they assume the road segment will be used by more traffic. This behaviour will influence the results of the survey and must be considered when interpreting the results. (Mohtashami et al. 2017)

This a obtained expression can be further elaborated by applying of more complete expressions of exergy and anergy for its formation, considering deformation processes that were issued here to simplify the demonstration of the application of the energy approach to such a class of hydromechanical systems.

CONCLUSIONS

Modern forestry techniques make heavy use of tires as tractive devices for nearly every field operation (Helexa, 2014). As a mechanical device, the traditional lugged forestry tire is rather inefficient at converting the torque and speed at a tractor axle into force and linear motion at the drawbar. Over the last 25 years, an increased focus on soil compaction has also renewed interest in the tractive efficiency of the tire. Despite advances made throughout that time, there is still an opportunity to improve the efficiency of the modern forestry tire. To take advantage of this opportunity, more data are required to understand the current method of traction generation to allow better decisions to be made during the tire development and design phases.

Setting tasks for structurally inhomogeneous hydromechanical systems in real processes taking into account dissipative factors requires the structuring of energy resource, as the sum of exergy and anergy. This leads to the formulation of the corresponding variational inequalities.

Important for environmental and practical reasons while designing roads for land transport is the task to evaluate the intensity of the rutting process due to the movement of technological transport by ground surfaces. The important theoretical results, which have considerable practical interest and can give impetus to a number of experimental studies that are complicated during the application of the vector-force approach to the above and other classes of problems, are obtained.

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CORROSIVE-MECHANICAL WEARING OF SAMPLES FROM HIGH-SPEED STEEL FOR WOODWORKING TOOLS WITH VACUUM-PLASMA COATINGS

KOROZÍVNO-MECHANICKÉ OPOTREBENIE VZORIEK Z RÝCHLOREZNEJ OCELE PRE DREVO REZNÉ NÁSTROJE S VAKUOVO-PLAZMOVÝM POVLAKOM

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ABSTRACT: The work is dedicated to the study of corrosion-mechanical wear of specimens made from high-speed steel with vacuum-plasma coatings in the condensate environment of wood pyrolysis products. Multicomponent nanostructured vacuum-plasma coatings applied to samples of high-speed steel. The methodology was developed and corrosion-mechanical tests of samples with vacuum-plasma coatings in a condensate environment of wood pyrolysis products were carried out. Indentation in the form of rhombus was applied to the surface of the samples with the aid of a micro-hardness meter. Wear was evaluated by decreasing the lengths of the indentations diagonals. The investigated vacuum-plasma coatings increase the corrosion-mechanical resistance of the samples in a condensate environment of pyrolysis products of hardwood.

Keywords: high-speed steel; vacuum-plasma coatings; wood pyrolysis products; corrosion-mechanical wear;

ABSTRAKT: Práca sa venuje štúdiu korozívno-mechanického opotrebovania vzoriek vyrobených z vysokorychlostnej ocele s vákuovo-plazmovým povlakom v kondenzátovom prostredí produktov pyrolýzy dreva. Na vzorky z vysokorychlostnej ocele sa aplikovali viaczožkové nanostruktúrované vákuovo-plazmové povlaky. Bola vyvinutá metodika a boli vykonané korozne-mechanické skúšky vzoriek s vákuovo-plazmovým povlakom v kondenzátovom prostredí pyrolýznych produktov z dreva. Na povrchu vzoriek sa pomocou mikrometra naniesla väzba vo forme kosoštvorca. Opotrebenie sa vyhodnotilo znížením dĺžok diagonál. Skúmané vákuovo-plazmové povlaky zvyšujú korozno-mechanickú odolnosť vzoriek v kondenzátovom prostredí produktov pyrolýzy tvrdého dreva.

Kľúčové slová: rýchlerezná oceľ; vákuovo-plazmové povlakovanie; produkty pyrolýzy dreva; korozívno-mechanické opotrebenie.

INTRODUCTION

Wood and wood materials have low thermal conductivity. Most of the evolving in the cutting process heat is absorbed by the tool blade. The blade of the wood cutting tool can be heated to a temperature of 150-350°C (Sheikh-Ahmad et al. 2003; Horman et al. 2014; Pei et al. 2016). Thermal degradation of the wood (pyrolysis) takes place with such a temperature (Di Blasi 2008; Cabalová et al. 2015). The initial stage of the decomposition of wood proceeds at a temperature of 150 to 270°C (Mohan et al. 2006).

Corrosion and mechanical abrasion of the blade are one of the main factors of wood-cutting tool wear (Klamecki 1978; Zotov&Pamfilov 1991; Porankiewicz et al. 2005). This type of wear is called corrosion-mechanical or tribocorrosion (Sorokin et al. 2002).

The main attention of scientists was previously directed to the study of instrumental materials tribocorrosion in the environment of wood material extract. In this case, electrochemical methods of research were used mainly (Watson et al. 1995; Landolt et al. 2001; ASTM standard G119 2002; Mischler 2008; Darmawan et al. 2012; Pamfilov& Prozorov 2012).

Studies of the interaction of instrumental materials with wood pyrolysis products are few. These studies were performed by dipping steel samples in the pyrolysis products environment and were not accompanied by mechanical abrasion (Moiseev 1981).

One of the directions increasing wear resistance is the use of vacuum-plasma coatings based on titanium nitride (TiN) with high hardness and corrosion resistance for wood-cutting tools (Sheikh-Ahmad& Morita 2002; Rudak et al. 2015; Latushkina et al. 2016). Doping of vacuum-plasma coatings based on TiN with aluminum (coatings AT12, AT13) or copper (coating AT72) makes it possible to increase the microhardness of the coating (Latushkina et al. 2015).

The purpose of the study, the results of which are presented in this paper, was to investigate the corrosion-mechanical wear of specimens made from high-speed steel with vacuum-plasma coatings in the condensate environment of wood pyrolysis products.

MATERIAL AND METHODS

During the experiments, the condensate of hardwood pyrolysis products was used (produced in Belarusian State Technological University, Belarus).

High-speed steel P6M5 (HS6-5-2) was chosen as a tool steel for testing. Samples in the form of plates measuring 50x30x3mm were cut from a metal cutting mill. Blanks from high-speed steel were leveled by abrasive processing and subjected to fine grinding with

attaining an average roughness parameter $R_a = 0,036 \mu\text{m}$ (arithmetic mean deviation of the assessed profile). The Struers LaboPol-5 grinding and polishing machine with a complex rotational motion and loading dosing device Struers LaboForce-3 (Struers GmbH, Denmark) was used for processing. The parameters of the roughness were controlled by the profilograph-profilometer Mitutoyo SurfTest SJ-210 (Mitutoyo Corporation, Japan).

The deposition of the coatings was carried out on a vacuum arc machine URMZ.279.048 (Smorgon Optical Machine-Tool Building Plant, Belarus) equipped with a particle separator (Physical-Technical Institute of the National Academy of Sciences, Belarus). Three types of multicomponent vacuum-plasma nanostructured coatings based on titanium nitride (TiN) were applied: TK12, TK13 (TiN/Cu) and AT72 ((Ti, Al)N). Coatings were formed by simultaneously spraying two cathodes, one of which was always titanium. The nitrogen pressure is $0,4 \times 10^{-2}$ Pa in the vacuum-arc device camera. The arc current for the titanium cathode was set at 55 A, for the additional cathode of copper for the TK12 coating was 70 A, for coating TK13 was 50 A. For the additional aluminum cathode for AT72 coating, the arc current was 50 A.

The thickness of the coating was determined using a microinterferometer MII-4 (JSC "LOMO", Russia). The hardness of the uncoated samples was determined on a hardness tester DuraJet (EMCO-TEST Prüfmaschinen GmbH, Austria) by the Rockwell method, C scale. The microhardness of the coatings was measured on a microhardness meter DuraMin 5 (Struers GmbH, Denmark) at a load of 25 g. Measurements of all parameters were performed at least 10 times and received average values.

To carry out studies of corrosion-mechanical wear, the samples of high-speed steel were pressed into thermoset phenolic resin Struers MultiFast (Struers GmbH, Denmark) with wood filler in cylinders with a diameter of 30 mm.

An automatic electro-hydraulic press for hot pressing Struers CitoPress-1 (Struers GmbH, Denmark) was used.

Tests on the corrosion-mechanical wear of samples from high-speed steel with multicomponent vacuum-plasma nanostructured coatings in a condensate environment of hardwood pyrolysis products were carried out in an experimental installation based on the LaboPol-5 (Struers GmbH, Denmark) grinding machine, complete with a complex rotational motion and dosing load LaboForce-3 (Struers GmbH, Denmark).

As a counter body, the Struers MD Mol (Struers GmbH, Denmark) disk was selected.

The disk is made of woven taffeta (100% wool), has high elasticity and low hardness (Struers Metalog Guide 2012). Its use makes it possible to reproduce in experiments conditions close to the effect of wood fibers.

To ensure during the tests the speed of the relative movement of the test specimens on the counter body, corresponding to the speed of interaction drill with the material being processed, it is necessary to ensure the rotation frequency of the counter body of 150 min^{-1} .

Three different samples were tested simultaneously. Force of pressing one sample to the disk 10 N.

As a parameter of corrosion-mechanical wear, the reduction in the length of the rhombic indentations diagonals on the samples surface was chosen. The prints were obtained by an indenter in the form of a regular tetrahedral diamond pyramid with an angle of 136° between opposite faces. The indentation and measuring the diagonals lengths was carried out on a microhardness meter DuraMin 5 (Struers GmbH, Denmark).

The samples were imprinted with an indentation force of 4,903 N (mean depth of indentation 4,47 μm) and 490,3 mN (mean depth of indentation 1,10 μm). Imprints with greater and lesser indentation effort have, respectively, excess or insufficient size for analysis. This is established based on preliminary experiments.

On the surface of samples from high-speed steel with coatings and without coatings, a grid of alternating prints with indentation forces of 4,903 N and 490,3 mN was applied at a distance of 0,1 mm from each other. Nine prints were applied in three regions on the surface of each sample (Figure 1).

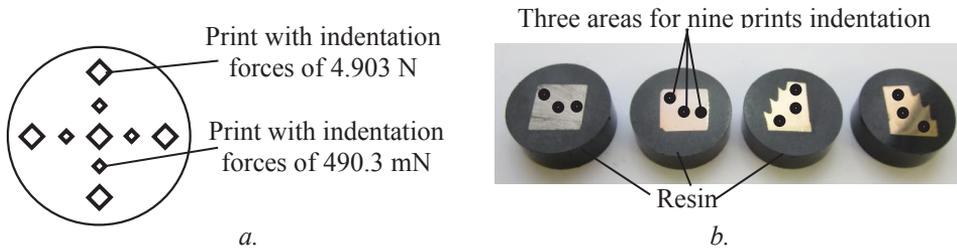


Fig. 1. Nine prints (a.) were applied in three areas (b.) on the surface of each sample
 Obr. 1. Deväť otlačkov (a.) aplikované v troch oblastiach (b.) na povrchu každej vzorky

Samples with indented surfaces were installed in the nests of the device of complex rotational motion and load dosing LaboForce-3 (Struers GmbH, Denmark) for carrying out the experiment.

The condensate of hardwood pyrolysis products, in volume of 20 ml, was applied to the disc surface at the beginning of the experiment and added every subsequent 10 min. Tests of samples for corrosion-mechanical wear were carried out at room temperature 21 °C.

The samples were removed from the experimental installation, washed with water, and the diagonals of the prints were measured every 10 min of the experiment. After measuring the diagonals, the samples were again installed in the device, the pressing force to the counter body (disk) was controlled and the experiment was continued.

RESULTS AND DISCUSSION

As a result of the measurement, it was established that the thickness of all deposited vacuum-plasma coatings was $2 \pm 0,2 \mu\text{m}$.

The roughness parameter (arithmetic mean deviation of the assessed profile) of all investigated samples with coatings was $R_a = 0,031 \pm 0,004 \mu\text{m}$.

By measurements, it was established that the hardness of samples from high-speed steel P6M5 without coating $62,03 \pm 0,8 \text{ HRC}$. At coating TK12 the average hardness was $38 \pm 0,4 \text{ GPa}$, at coating TK13 was $23 \pm 0,6 \text{ GPa}$, at coating AT72 was $32 \pm 0,7 \text{ GPa}$.

Photographs of prints on a sample without coating (UC) and coated with TK12 coating in the process of corrosion-mechanical wear are presented in Figure 2.

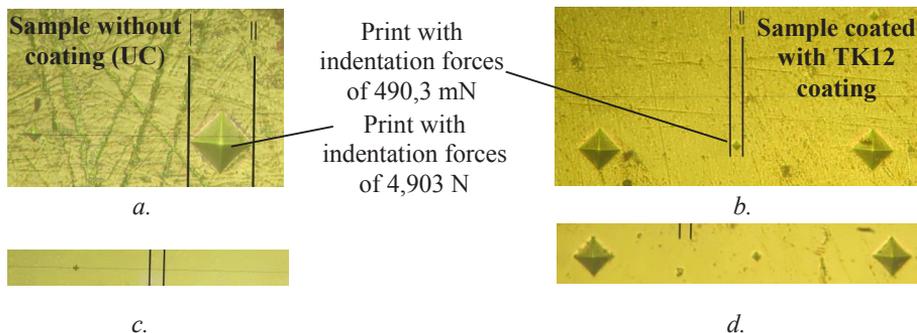


Fig. 2. Photos of prints on a sample without coating (UC) and coated with TK12 coating in the process of corrosion-mechanical impact: samples of UC (a.) and TK12 (b.) before testing; After 60 min of the experiment: UC (c.) and TK12 (d.)

Obr. 2. Snímky otláčkov nepovlakovanej vzorky (UC) a povlakovanej vzorky s TK12 povlakom v procese korozívno-mechanického pôsobenia: vzorky UC (a.) a TK12 (b.);

Po 60 min experimentu: UC (c.) a TK12 (d.)

Figure 3 shows the graphs of the diagonals d_1 prints on the surface of the samples when indenting with a load of 490,3 mN (a.) and the graphs of the diagonals d_2 prints on the surface of the samples when indenting with a load of 4,903 N (b.) from the time of the corrosion-mechanical action t .

Table shows the data on the percentage of the average decrease in diagonals of prints (indentation with a load of 490,3 mN) after 20 min and 60 min of corrosion-mechanical action in comparison with their average initial values.

The highest intensity of corrosion-mechanical wear was observed in the uncoated sample.

This is consistent with the previously published results (Sheikh-Ahmad& Morita 2002; Latushkina et al. 2016).

According to the data in Table, the wear resistance of samples with coating TK12 is seven times, of samples with AT72 coated five times, and of samples with coating TK13 is four times higher than that of uncoated samples after 20 minutes of corrosion-mechanical action.

The wear resistance of samples coated with TK12 is ten times, the samples with coatings AT72 and TK13 are six times higher than that of uncoated samples after 60 minutes of corrosion-mechanical action.

The coating of TK12 showed the greatest increase in wear resistance in comparison with uncoated samples under corrosion-mechanical action. This coating is also characterized by the greatest microhardness and chemical resistance. The TK13 coating has a lower hardness than the AT72 coating, but the chemical resistance of this coating is higher (Latushkina et al. 2015).

The hardness of the coating AT72 is higher than the hardness of the coating TK13. However, the coating AT72 showed a higher intensity of material loss from the surface compared with the coating of TK13 with corrosion-mechanical action for 60 minutes. At the same time, the wear of the samples with coating AT72 was 5% less compared to the samples coated with TK13 in 20 minutes after the beginning of the corrosion-mechanical action.

This can be explained by the fact that in the first stages of wear, the hardness of the coating plays the main role in the obstacle to material dissipation. The chemical resistance of the sample surface becomes especially important for longer interactions with the condensate of hardwood pyrolysis products.

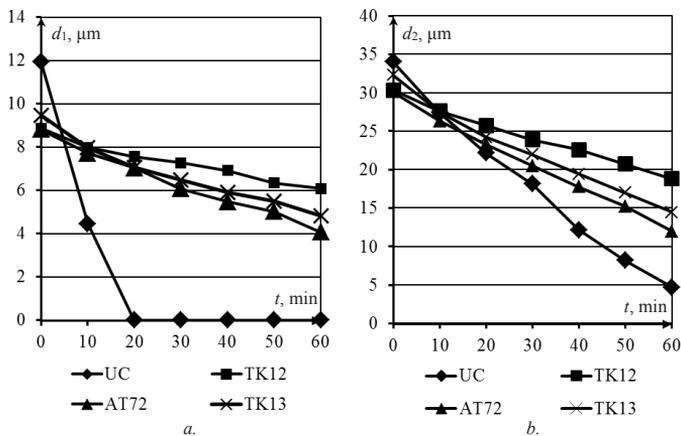


Fig. 3. The dependence of the diagonals d_1 of prints on the surface of the samples when indenting with a load of 490,3 mN (a.) and the dependence of the diagonals d_2 of prints on the surface of the samples when indenting with a load of 4,903 N (b.) from the time t of corrosion-mechanical action

Obr. 3. Závislosť uhlopriečok d_1 otláčkov na povrchu vzoriek po odstani pri zaťaží 490,3 mN (a.) a závislosť uhlopriečok d_2 otláčkov na povrchu vzoriek po odstani pri zaťaží 4,903 N (b.) od času t korozívno-mechanického pôsobenia

Table. Data on the percentage of the average decrease in diagonals of prints (indentation with a load of 490,3 mN) after 20 min and 60 min of corrosion-mechanical action in comparison with their average initial values

Tabuľka. Údaje o percentuálnom priemere poklesu uhlopriečok otláčkov (so záťažou 490,3 mN) po 20 min a 60 min korozívno-mechanickom účinku in porovnaní ich priemernými počiatocnými hodnotami

Marking of the coating	Average decrease in diagonals of prints after exposure time, %	
	20 min	60 min
Without coating (UC)	100	100
TK12	14	31
AT72	20	54
TK13	25	49

Comparing the graphs in Figure 3 a. and b., it was found that the decrease in the diagonal values of the prints obtained with the 4,903 H load is somewhat more intensive, compared with the decrease in the diagonals of prints obtained at a load of 490,3 mN. This can be explained by the fact that deeper prints reach the base material of the sample, providing contact with pyrolysis products.

CONCLUSION

It is established that the hardness of the coating plays the main role in the obstacle to material dissipation in the first stages of wear. The chemical resistance of the sample surface becomes especially important for longer interactions with wood pyrolysis products.

It has been found that the multicomponent nanostructured vacuum-plasma coatings based on titanium nitride doped with copper (coatings TK12, TK13) or aluminum (coating AT72) obtained under bombardment with a stream of low-energy gas ions increase the corrosion-mechanical resistance of the samples in the condensate environment of hard-wood pyrolysis products from 4 to 10 times in comparison with uncoated samples.

The obtained data can be used in the development of new materials and protective coatings for wood-cutting tools.

ACKNOWLEDGMENT

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RESEARCH OF INFLUENCE OF PRELIMINARY TORREFACTION OF WOOD FUEL ON ITS GASIFICATION

VÝSKUM VPLYVU PREDSUŠANIA PALIVOVÉHO DREVA NA SPLYŇOVANIE

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Abstract: The keen interest of researchers in process of gasification of wood waste as to one of the most available types of renewable energy is observed in recent years. The generator gas, received thanks to this process, can be used in thermal processes and also for further synthesis for the purpose of receiving valuable chemical products. In this work wood flour which had been subjected to preliminary high-temperature heat treatment was applied to fuel granules as material. The tight heat chamber was used for implementation of that process. Bulk material was loaded into the container with six cross fins, dividing it into sections. Thanks to a section structure of the container there is a uniform heating of the wood flour due to high heat conductivity of cross fins. The temperature of processing varied from 220 to 280 degrees and the duration – for 2,5 hours. Then the container with the material was exposed to cooling in hermetic conditions. It has been established that the increase of hydrogen and carbon oxide in content of generator gas, which is observed with temperature increase of heat treatment, allows us to claim that use of the thermally processed fuel in processes of gasification during the production of liquid synthetic hydrocarbons (oils and fuels) with Fischer-Tropsch's reaction is expedient.

Key words: gasification; heat treatment; raw wood

Abstrakt: V súčasnej dobe narastá záujem výskumných pracovníkov o proces splyňovania drevného odpadu ako jedného z najviac dostupných druhov obnoviteľnej energie. Generátorový plyn, ktorý sa produkuje vďaka tomuto procesu, sa môže použiť v tepelných procesoch a tiež pre ďalšiu syntézu na účely získania cenných chemických produktov. V tejto práci sa drewná múčka, ktorá bola podrobená predbežnému vysokoteplotnému spracovaniu, naniesla na granulát paliva. Na realizáciu tohto procesu sa použila úzka tepelná komora. Sypký materiál bol vložený do kontajnera so šiestimi krížovými rebrami a rozdelený na sekcie. Vďaka štruktúre konštrukcie kontajnera dochádza k rovnomernému zahriatiu drevnej múčky kvôli vysokej tepelnej vodivosti priečných rebier. Teplota spracovania sa pohybovala od 220 do 280 stupňov, spracovanie trvalo 2,5 hodiny. Následne sa

nádoba s materiálom vystavila chladeniu v hermetických podmienkach. Bolo zistené, že zvýšenie obsahu vodíka a oxidu uhličitého v obsahu generátorového plynu, ktoré sa pozoruje pri zvýšení teploty tepelného spracovania, nám umožňuje tvrdiť, že je výhodné použitie tepelne spracovaného paliva v procesoch splynovania počas výroby kvapalných syntetických uhl'ovodíkov (oleje a palivá) pomocou Fischerov-Tropschovho procesu.

Kľúčové slová: splynovanie, tepelná úprava, surové drevo

INTRODUCTION

The keen interest of researchers in process of gasification of wood waste as to one of the most available types of renewable energy is observed in recent years. The generator gas, received thanks to this process, can be used in thermal processes and also for further synthesis for the purpose of receiving valuable chemical products.

The laboratory granulometric gasification of wood fuel granules is considered in the article of Ngusale G. K., Yonghao L. etc. (Ngusale G., et al 2016). Studying of characteristics of the emitted gases from the gasifier, which was constructed and built in university laboratory, is a research objective. Wood granules with a diameter of 5 mm, from 5 to 20 mm long were applied to a research. The research has shown that the main products of gas generation are CO₂, CO and H₂, an exit of CH₄ and some other substances is insignificant.

The gasification of mix of wood sawdust and chips (0, 30, 70 and 100%) is studied in the article of Lenis Y. A. and Pérez J. F. (Lenis Y., Pérez J. 2014). The experiments were made in the laboratory reactor with the blown layer. The pseudo-liquefaction forced particles of the smaller size to leave the reactor irrespective of percentage of sawdust. This process has been caused by reduction of weight and the sizes of particles during processes of drying and removal of flying components.

The process of gasification of five types of forest cultures from Colombia (*Acacia mangium*, *Eucalyptus* sp., *Pinus* sp., *Pinus patula* and *Gmelina arborea*) has been carried out in the work of Lenis Y A., Osorio L. F. and Pérez J. F. (Lenis Y., et al. 2013). The researches were conducted in the descending reactor with a motionless layer in the laboratory conditions. During the experiment it has been revealed that pine and eucalyptus had the greatest liberation of gas and volatiles. The most saturated generator gas has been received from the wood of that breeds. The received results are explained by the fact that pine and eucalyptus have lower moisture content and higher density and calorific ability.

The hydrothermal gasification of waste of wood has been considered and the system for production of hydrogen has been developed in the article of Kong L. (KONG L., et al. 2008). The main objective of the research consists in an assessment and introduction of hydrothermal gasification of the waste containing various impurities.

At the same time the so-called «black» pellets (the wood fuel which has been processed at temperatures of 200-300 °C without air oxygen access) actively gain popularity in recent years.

The researches on definition of efficiency of carrying out preliminary heat treatment of wood raw materials have been executed by Uslu A., Faaij A.P. etc. (Uslu A., et al. 2008).

It is established that the torrefaction in combination with a granulation allows receiving fuel granules with the maintenance of energy to 22,7 MJ/kg. Mark J. Prins, Ptasinski K.J. etc. (Prins M.J., et al. 2006) has been established that the content of volatiles decreases and calorific ability of wood increases to 20,7 MJ/kg at temperature of heat treatment of 270 °C in comparison with 17,7 MJ/kg for the raw wood.

The influence of characteristics of torrefied solid wood fuel on productivity of the offered drying complex is considered in work (Safin R.R., et al. 2016). As a result of the experiments it has been revealed that generator gas with the best calorific ability is emitted at gasification of torrefied wood fuel in comparison with gasification of the raw wood and thereby increases productivity of a drying complex.

The comparative analysis of solid biofuel from various wastes is presented in the article (Shayakhmetova, et al. 2015): granules from pod of sunflower, granules from wood waste and granules on the basis of thermally modified raw materials. The chemical composition of these types of fuels has been analyzed and the results of researches on burning and calorific ability are given. The authors have established that torrefied granules from pod of sunflower are competitive in the fuel market as have heat of combustion comparable to wood granules, but at the same time have lower cost.

The results of the analysis of chemical changes of wood particles in the course of their high-temperature processing without air oxygen access are presented in work (Safin R.R., et al. 2015). The authors have established the rational temperature range which effectively influences the characteristics of wood raw materials. The calorific properties of the solid fuel from the wood particles which had been treated at temperatures of 200, 220, 240, 260 and 280 °C within 30 and 40 minutes were defined. The authors claim that temperature processing exerts considerable impact on the highest heat of combustion of wood while duration of processing has smaller effect.

Proceeding from the above-mentioned it is possible to draw a conclusion, that preliminary heat treatment and gasification have expediency of the application and that this subject is urgent for a further research and finding of ways of reduction in cost of processes.

METHODS AND MATERIALS

Wood flour which had been subjected to preliminary high-temperature heat treatment (Razumov E.Y., et al. 2013; Demirbas T., Demirbas C. 2009) was applied to fuel granules as material. The tight heat chamber was used for implementation of that process (fig. 1). Bulk material was loaded into the container with six cross fins, dividing it into sections. Thanks to a section structure of the container there is a uniform heating of the material due to high heat conductivity of cross fins. The temperature of processing varied from 220 to 280 degrees and the duration – for 2,5 hours. Then the container with the material was exposed to cooling in hermetic conditions (Westover T.L., et al. 2013; Zheng A., et al. 2012; Prins M.J., et al. 2006; Safin R.R., et al. 2014).

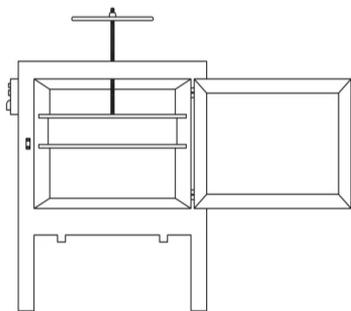


Fig. 1 The heat chamber and the container with the processed material
Obr. 1 Teplotná komora a kontajner so spracovaným materiálom

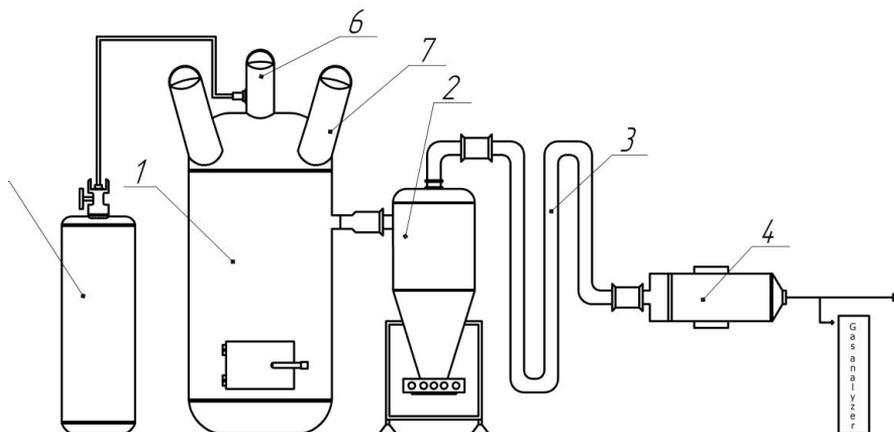


Fig. 2. The experimental installation for gasification of thermally processed wood fuel
Obr. 2 Experimentálna inštalácia pre splynovanie termicky spracovaného drevného paliva

The installation for research of process of gasification of thermally processed wood fuel has been created (fig. 2.). It includes the reactor of direct-flow gasification of wood waste 1, the cyclone for rough purification of generating gas 2, the coiled heat exchanger 3 and the bag filter for thin cleaning 4. The cylinder 5 for adjustable supply of oxygen in a reaction zone is connected to an entrance opening of the reactor 1. Loading of the studied gasifiable fuel is carried out in the central branch pipe of the 6th reactor 1. Side branch pipes 7 are used for initial ignition of the studied fuel by loading of the burning charcoal. Selection of products of gasification of wood fuel for the further analysis is carried out at the exit from the filter 4.

RESULTS

The results of researches of structure and relative calorific ability of the generating gas, received as a result of gasification of thermally processed fuel are presented in fig. 3 and in table 1. The analysis of the submitted data demonstrates that not condensed gaseous products are in the main CO, H₂ and CO₂. The maintenance of CH₄ is insignificant, that is coordinated with the known literary data. Heat treatment reduces the amount of moisture, oxygen and a ratio oxygen/carbon and leads to increase in maintenance of H₂ and CO in synthesis gas in comparison with gasification of the raw granules. There is respectively a reduction of maintenance of CO₂. Besides, some decrease in maintenance of H₂ at temperature increase of processing of wood particles above 240 °C towards formation of CH₄ is observed. This results from the fact that the maintenance of H₂ depends not only on the amount of oxygen, but also on the content of hydrogen in thermally processed fuel.

Besides it should be noted, that power consumption of gas is considerably improved as a result of temperature increase of heat treatment. This is also confirmed by increase in the relation of amount of thermal energy, emitted at combustion of generating gas from the processed fuel, to amount of thermal energy emitted at combustion of the most gasifiable raw materials (tab. 1). However the analysis of tab. 1 also shows that calorific ability of generating gas from the thermally processed wood fuel in relation to calorific ability of the raw wood fuel significantly decreases with growth of temperature of heat treatment, owing to loss of energy together with the combustible substances removed from wood in the course of a torrefaction.

As the removal of volatiles is strengthened due to increase in temperature of heat treatment, the relative calorific ability of generating gas decreases with growth of temperature of heat treatment. At the same time gasification of the processed fuel in relative units is above gasification of the raw fuel (80–87% against 76% depending on processing temperature).

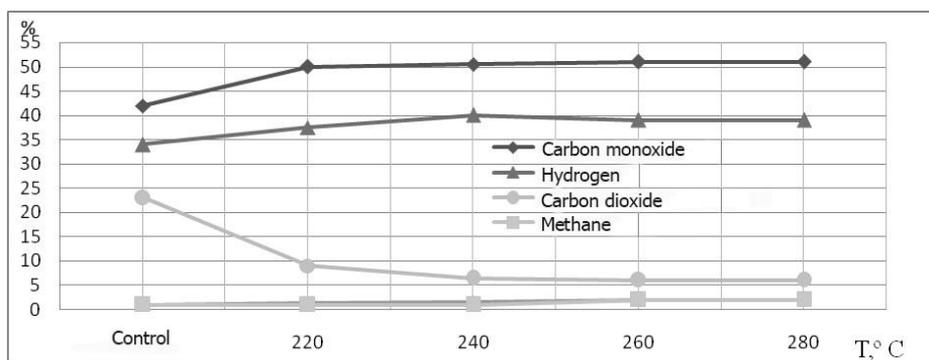


Fig. 3. The structure of synthesis gas, received as a result of gasification of thermally processed wood fuel

Obr. 3 Štruktúra syntetického plynu ako výsledok splynovania termicky spracovaného drevného paliva

Table 1. Relative calorific ability of synthesis gas from the thermally processed fuel.

Tabuľka 1 Relatívna výhrevnosť syntetického plynu z termicky spracovaného paliva

Treatment temperature, °C	In comparison with direct burning of the thermally processed fuel, %	In comparison with direct combustion of unprocessed fuel, %
220	82	72
240	87	71
260	82	66
280	81	50
Relative calorific ability of synthesis gas from torrefied fuel in comparison with direct combustion of untorrefied fuel		76

The presented results are comparable with the results of Prince M. J., Ptasinski K. J., Janssen, F. J.

CONCLUSION

The increase of hydrogen and carbon oxide in contents of gas, which is observed with temperature increase of heat treatment, allows us to claim that use of the thermally processed fuel in processes of gasification during the production of liquid synthetic hydrocarbons (oils and fuels) with Fischer-Tropsch's reaction is expedient. In this regard, the results of these researches will be used in further work for receiving chemical products, in particular, in production of methanol and dimethyl ether.

ACKNOWLEDGEMENT

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GLOBAL AND LOCAL THRESHOLDING TECHNIQUES FOR SAWDUST ANALYSIS

GLOBÁLNE A LOKÁLNE PRAHOVANIE PRE ANALÝZU PILÍN

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ABSTRACT: The article deals with thresholding of image with sawdust for their identification and analysis using different thresholding algorithms. Individual algorithms are subsequently assessed for sawdust images thresholding suitability. During thresholding of these pictures the sawdust would not be wrong identified what would incorrectly determine their dimensions. Information about particles size in the wood machining analyses machining from the point of view of dustiness in working environment as well as the geometry of the cutting tool and tool wear.

Key words: thresholding, sawdust, wood, local techniques.

ABSTRAKT: Článok sa zaoberá prahovaním obrazov s pilinami pre ich identifikáciu a analýzu pomocou rôznych prahovacích algoritmov. Jednotlivé algoritmy sa následne vyhodnotia z hľadiska vhodnosti pre analýzu obrazov s pilinami. Počas prahovania týchto obrazov by nemali byť piliny identifikované nesprávne, čo by spôsobilo nesprávne určené ich rozmery. Informácie o veľkosti častíc pri obrábaní dreva analyzujú obrábanie z hľadiska prašnosti v pracovnom prostredí, ako aj geometriu rezného nástroja a opotrebenie nástroja.

КПүчөвө словá: prahovanie, piliny, drevo, lokálne techniky.

INTRODUCTION

Wood is considered as a complexity matter that had multi-purpose functions. In the wood sawing process the sawdust is produces as a by-product. Its shape, size and quantity are depend on physical and mechanical properties of the sawn timber as well as on the shape, dimensions and sharpness of cutting tool, and on technical and technological conditions of sawing process (Kvietková 2015). The processes of woodworking by cutting tools are always connected with forming of chips. Depending on the kind of technological operation, the chips of various sizes, forms, and quantities are created. Particles size is one of the most important physical property of solids, which are used in many fields of human activity, such as construction, waste management, metallurgy, fuel fabrication, etc. Sawdust

and wood shavings are waste products resulting from wood processing. Very promising is the use of waste products as fuel directly in the place where the waste has been produced.

Small chips can be dangerous for human health. Risk factors in the wood processing using various technologies solve many authors (Barčík 2007, Očkajová 2006). Dimensional representation knowledge of sawdust is therefore important for the health protection of workers, who work directly in the processing of wood. Writes by Očkajová (2010), whereas the particles greater than 10 μm can cause only irritation of upper respiratory organs with cough and sneeze or irritation of eye conjunctivae, smaller particles get further to lower respiratory organs, and the particles with dimensions below 2.5 μm can interpenetrate into pulmonary alveoli and either settle in the lungs or penetrate into blood circulation.

Modern methods of measuring of sawdust dimensions are used by non-destructive image analysis. Optical method of sawdust dimensions measuring is preferable; it also gives more information about the measured sample (Pivarčiová 2014). Sawdust are recorded by camera and then using computer has identified and assessed the required parameters. In this process it is necessary to properly identification the measured particles in the image. For these identification are used a different thresholding methods.

Thresholding is the process of separation of pixel values into two groups, white as background and black as foreground. They can be categorized into global thresholding and local thresholding. In images with uniform contrast distribution of background and foreground, like document images, global thresholding is more appropriate. In pictures with uneven background, where considerable background noise or variation in contrast and illumination exists, there exists many pixels that cannot be easily classified as foreground or background. In such cases, binarization with local thresholding is more appropriate.

MATERIALS AND METHODS

Individual thresholding methods are suitable for specific images. All thresholding methods are based on analysis of the 2D image in grey scale. The conversion of input truecolor image in RGB to the grayscale intensity image can be performed by forming a weighted sum of the R, G, and B components:

$$0,2989 * R + 0,5870 * G + 0,1140 * B \quad (1)$$

where:

R – red colour component,

G – green colour component,

B – blue colour component.

Writes by Koleda (2013), the input image contains objects that are bad lighted, or casts a shadow. The reasons can be, that simple thresholding methods are fail. The solution are local (adaptive) thresholding methods.

Global thresholding

Global thresholding is based on the assumption that the image has a bimodal histogram and, therefore, the object can be extracted from the background by a simple operation that compares image values with a threshold value T . The object and background pixels have grey levels grouped into two dominant modes. One obvious way to extract the object from the background is to select a threshold T that separates these modes. The thresholded image $g(x, y)$ is defined as (Bankman 2008):

$$g(x, y) = \begin{cases} 1 & \text{if } (x, y) > T \\ 0 & \text{if } (x, y) < T \end{cases} \quad (2)$$

Otsu's global thresholding

Determination of the optimum threshold value T is not easy. One of the possibilities, as determined, is Otsu algorithm. This method is based on the minimisation the intraclass variance of the thresholded black and white pixels (Xu 2011).

$$\sigma_w^2(T) = p_1(T)\sigma_1^2(T) + p_2(T)\sigma_2^2(T) \quad (3)$$

where:

T – threshold value [-],

$p_1(T)$ – mean value of background points [-],

σ_1 – probability distribution of background points [-],

$p_2(T)$ – mean value of object points [-],

σ_2 – probability distribution of object points [-].

Optimal threshold is determined by:

$$\begin{aligned} \sigma_w^2(T^*) &= \min_{1 < T < L} \sigma_w^2(T) \\ T^* &= \arg \min_{1 < T < L} \sigma_w^2(T) \end{aligned} \quad (4)$$

where: T^* is optimal threshold.

Local thresholding

In local adaptive technique, a threshold is calculated for each pixel, based on some local statistics such as range, variance, or surface-fitting parameters of the neighbourhood pixels.

Niblack's technique

In this method the local threshold value $T(x, y)$ at (x, y) is calculated within a window of size $w \times w$ as (Singh 2011):

$$T(x, y) = m(x, y) + k \cdot \delta(x, y) \quad (5)$$

where:

- $m(x, y)$ – local mean of the pixels inside the local window,
- $\delta(x, y)$ – standard deviation of the pixels inside the local window,
- k – a bias.

The local mean and standard deviation adapt the value of the threshold according to the contrast in the local neighbourhood of the pixel. The bias controls the level of adaptation varying the threshold value.

Sauvola's technique

In Sauvola's binarization method, the threshold $T(x, y)$ is calculated using the mean $m(x, y)$ and standard deviation $\delta(x, y)$ of the pixels within a window of size $w \times w$ as (Singh 2011):

$$T(x, y) = m(x, y) \left[1 + k \left(\frac{\delta(x, y)}{R} - 1 \right) \right] \quad (6)$$

where:

- R – the maximum value of the standard deviation ($R = 128$ for a grayscale document),
- k – a bias, which takes positive values in the range 0.2 to 0.5.

The local mean $m(x, y)$ and standard deviation $\delta(x, y)$ adapt the value of the threshold according to the contrast in the local neighbourhood of the pixel. When there is high contrast in some region of the image, $\delta(x, y) \sim R$ which, results in $T(x, y) \sim m(x, y)$. This is the same result as in Niblack's method. However, the difference comes in when the contrast in the local neighbourhood is quite low. In that case the threshold $T(x, y)$ goes below the mean value thereby successfully removes the relatively dark regions of the background.

Wolf's technique

Wolf's technique is based on Sauvola's algorithm. It proposes to normalize the contrast and the mean grey value of the image and computes the threshold as:

$$T = m \cdot (1 - k) + k \cdot M + k \frac{s}{R} (m - M) \quad (7)$$

where:

k – fixed to 0.5,

M – the minimum grey value of the image,

R – set to the maximum grey value standard deviation obtained over all the local neighbourhoods (windows).

Writes by Khurshid (2009), this method in most cases outperforms its predecessors. However, degradation is observed in its performance if there is a sharp change in background grey values across the image. This is due to the fact that the values of M and R are calculated from the whole image. So even a small noisy patch could significantly influence M and R values, thus eventually calculating misleading binarization thresholds.

Mean thresh technique

The concept of integral images was popularized in computer vision based on prior work in graphics. An integral image I of an input image g is defined as the image in which the intensity at a pixel position is equal to the sum of the intensities of all the pixels above and to the left of that position in the original image. So the intensity at position (x, y) can be written as:

$$I(x, y) = \sum_{i=0}^x \sum_{j=0}^y g(i, j) \quad (8)$$

The integral image of any greyscale image can be efficiently computed in a single pass. Once we have the integral image, the local mean $m(x, y)$ for any window size w can be computed simply by using two addition and one subtraction operations instead of the summation over all pixel values within that window:

$$m(x, y) = \frac{\left[I\left(x + \frac{w}{2}, y + \frac{w}{2}\right) + I\left(x - \frac{w}{2}, y - \frac{w}{2}\right) - I\left(x + \frac{w}{2}, y - \frac{w}{2}\right) - I\left(x - \frac{w}{2}, y + \frac{w}{2}\right) \right]}{w^2} \quad (9)$$

RESULTS

Described algorithms was tested on an image with sawdust (Fig. 1a). Sawdust sample was obtained from Norway spruce (*Picea abies*), which was sawn by circular saw. The sample was captured on a contrast black background. Before thresholding it was necessary to adjust the image: colours inversion in order to objects were dark and background white; conversion of image to grayscale. Edited image is shown in the Fig. 1b.

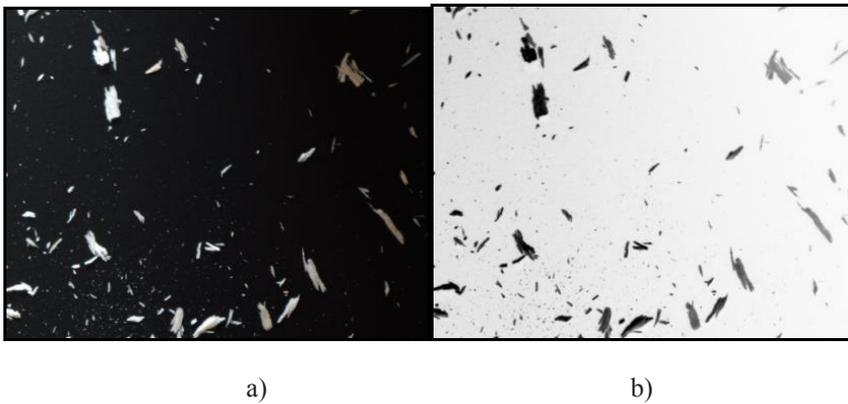


Fig. 1. Image with sawdust: a) original, b) corrected before thresholding.
 Obr. 1 Obraz s pilinami: a) originálny obraz, b) upravený obraz pred prahovaním

For global thresholding a threshold was determined using the Otsu's method. For the tested image according to the histogram (Fig. 2) threshold value T was calculated by mentioned method: $T = 138$.

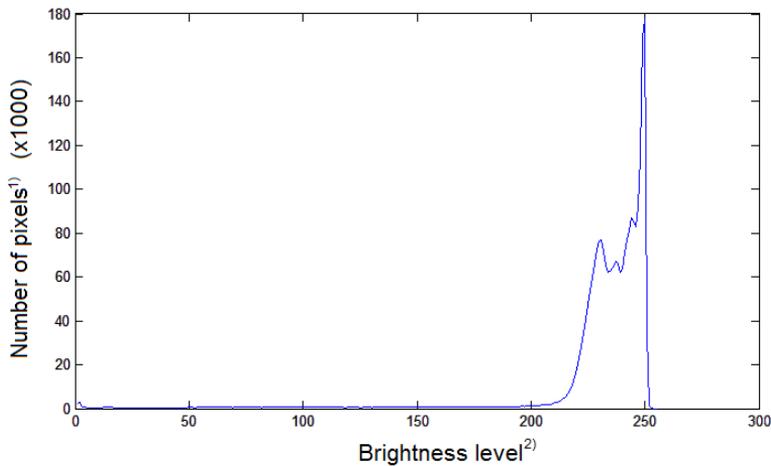


Fig. 2: Brightness level histogram.
 Obr. 2. Histogram úrovni jasu
 ¹) Počet pixelov, ²) Úroveň jasu

The results of each thresholding method are in the Fig. 3.

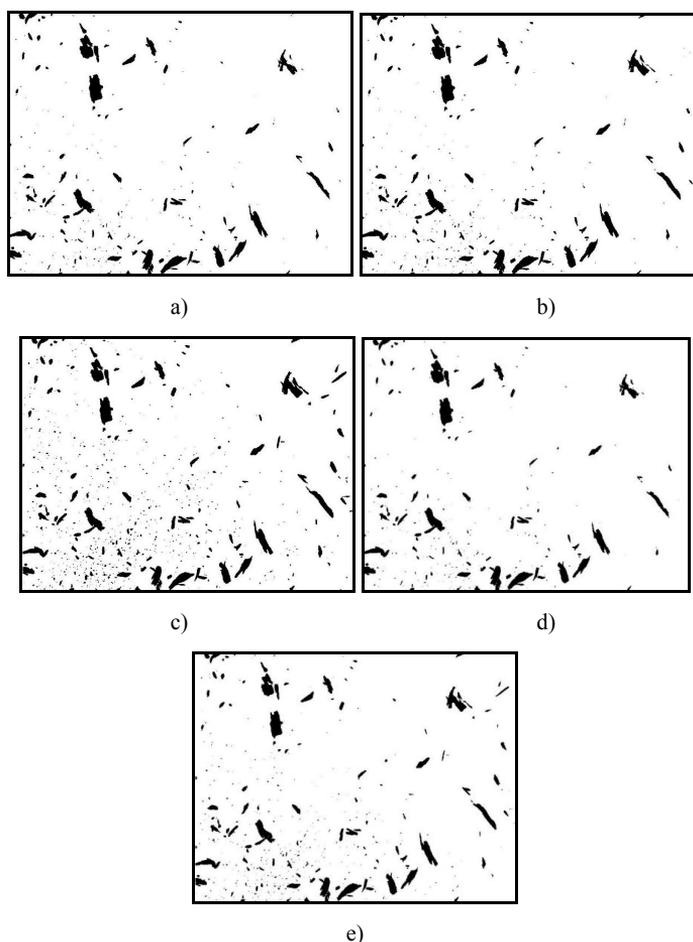


Fig. 3. Resultant threshold images: a) global thresholding with threshold $T = 138$; b) Niblack's algorithm at $k = -0.2$, windows size 160×160 ; c) Sauvola's algorithm at $k = 0.2$, $R = 160$;

d) Wolf's algorithm at $k = 0.5$, windows size 200×200 ; e) mean thresh algorithm
 Obr. 3. Výsledné prahované obrazy: a) globálne prahovanie s prahom $T = 138$; b) algoritmus Niblack s konštantou $k = -0,2$, veľkosť okna 160×160 ; c) algoritmus Sauvola s $k = 0,2$, $R = 160$; d) algoritmus Wolf s $k = 0,5$, veľkosť okna 200×200 ; priemerovací algoritmus

The result of thresholding using threshold algorithms shows that not all methods are able to find small particles. For example, the small particles aren't found using global thresholding and mean thresh algorithm. Some algorithms, like global thresholding, Wolf's algorithm and mean thresh algorithm, have incorrectly determined the boundaries of particle regions. All algorithms show good results if the particles are enough contrasting with background. Weak particle contrast can be caused by a particle colour that is similar to background or bad illumination (light reflection, shadows). The object in the upper-right corner of the image was used for comparison of image threshold with low contrast, (Fig. 4).

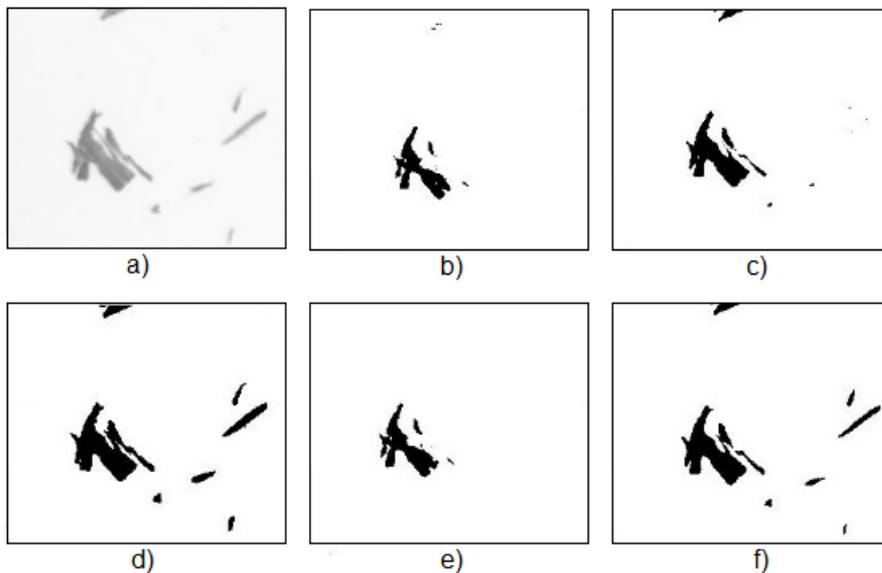


Fig. 4 Comparing of threshold algorithms at low contrast of objects in image: a) original image; b) global thresholding; c) Niblack's; d) Sauvola's algorithm; e) Wolf's algorithm; f) mean thresh algorithm

Obr. 4. Porovnanie prahovacích algoritmov s nízkym kontrastom objektov v obraze: a) originálny obraz, b) globálne prahovanie; c) algoritmus Niblac; d) algoritmus Sauvola; e) algoritmus Wolf; f) priemerovací algoritmus

As shown in figure 4, the best results of the sawing thresholds at low contrast give Sauvola's and mean thresh algorithm. Other algorithms misidentified small low-contrast sawdust.

DISCUSSION

Writes by Singh (2011) and as we can see in the Fig. 3, the best results are obtained using a local Sauvola's algorithm. In this method, sawdust were correctly identified with different lighting, as well as small dust particles in the samples. This method, however, was most difficult for the time requirements of analysis. Mean thresh algorithm has also completely good results. Using this algorithm many small sawdust are not found, what it not suitable for the correct analysis of the sample. Other algorithms could not correctly identify sawdust with low light (in images top right), also they failed to identify small particles. As writes Khurshid (2009), some algorithms can even produce noise in the image, but this has not been confirmed in this case.

CONCLUSIONS

This paper describes various thresholding methods for identification of sawdust using an optical analysis, qualitative and quantitative parameters of the sample, such as dimensions, position of centre of gravity, numerous representation of fractions, eccentricity, area, perimeter and many others. Described thresholding techniques allow to search measured sawdust in images. Local threshold methods are more suitable for real images, when lighting is not ideal and so places with stronger and with weaker lighting appear in pictures. From testing algorithm of sawdust thresholding Sauvola's algorithm was the most suitable. Its calculation is admittedly time consuming, but in determining of particle size it is essential to increase the quality, not quantity.

Described methods can work not only with sawdust sample, but also with other fractal particles.

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REFERÁTY

MAINTAIN THE LEVEL AND FLOW OF WATER SYSTEM IN A TANK USING PID CONTROLLER

SYSTÉM PRE UDRŽANIE HLADINY A PRIETOKU VODY V NÁDRŽI POMOCOU PID REGULÁTORA

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Abstract: This paper present some results about how to maintain the level and flow of water in a tank using the Proportional, Integral and Derivative (PID) controller based on a digital signal processing device. The concept of this process, is to control the level and flow of the water in the tank and make sure, the level and flow of water always follow the range that have been set. The collected data was analyzed and comparisons between the actual and the desired performance of the system. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. The level and flow process unit consists of a process tank and two centrifugal pumps, driven by an electrical motor, provides the necessary water to reach and keep the level. Water level and flow measurement and control is essential in water treatment and supply units for effective operation.

Keywords: Proportional Integral Derivative Controller (PID), Level, Flow, PID control, Centrifugal Pumps, Valves

ABSTRAKT: Článok popisuje možnosti udržania hladiny a prietoku vody v nádrži pomocou proporcionálneho, integrálneho a derivačného regulátora. Konceptiou tohto procesu je riadenie hladiny a prietoku vody v nádrži tak, aby boli vždy v zadanom rozsahu. Získané údaje boli analyzované a bol porovnaný skutočný a požadovaný výkon systému. PID regulátor počíta hodnotu chyby ako rozdiel medzi odmeranou premennou a požadovanou hodnotou. Regulátor sa pokúša minimalizovať chybu úpravou vstupov. Zariadenie pozostáva z nádrže a dvoch odstredivých čerpadiel, poháňaných elektrickým motorom, poskytuje nevyhnutnú vodu na dosiahnutie a udržanie hladiny. Meranie hladiny a prietoku vody a ich regulácia je nevyhnutné pre úpravu a dodávku vody pre efektívnu prevádzku.

Kľúčové slová: PID regulátor, hladina, tok vody, odstredivé čerpadlá, ventily

INTRODUCTION

In the last couple of decades an automatic control theory has been developed significantly; in the present industrial set up, processes (temperature, flow, level, pressure, etc.) are increasingly being controlled using the Proportional plus Integral plus Derivative (PID) controller [Opar, 2011]. A proportional integral derivation (PID) controller is a generic control loop feedback mechanism used in industrial control system. The PID controller is the most commonly used feedback controller. The PID controller calculate an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs [Nithyarsee, Kandasamy, 2012]. The advantage of a PID controller is that it can provide the strong performance for a wide range of operating conditions. It can also reduce the dynamic range error, eliminate the steady state error, and improve in the transient response of loop back functions system [Supol, Wudhichai, 2016]. We can control the level and flow in a tank by a sensor and a controller configured for proportional outputs, without the typical oscillations of the on/off control. The response of the control loop can be studied in comparison to the interferences in the variables of the process (flow) or variations in the set points (the flow is changed fixing different set points). By modifying the set point in a remote way, the level and flow change can be observed oscillating around the new values. We can have a case that the set point is not reached if the range of the actuator (manipulated variable) it is not enough to control the in interferences or the changes in the set point, so it will be stabilized only until the maximum that the available water allows. In our case, the manipulated variable is the water level and flow that circulates through a motorized valve, managed automatically from the controller, by means of superimposed actions of proportional, integral, and derivative type [Edibon, 2014]. In addition to control the level and flow of the water in the tank and make sure, the level and flow of water always follow the range that have been set. The main control are used in this process is PID controller, in this case the final control element is a valve which the function of the valve is control outflow of the water [Sabri, 2005]. Many authors were completed their research in the area of PID controller to measured different parameters such as (Level, Flow, Temperature, Pressure, PH) in industrial processes. Sena Temel, Semih Yağlı and Semih gören was written the report to analyze the recitation about P, P-D, P-I and P-I-D controllers [Sena et al, 2013]. Sabri Bin Baladi has written a report about water tank level control using PID at Universiti Teknikal Kebangsaan Malaysia [Sabri, 2005]. Maria João Mortágua Rodrigues was written the thesis assignment about to build a PID control that was able to control two tanks of water [Maria, Mortágua, 2011]. Ditefano, Stubberud, and Williams, was written the second edition book about Theory and problems of feedback and control system [Ditefano et al, 1990]. Blevins has been actively involved in the application and design of process control systems throughout his career [Blevins, 2013].

PROCEDURE OF THE SYSTEM AND DESCRIPTION OF THE UNIT

In this experiments we use PID controller to maintain the level and flow of water in a tank for a common industrial process, a flow rate, and level unit, and present some experimental results [Dotoli et al, 2016]. The process unit and the control loops used in

measuring experiments for level and flow regulation are described together with different equipment and necessary instruments for the physical simulation of the corresponding dynamic system. This unit consists of a hydraulic circuit with a bottom tank (1) and upper process tank (2), both dual, two centrifugal pumps (3), two flow meters with manual control valves (4), three on/off solenoid valves (5), and a motorized proportional valve (infinity variable) (6). In addition, it includes the appropriate tubes, elbows, connections, bulkheads and drains for the circuit operation. All the above mentioned is set on a support frame designed to be placed on a work bench and connected to interface box and computer. Additional fixed elements include a flow sensor that is installed in one of the upward lines of flow (8), and a temperature sensor located in the process (13), together with an electric heating coil (10). The interchangeable additional elements in the unit are a stirrer (9), the immersion level sensor located in the process tank (11), and the pH sensor which can be placed in the process tank or in the bottom tank (12) to study the effect of the time out [Edibon, 2014]. The unit of Edibon supervisory control and data acquisition (SCADA) system and PID control is shown in Fig 1.

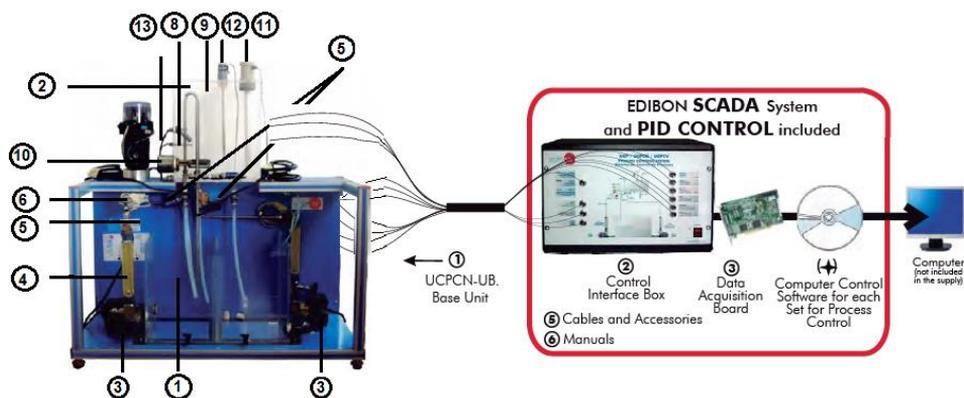


Fig. 1 The unit of Edibon SCADA system and PID controller (UCP) [Modified Edibon, 2013]
 Obr. 1 Zariadenie Edibon SCADA a PID regulátor (UCP) [Modified Edibon, 2013]

This automation control consist on the selection of a set point for example the level in the case of the Process Control Unit (UCP_L) level control and flow control (UCP_F). On the other hand, some values are assigned for AVS-1 (when the level exceeds the assigned values, the AVS- 1 valve is closed), AVS-2 and AVS-3 (when the level exceed the assigned values, the AVS-2 and AVS-3 valves are opened to drain the solution) and AB-2 (when the level does not reach the assigned value, the AB-2 is switched on if the level exceeds the assigned value, AB-2 is switched off). The procedure of the process and Software main screens for level and flow control is shown in Fig 2.

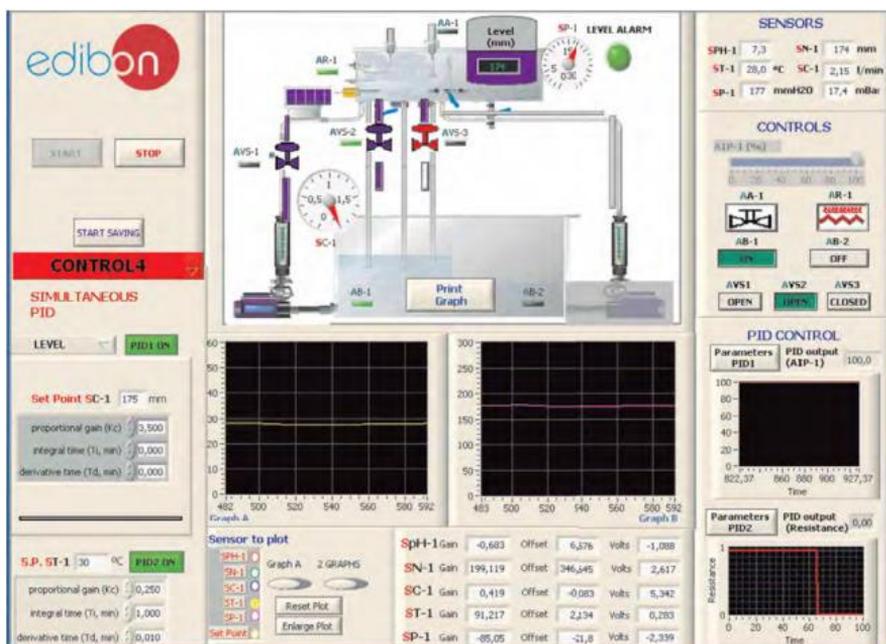


Fig. 2 Software main screens for level and flow control [Edibon, 2013]

Obr. 2 Hlavná obrazovka softwaru pre kontrolu hladiny a prietoku vody [Edibon, 2013]

For the level and flow control test the fluid (water) is impelled from the tank by the pump, located to the left on the front of the equipment. Then it proceeds through the flow meter, the solenoid valve is usually open, the motorized valve, the turbine (flow sensor), and the process tank. It is possible to use the second pump in the level test, as it will be indicated [Edibon, 2014]. In the two dimensional controller, we control the water and level according to the error variables (e) and the derivative of the error variables [Guo-Duo et al, 2012].

DESCRIPTION OF THE PID CONTROLLER AND APPLIED FORMULAS

It is often convenient to express a control system with a block diagram. These diagrams help to visualize the relationships between each part of the control system [CP-DAC, 2007]. The system consists of a block that represents the process, the process consists of an input (q), a manipulated variable also called feedback variable (m), and an output (c) controlled variable. The controlled variable is subtracted to the set point (r) to obtain the error (e) input to the controller [Edibon, 2014]. Consider Fig 3 the system with a block diagram.

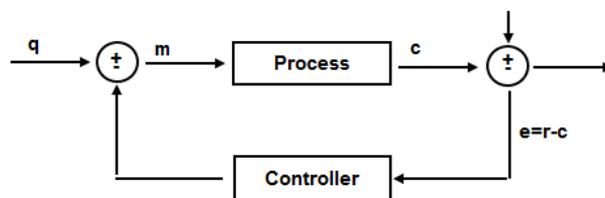


Fig. 3 Block diagram representing a control system
Obr. 3 Blokový diagram riadiaceho systému

The control system shown is called a closed loop system or a feedback system because the measured value of the controlled variable is returned or “fed back” to the comparator. In the comparator the controlled variable is compared with the desired value or set point [CPDAC, 2007]. The PID controller calculation (algorithm) involves three separate parameters, and is accordingly sometimes called three term control: the proportional, the integral and derivative values, denoted P , I , and D . these parameters can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change [Mohammady, 2010]. A PID Loop Control is shown in Fig 4.

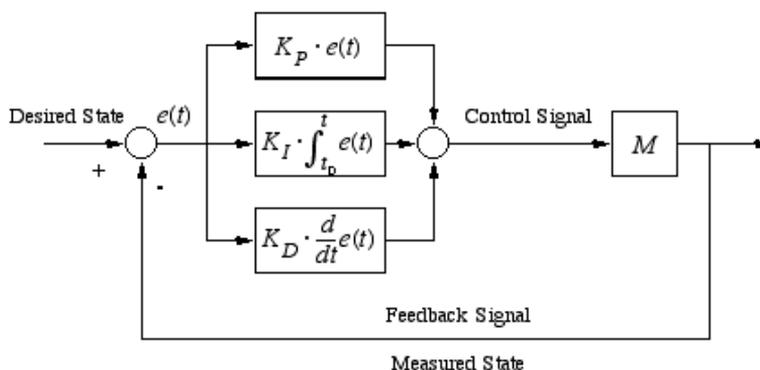


Fig. 4 PID Loop Control [Mohammady, 2010]
Obr. 4 Riadenie PID [Mohammady, 2010]

The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element [Mohammady, 2010]. The PID controller is complemented by the D component. This takes the rate of change of the system deviation into account [Bischoff et al, 1997].

The PID controller compares the set points (SP) with the variable processes (VP) to obtain the error (e).

$$e = SP - VP \tag{1}$$

The error being the difference between the set point and the measure, the controller computes a correction based on the integral and derivative of the error and also from a proportional error term [Damouche, Martel, 2015]. The final change in the output for this unit input change is called the steady state gain [Air Products and Chemicals, Inc., 2006]. The proportional gain, or just gain, is a measure of how sensitive the valve change will be to a given error [Honeywell, 2000]. Then the PID controller calculates controller's action, $u(t)$ where K_c is the controller's gain.

$$u(t) = K_c \left(e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de}{dt} \right) + C \quad (2)$$

Where the $u(t)$ is the input signal to the unit model, K_c = controller gain, $e(t)$ = error, T_i = integral time, T_d = derivative time constant, C = initial value of controller [Dingyu et al, 2007],[Open Michigan, 2006]. If the error and the controller's output have the same range, from (-100 % to 100 %), the controller gain is reciprocal. The following formula represents the proportional action [Desborough Honeywell, 2000].

$$u_p(t) = K_c e(t) + b \quad (3)$$

Where $u_p(t)$ = controller output, K_c = controller gain, $e(t)$ = error, b = bias, the following formula represents the integral action. This action corrects the stationary error over time.

$$u_i(t) = \frac{1}{T_i} \int_0^t e(t) dt + c(t_0) \quad (4)$$

Where $u_i(t)$ = controller output, T_i = integral time, $e(t)$ = error, $c(t_0)$ = controller output before integration, the following formula represents the derivation action. The derivation action softens the proportional action, preventing the action changes from being abrupt.

$$u_D(t) = T_d \frac{de}{dt} \quad (5)$$

Where $u_D(t)$ = controller output, T_d = derivative time constant, de = change in error, dt = change in time [Open Michigan, 2006], the total action $u_D(t)$ acts on the proportional valve following this pattern.

$$AVP - 1 \text{ output}(t) + u(t) + AVP - 1 \text{ output}(t - 1) \quad (6)$$

Thereupon, it depend on whether the system is getting closer or moving away from the point (the error is close to zero). The total action is moving away cancelling the error progressively [Edibon, 2014].

EXPERIMENTAL PROCEDURE TO MAINTAIN THE LEVEL AND FLOW OF WATER

For investigation to maintain the level and flow of water in a tank used the PID controller device in Kabul Polytechnic University from Edibon Company is used. We can choose a certain level of water and flow and the system has to be capable of adjusting itself in order to maintain the certain level and flow [Maria, Mortágua, 2011]. A PID controller makes it possible to fix the set point value more accurately, correcting stationary errors over time, and avoiding perturbations in the system with instantaneous answers. The properties available in the PID controller included in the supervisory control and data acquisition (SCADA) program, is shown in Fig 5.

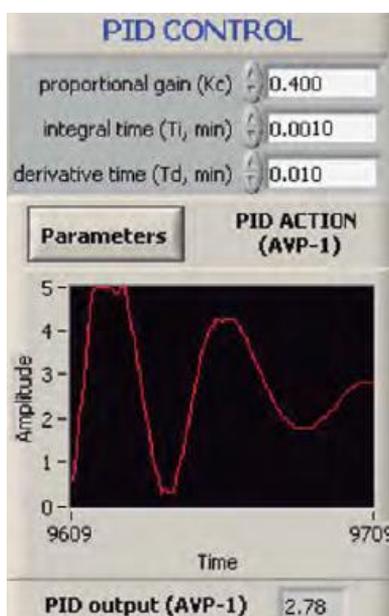


Fig. 5 The parameters available in the PID controller [Edibon, 2013]

Obr. 5 Parametre PID regulátora [Edibon, 2013]

We may perform complex mathematical functions to compare a set of data to set point or we may perform simple addition or subtraction functions to make comparisons [PAC-control, 2006]. Data will be saved during the process in a text file selected when running the program. The cause and notification of this experiment that carried out in Kabul Polytechnic University to obtain the parameters of different action of PID controller appears, is shown in Fig 6.

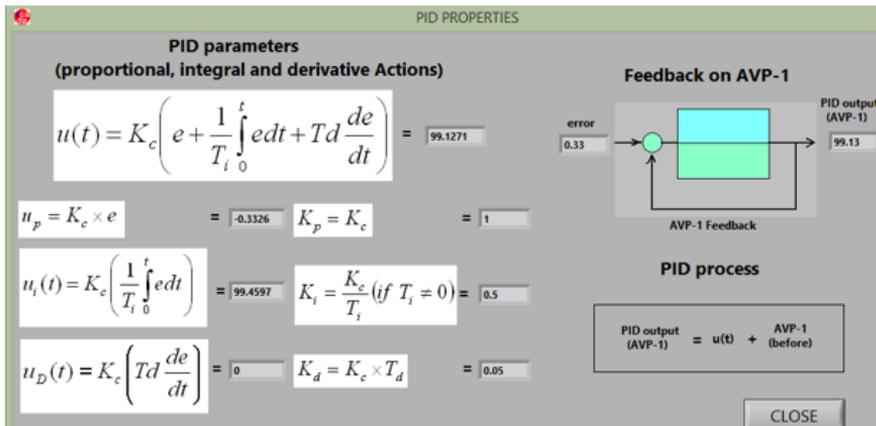


Fig. 6 The plot of PID properties action [Edibon, 2013]
 Obr. 6 Ukázka parametrov PID [Edibon, 2013]

These three variables K_p , K_i and K_d are usually tuned within given ranges. Therefore, they are often called the tuning parameters of the controller. By proper choice of these tuning parameters a controller can be adapted for a specific device to obtain a good behavior of the controlled system [Kambiz, Augustin, 2012]. A polyhedral sets in the three dimensional search band parameter space K_p , K_i and K_d are resulted from set of stable PID controllers for a fixed value of K_c , and it is faster and simple to identify these regions [Kadua, Patil, 2016].

- $K_p=K_c$. “Proportional constant”. Its value ranges from 0 to 1.
- $K_d=T_d$. “Derivative constant”. It is the derivative time in minutes, also called time. With this constant, possible perturbation generated in the system can be corrected whit in the band of action, acting immediately. Its value is also between 0 and 1.
- $K_i=T_i$. “Integral constant”. It is the integral time in minutes, also called *time*. The integral action in a controller makes it possible to correct the stationary error generated in an Off/on control. Its value must be higher or equal to 0.

RESULTS

To validate the stable PID controller, we have carried out a real time experimentation on level and flow control loop. We establish the set point for level 200 [mm] and for flow 2 [l.min⁻¹] the result that obtain according to equation (2) controller’s action, = 99.13 whenever the derivation action adapting to equation (5) the the equation (4) integral action is, and the variables or tuning parameters K_p , K_i and K_d are (1, 0.5, 0.005) respectively. Then the error (e) will be 0.33 these results is shown in Figure 5. According to these values for level of 200 [mm] the Gain, Offset and Volts obtained (45.82, 263.71, -1.36). If the reference points transformed for flow 1.84 [l .min⁻¹] we may have realized that value under 1 [l min⁻¹] are difficult to obtain because the proportional valve regulates this range

worse, the error reached to minus value $e = -2.1$ and the parameters achieved K_p , K_i and K_d are (1, 0.03, 0.08) respectively. According to these values for flow of water 2 [l min⁻¹] obtained the Gain, Offset and Volts obtained (0.64, 0.14, 2.8). If we select $K_c = 2$ or 3 we may see the oscillation of flow, when reducing the value of K_c even down to 0.25, the oscillation decreases. If the reference points transformed for level 1.98 [mm] and for flow 1.69 [l.min⁻¹] we may have realized that value under 1 [l.min⁻¹] are difficult to obtain because the proportional valve regulates this range worse, the error reached to minus value (-1.73), and the parameters achieved K_p , K_i and K_d are (1, 0.1, 0.008) respectively. If we select $K_c = 2$ or 3 we may see the oscillation of flow, when reducing the value of K_c even down to 0.25, the oscillation decreases. On the other hand K_d can have values from 0 to 0.01, the oscillation is softened. If K_d values are higher than 0.01, the system may be unstable. When the error (e) is below 0.1, [l.min⁻¹], the proportional and derivative actions stop working. In this moment, a stationary error is obtained and the integral action can be observed. If the process variable is not at set point, control action is taken to return the process variable to set point.

DISCUSSION

Generally, flow control loops are regarded as fast loops that respond to changes quickly. The speed of changes in a level control loop largely depends on the size and shape of the process vessel and the flow rate of the input and outflow pipes. A PID control allows keeping the set point value with greater accuracy correcting steady state errors with time and avoiding perturbations in the system with instantaneous answers. The control that will allow a PID control on any of our sensor will be control 3 and control 4. The difference between them is that on the first case, we can make a simultaneous PID on two variables; one of them is the resistance, and the other one is the Pressure, Flow, or PH. In the control 3, there is the possibility to make a PID on any of the variables. However, we divided the PID in two (PID 1 and PID 2), according to the performance: PID1 will always act on the motorized valve, controlling the water inlet to the upper tank and controlling the pH, level, flow or pressure. On the other side, the second one will always act on the resistor, controlling the temperature of the upper tank. In this control, both or two PID controls cannot be run simultaneously.

CONCLUSION

There are techniques to obtain the different values of the variable of a PID controller and they should be determined for any particular process. The values obtained by any of the different methods differ, and they should be treated as starting values for the good regulation of the process, which should be slightly modified by the operator, carrying out this way their fine adjustment until obtaining the optimum values. There are method automatic adjustment in which the equipment has an algorithm of self-adjustment of the control actions that allow it to tune in with a wide range of industrial processes. The application of a test signal to the process and the analysis of the obtained response, and its mathematical modeling, leads to the controller analytic design or we can use an iterative process to the method of the gain limit. A variable gain limit is the technique of minimum over flow

of the set point. From the results obtained by the on/off control on the flow variable, we can affirm that this controller is not the most appropriate due to the quick variation of the magnitude before a small interference. Only with small values in the performance times and the tolerances, we can obtain a flow control next to the set value. Although we will not have a stable value of the flow in any case. The future investigation of PID control will have been done in the area of different parameters measurement such as (Temperature, Pressure, Level, PH, ...etc.).

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