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FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY
SLOVAK UNIVERSITY OF TECHNOLOGY IN TRNAVA

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MONTE CARLO SIMULATION OF THE ELECTRICAL CONDUCTIVITY OF RUBBER COMPOUNDS DURING SILANIZATION

Ján HRONKOVIČ[2], Marian KUBLIHA[1], Stanislav MINÁRIK[1], Ondrej BOŠÁK[1], Martin TÓTH[1], Ján KALUŽNÝ[1]

Abstract

Monte Carlo simulation of temperature dependence of electric conductivity of a model mixture system, which involves reaction with first order kinetics, was carried out on the basis of chemical kinetics laws. The temperature dependence of the conductivity of rubber compounds during the process of silane treatment was studied experimentally. Simulated temperature dependence of conductivity was compared with measured experimental results. The obtained experimental results and the data derived from numerical simulation are in satisfactory agreement. Effective method for monitoring and control of silane treatment of rubber compounds directly during the material preparation process can be proposed on the basis of the abovementioned finding.

Key words

Monte Carlo simulation, chemical kinetics, reaction of first order kinetics, rate constant of reaction, silane treatment

Introduction

Rubber mixtures have attracted attention of materials technologists for several decades because these materials have found wide application in the manufacture of tires. Silane or silica treatment of resin composite is a very important technology step within the rubber mixture preparation which is oriented on cross linking and reinforcement of silica/silane-filled

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rubber compounds. The purpose of the presented paper is to find a method for investigation of the effect of silane treatment on rubber composites microstructure. Silanization to indirect resin composite enhances significantly higher bonds strength, and bonds strength are affected by the type of silane treatment ultimately. Application of a silane treatment improves the bond strength to indirect resin composite for repair. Main goal of the silanization process study is to find the most effective silane system. The experience suggests that the silane treatment should be considered to be a chemical reaction which is obeying laws of chemical kinetics. Chemical kinetics deals with the problem of the speed with which a chemical reaction occurs.

Theory of chemical reactions analyses the factors that affect the reaction speed and looks for the information useful for determining how the reaction process occurs. The speed of a reaction is the rate at which the concentrations of reactants and products change. It is well known that chemical reaction affects the physical and chemical properties of reacting system. In case the charge carriers are products of the reaction, it is expected that the electric conductivity of the system changes continuously during the reaction process, because values of electrical conductivity are considered to be sensitive to concentration of charge carriers. Nevertheless, there has been no experimental or theoretical study to determine the effect of chemical reaction process on the temperature dependence of electrical conductivity of system during the reaction. Our contribution deals with this problem in connection with the rubber compounds silanization process.

Theory

The study of dielectric properties of industrial rubber compounds is of great practical interest. As it is known, the electrical conductivity of rubber is caused by presence of impurities which transfer ions and thus electric current. The mechanism of electrical conductivity in the concerned materials was investigated in our earlier experiments [1, 2, 3, 4]. However, the mechanism of electrical conductivity in rubber compounds during the process of silane treatment is not even clear entirely. In the present paper, we investigate the problem of changes of electrical conductivity of such reactive dielectric system within the numerical approach. In most of transport mechanism models, the electrical conductivity is explained by means of concentration of charge carriers in structure. We suggest that the electrical conductivity of rubber compounds system during silane treatment reaction can by determined as:

$$\sigma = \sigma_{\mathrm{Pol}} + \sigma_{\mathrm{Sil}}, \tag{1}$$

where σ_{Pol} is electrical conductivity of reactionless compounds of structure and σ_{Sil} is a contribution of reactants to electrical conductivity. We expect that both contributions in (1) follow Arrhenius equation [5, 6, 7]:

$$\sigma_{\mathrm{Pol}} = \sigma_{01} e^{-\frac{E_A}{kT}} , \quad \sigma_{\mathrm{Sil}} = \sigma_{02}\left(C_N\right) e^{-\frac{E_A^{(S)}}{kT}} , \tag{2}$$

where activation energy of charge carriers in reactionless compounds E_A and activation energy of charge carriers in reactants $E_A^{(S)}$ do not have to be equal. Pre-exponential factor σ_{02} depends on immediate concentration C_N of that reactant which contributes to electrical conductivity of the system. We expect that the factor σ_{02} is proportional to the reactant concentration C_N, i.e. the factor σ_{02} may be expressed as:

$$\sigma_{02} = K' C_N \ , \tag{3}$$

where K' is constant. For determination of σ_{02} it is essential to know how the concentration of the reactant C_N changes when reaction progress:

$$C_N = C_N\left(t,T\right) \ . \tag{4}$$

We start with the rate law for the reaction, which follows first-order kinetics [8]:

$$\frac{dC_{\mathrm{N}}}{dt} = -c_{\mathrm{r}} C_N \ , \tag{5}$$

where c_{r} is the reaction rate constant which depends on temperature T and follows Arrhenius equation in the form [9, 10]:

$$c_r = Be^{-\frac{E_{\mathrm{D}}}{kT}} \ . \tag{6}$$

E_D is activation energy of the reaction and B is constant. If we consider both the time and temperature dependence of concentration C_N we obtain:

$$\frac{dC_{\mathrm{N}}}{dt} = \frac{\partial C_N}{\partial T}\frac{\partial T}{\partial t} + \frac{\partial C_N}{\partial t} = \eta \frac{\partial C_N}{\partial T} + \frac{\partial C_N}{\partial t} \ , \tag{7}$$

where η is the rate of temperature change. If we consider linear changes of temperature during reaction, then:

$$\eta = \frac{dT}{dt} = const \ . \tag{8}$$

After substitution (7) in equation (5) we obtain:

$$\eta \frac{\partial C_N}{\partial T} + \frac{\partial C_N}{\partial t} = -c_{\mathrm{r}} C_N \ . \tag{9}$$

Solution of equation (9) is expected in the form:

$$C_N = C_N\left(t,T\right) = \varphi\left(t\right)\chi\left(T\right) \tag{10}$$

and after substitution (6) and (10) to (9) we obtain:

$$\eta \frac{1}{\chi\left(T\right)}\frac{\partial \chi\left(T\right)}{\partial T} + Be^{-\frac{E_D}{kT}} = -\frac{1}{\varphi\left(t\right)}\frac{\partial \varphi\left(t\right)}{\partial t} \ . \tag{11}$$

Problem of solution of equation (11) leads to the next differential system:

$$\eta \frac{1}{\chi\left(T\right)}\frac{\partial \chi\left(T\right)}{\partial T} + Be^{-\frac{E_D}{kT}} = C'' \ , \tag{12}$$

$$-\frac{1}{\varphi\left(t\right)}\frac{\partial \varphi\left(t\right)}{\partial t} = C'' \ , \tag{13}$$

where C'' is constant. System (12), (13) is solvable and solution of this system can be written in the next form:

$$\chi(T) = e^{\frac{C''}{\eta}(T-T_0) - B\frac{1}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT'}, \tag{14}$$

$$\varphi(t) = A''e^{-C''t} \text{ , where } A'' = const. \tag{15}$$

T_0 is initial value of reacting system temperature by which the reaction runs. Consequently, the concentration of the reactant C_N can be expressed as:

$$C_N = \varphi(t)\chi(T) = A''e^{\frac{C''}{\eta}T - \frac{C''}{\eta}T_0 - C''t - \frac{B}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT'} = A''e^{C''\left(\frac{T}{\eta}-t\right) - \frac{C''}{\eta}T_0} e^{-\frac{B}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT'}. \tag{16}$$

Assuming (8) the linear dependence of system temperature on time can be written as:

$$T = \eta t + b, \tag{17}$$

where b is constant, and next we find:

$$\Rightarrow \quad C''\left(\frac{T}{\eta} - t\right) = C''\left(\frac{\eta t + b}{\eta} - t\right) = C''\frac{b}{\eta}. \tag{18}$$

Thereby the solution (16) can be rewritten as:

$$C_N = Ae^{-\frac{B}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT'}, \tag{19}$$

where:

$$A = A''e^{-\frac{C''}{\eta}T_0} e^{-\frac{C''}{\eta}b} = const. \tag{20}$$

Pre-exponential factor σ_{02} can be obtained by substituting (19) to (3).

$$\sigma_{02} = K'Ae^{-\frac{B}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT'} = Ce^{-\frac{B}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT'} \text{ , where } \quad K'A = C = const. \tag{21}$$

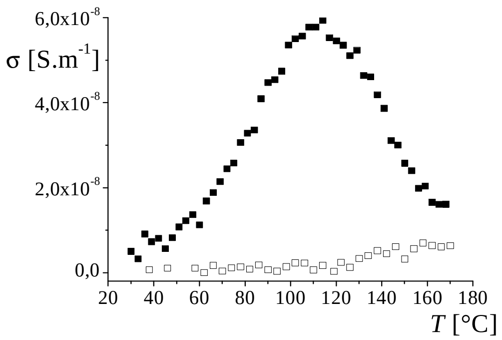
Consequently assuming (21) in (2), we can find a contribution of reactant to electrical conductivity σ_{Sil} as:

$$\sigma_{\mathrm{Sil}} = Ce^{-\left(\frac{E_A^{(S)}}{kT} + \zeta(T)\right)} \qquad \text{where:} \quad \zeta(T) = \frac{B}{\eta}\int_{T_0}^{T} e^{-\frac{E_D}{kT'}}dT' \text{ .} \tag{22}$$

Expression (20) indicates the temperature dependence of reactant contribution to electrical conductivity of reacting system under the condition of reaction with first order kinetics. In the frame of the model described above, we considered that only concentration of one reactant changes during the reaction involving only a one-step mechanism. In summary, we have proposed a simple model with emphasis on the chemical reaction effect on the electronic transport behaviour in a mixture system. This effect is reflected through the changes of charge carriers' concentration which is proportional to the concentration of reactant. Numerical simulation of temperature dependence of electrical conductivity can be realized by means of result (20). There are difficulties in evaluating the integral expression in (20) because the integral cannot be evaluated analytically. Highly effective Monte Carlo methods can be applied for its evaluation [11-18].

Experiment and simulation

Rubber compounds marked as SCR-3-X prepared in temperature range from 140 °C till 145 °C were investigated experimentally. Duration of silane treatment process of the prepared samples was from 0 till 7 minutes. Temperature dependences of AC electrical conductivity of prepared samples $\sigma(T)$ were persistently measured by GoodWill LCR 819 equipment at linear increasing temperature ($1°C\cdot min^{-1}$) until to 170 °C. Details of the investigated rubber mixture composition and experiment details can be found in [4]. In the next text, we will substitute the letter *X* in the sample identification symbol by the duration of thermal exposure of the sample. Comparison of the obtained results showed notable differences between the data of AC electrical conductivity measured during the first and the second cycles of heating process. The abovementioned differences can be seen in Fig. 1 which shows the graphs of temperature dependence of AC conductivity of SCR-3-7 sample. It is evident that the increase of AC electrical conductivity measured during the first cycle of heating process is caused by the silanization process since such increase is not measurable in the second cycle. The results showed that if the duration of silane treatment of a sample increases, then the size of the area below measured curves $\sigma(T)$ gradually decreases in both the first and the second cycles of heating. In case of some samples, we observed the abortion of silanization reaction at the first cycle of heating, and then the reaction continued during the second cycle. That fact was registered as a smaller maximum in $\sigma(T)$ curve measured in the second cycle. The values of electrical conductivity of non-silanized sample (SCR-3-0) were lower than we expected. It can be concluded on the basis of the mentioned results that if the increase of AC conductivity values (i.e. differences between values $\sigma(T)$ measured in the first and the second cycles of heating - see Fig.1) respond to the chemical reaction rate, then the size of the area below the curve represents the charge carriers concentration which is proportional to the size of the concentration of reactive substances. The dependence of the size of area below the measured $\sigma(T)$ curve on mixing duration is shown in Fig. 2. As it can be seen, the mentioned dependence of area on mixing duration decreases linearly (except the sample 0 min, which was mixed and heated only to 110 °C). This responds to the fact that the silane treatment was in progress during the mixing already and only finalization of treatment during the AC conductivity measurement was observed there consequently.



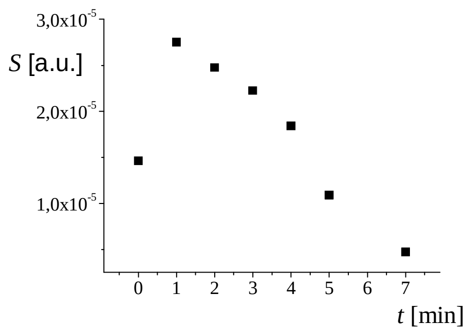


Fig. 1 *Temperature dependence of AC electrical*

Fig. 2 *Dependence of size of area below*

conductivity of sample SCR-3-7 measured at 1 kHz and with heating rate 1°C·min^{-1}
■ *in case of the first cycle of heating*
□ *in case of the second cycle of heating*

measured σ(T) curves on mixing duration

We simulated the measured σ(T) curves by the model presented above. That needs to determine some parameters contained in (20) and from these parameters σ_{SIL} can be calculated persistently. The best numerical fit of the measured temperature dependence of electrical conductivity of system during silane treatment must be obtained during the process of simulation. Results are shown in Fig. 3.

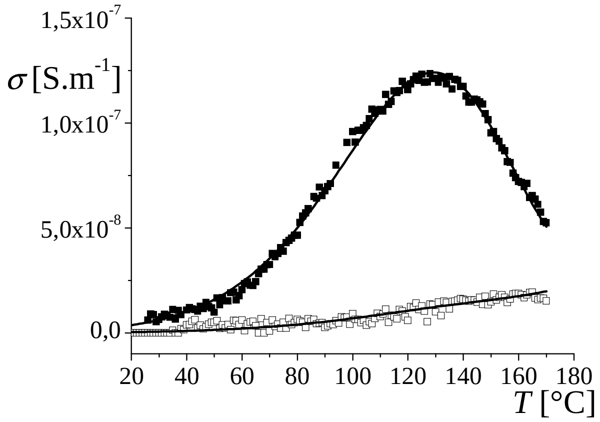


Fig. 3 *Temperature dependence of AC electrical conductivity of sample SCR-3-5 measured at 1 kHz and with heating rate 1°C·min^{-1}*
■ *in case of the first cycle of heating*
□ *in case of the second cycle of heating. Solid lines represent simulated data*

Conclusion

Potential applications of the presented method are in computer aided optimization of the rubber compounds silane treatment process. Presented numerical investigation indicates that the formula (20) could be usable for the process of rubber compounds silanization modeling. This make possible to use AC electrical conductivity as a measure of the extent of chemical reaction. Then we can realize an effective analysis and control of silane treatment process and find possibilities for the process improvement. This contribution was supported by the Slovak National Science Foundation under VEGA No.1/0645/10 and KEGA 327-010STU-4/2010 grants.

References:

[1] KUBLIHA, M. Utilization of electrical and dielectric methods in materials science of non-metallic materials. Trnava: AlumniPress, 2007, 70 p. (Vedecké monografie, 11/2007). ISBN 978-80-8096-026-1 (http://www.mtf.stuba.sk)

[2] MINÁRIK, S., LABAŠ, V., BERKA, M. Dielectrical relaxation dynamics and thermally stimulated depolarization current in polymers [online 14.9.2007]. - 1/20077/05, APVT 20/011/307. In *Journal of Optoelectronics and Advanced Materials*, 2007, Vol. 9, No 6, pp. 1592-1596. ISSN 1454-4164

[3] SLABEYCIUS, J., RUSNÁKOVÁ, S., BAKOŠOVÁ, D., Minárik, S. Study of glass and ceramic materials by ESPI. In *Trends in the Development of Machinery and Associated*

Technology. TMT 2009 : 13th International Research/Expert Conference. Hammamet, Tunisia, 16-21 October 2009, 2009, pp. 577-580. ISBN 1840-4944
[4] HRONKOVIČ, J., TÓTH, M., BOŠÁK, O., ČAVOJSKÝ, K. Štúdium procesov v kaučukových zmesiach pomocou sledovania dielektrických parametrov. In *SEMDOK 2010 : 15th International of PhD. students´ seminar*. Žilina: Žilinská univerzita, 2010, pp. 226-229. ISBN 978-80-554-157-7
[5] ŠIMEK, I. Fyzika polymérov, SVšT, Bratislava, 1987.
[6] WANG, Z.H., ZHANG, H. Physica C 320, 1999, pp. 218–224.
[7] Masagi Mizuno, Hisashi Kokubo and Kazumasa Honda: J. Mater. Chem., 2001, 11, pp. 2192–2198.
[8] HAKL, J. Thermochimica Acta, Volume 81, 15 November 1984, p. 319-325.
[9] SRIVASTAVA, S., METHA, N., AGARVAL, P., KUMAR, D., KUMAR, A. Journal of Ovonic Research, 2008, Vol. 4, No. 6, pp. 147 – 157.
[10] PROCHOWSKA-KLISCH, B., MALECKI, A. Thermochimica Acta, Volume 335, Issues 1-2, September 1999, pp. 99-104.
[11] CHENEY, Ward, KINCAID, David. *Numerical Mathematics and Computing.* Fifth Edition. Belmont: Thomson Learning, 2004.
[12] LEPAGE, G.P. A New Algorithm for Adaptive Multidimensional Integration. In *Journal of Computational Physics*, 1978, 27, 192-203.
[13] LEPAGE, G.P. VEGAS: An Adaptive Multi-dimensional Integration Program. Cornell preprint CLNS 80-447, March 1980.
[14] HAMMERSLEY, J. M., HANDSCOMB, D.C. *Monte Carlo Methods*. Methuen. ISBN 0-416-52340-4, 1964.
[15] CAFLISCH, R. E. Monte Carlo and quasi-Monte Carlo methods. In *Acta Numerica*, 1998, vol. 7, pp. 1-49. Cambridge University Press.
[16] FAURE, H. Discrepance de suites associees a un systeme de numeration (en dimensions). In *Acta Arithmetica*, 1992, XLI, 337–351.
[17] HALTON, J. H. On the efficiency of certain quasi-random sequences of points in evaluating multi-dimensional integrals. In *Numer. Math*., 1960, 2, 84–9,.
[18] KARAIVANOVA, A., DIMOV, I. Error analysis of an adaptive Monte Carlo method for numerical integration. In *Mathematics and Computers in Simulation*, 1998, 47, 201–213.

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INFLUENCE OF Bi ON THE MICROSTRUCTURE EVOLUTION OF SOLDER JOINTS IN MICROELECTRONICS

Emil LECHOVIČ, Beáta SZEWCZYKOVÁ, Erika HODÚLOVÁ, Koloman ULRICH

Abstract

The aim of this article is study the influence of Bi on the microstructure evolution of lead-free solder joints in microelectronics. The key factors affecting the reliability of electronic products are the interfacial reactions in solder joints, the secondary products of which are brittle intermetallic compounds. Formation and growth of intermetallic compounds are dependent from the chemical composition of solder and base material, from the effects time of the moltent solder on the base material and from the operating temperature. It is very important to mention that these reactions occur not only near the contact of the base material and molten solder in the process of melting and cooling the soldered joint, but they continue even after the solder solidifies.

Key words

soldering, lead-free solder, reliability, intermetallic compound, bismuth

Introduction

The unhealthy effect of lead to the environment and human health has accelerated the research and development of solder in direction of a complete elimination of lead. Besides higher melting temperature and worse wettability (from different temperature profile, different flux...), the lead-free solders differ from the lead containing solders also by different electrical and mechanical properties.

The most of lead-free solder alloys are setup mainly to the addition of a small amount of the third and fourth alloys to the binary alloy in order to enhance their properties. Bismuth is added to the solder alloys in order to decrease the melting point, improve mechanical

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properties and increase of creep resistance. Bismuth also enhances the wettability, what can play the role in the use of lower soldering temperature [1, 4].

The alloy systems with the Bi addition are used by the Japanese producers of electronics. They use the alloys with high amount of Sn, mainly SnAgBi and SnAgCuBi.

The typical compositions were tested by the Japanese project NEDO (New Energy and Industrial Technology Development Organization) – SnBi3.0Ag2.0Cu0.5, and later by IMS (Intelligent Manufacturing Systems) project – SnAg3.0Bi2.0Cu0.5. Only a low amount of bismuth content is necessary to reduce melting temperature and achieve better wettability. The addition of higher amount, approximately 5-20% Bi, decreases the melting point to the temperature of eutectic SnPb solders, but good properties of SnAgCu alloy system disappear [6].

The influence of intermetallic compounds on the joint reliability

The most widespread questions regarding lead-free solder reliability is the growth of the intermetallic compounds which are localized on the interface between the solder and substrate. All the known base materials and coatings in electronic together with the active element (Sn) the molten solder form the intermetallic compounds (IMC) on the solder – substrate interface. Their occurrence on the contact area indicates that a good-quality metallurgical joint [2].

Unwanted is mainly the excessive IMC growth, induced by the joint heating in working process (changes of atmosphere temperature or temperature changes due to heat abstraction from the cover) and leading to the growth of IMC to the heavy thickness, and thus the solder – IMC interface becomes a source of cracks formation and spreading.

The growth begins at the room temperature and continues to the area of working temperature of electronics. The growth of layers and cracks brings about the degradation of mechanical and electrical properties which is manifested by the decrease of electrical conductivity of joint. The more cracks in the layer, the higher the transfer resistance, which causes higher heat strain of the joint and further extension of the layer and cracks. This process leads to the joint degradation and gradually to the non-functional joint [3, 7].

The excessive growth also consumes the basic metal and thereby gradually reduces the soldered joint. This may result into the adhesion loss to the substrate which is not wetted by the solder, or into the formation of cracks due to the strain in the intermetallic layer owing to its excessive thickness [3, 5].

Experiments

A four-element alloy SnAgCuBi with a small amount (0.5 and 1.0%) of bismuth was chosen for the experiment. The basic material used was Cu with 99.995 % purity, a frequently used material in electronics. The joints Cu – SnAg1.0Cu0.5Bi0.5 and Cu – SnAg1.0Cu0.5Bi1.0 were formed by hot plate soldering. The soldering temperature was 255 °C through 5 s.

The samples produced were subsequently annealed at 160 ° C for 15 days and were collected from the vacuum furnace at intervals of 1, 3, 7, 11 and 15 days. For observations of IMC (shape and size) present in the structure of solders and at the interface of soldered joints, light optical microscopy was used. To assess the representation of different phases present, the line EDX microanalysis was carried out.

Results

The microstructure of the interface of soldered joint *Cu - SnAg1.0Cu0.5Bi0.5* after the process of soldering followed by heat treatment are shown in Figs. 1a, b, c. After soldering (Fig. 1a), the structure of solders SnAgCuBi0.5 consists predominantly of fine-grained structure. The phases Cu_6Sn_5 and Ag_3Sn which change their shape and size after the heat affecting are dispersed in the volume of solder. These phases are formed from Ag and Cu, which are contained in the composition of solders.

Since the use of soldering materials based on Cu and Sn, formation of IMC Cu_6Su_5 can be observed at the interface of Cu-substrate/solder. The size of IMC layer does not get over 1μm. After annealing, another reaction layer is formed at the interface of substrate and Cu_6Su_5phase documented as Cu_3Sn (Fig. 1b). From Fig. 1b, 1c it is evident that with increasing annealing time the thickness of the IMC at the interface and also increasing while causing significant thickening of solder’s structure.

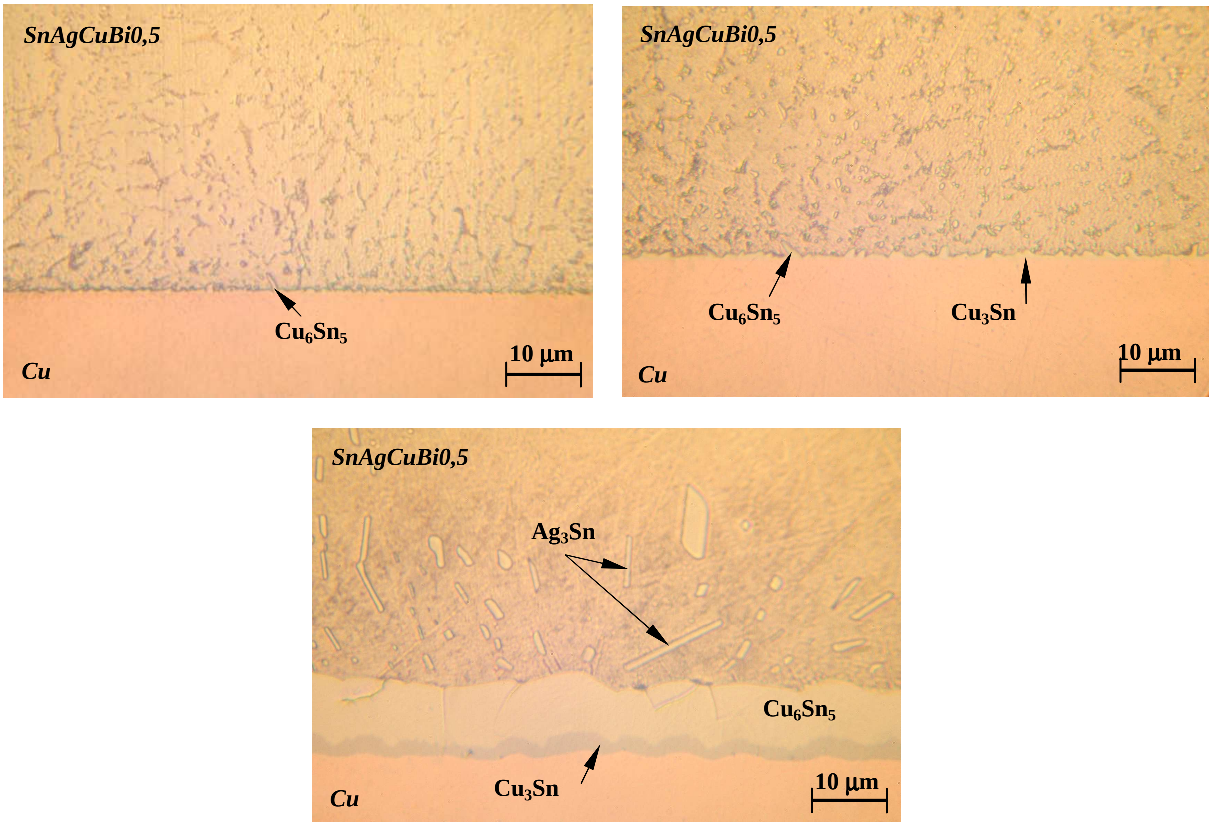

Fig. 1 *Microstructure of the interfacial area of Cu-SnAg1.0Cu0.5Bi0.5 soldered joint*

a) after soldering T = 255 °C, t = 5 s

b) aged at 160 °C for 24 h

c) aged at 160 °C for 360 h

Growth of Cu_3Sn phase can be explained by the fact that the big thickness of Cu_6Sn_5 phase leads to Cu diffusion at the interface, and, due to the lack of Sn, a phase rich in Cu (Cu_3Sn) appears at the interface of the soldered joint. And vice-versa, if Sn phase is located close to the interface, the growth of phase Cu_6Sn_5 is faster and reaches greater thickness due to the reaction of Sn with Cu.

Morphology of the IMC is significantly different. IMC Cu_6Sn_5 is initially characterized by its high inequalities in comparison with laminated Cu_3Sn phase. Over time, however, serrated shape of Cu_6Sn_5 phase takes laminated shape with a unique layered scallop. During the longest time of annealing 360 hrs (Fig. 1c), a relatively continuous layer of the two phases of average thickness of 22 µm was formed. The thickness of the IMC in view of the mechanical properties of the phases can be considered large enough for the joint to be reliable.

In Figs. 2 and 3 of the line EDX microanalysis, the structure of heat affected soldered joint together with the individual increased phases can be observed. The line analysis confirms the presence of Ag_3Sn and Cu_6Sn_5 phases near the interface. Generally, however, larger particles tend to Cu_6Sn_5 phase and smaller particles to Ag_3Sn phase.

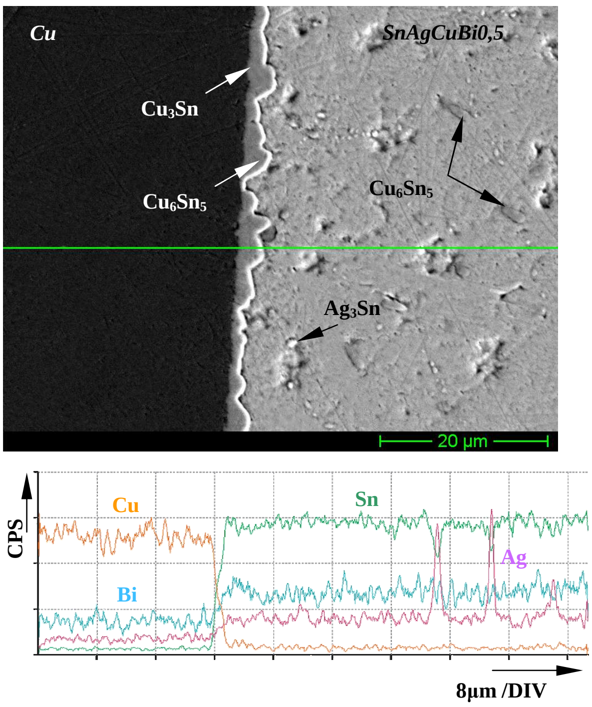

Fig. 2 *Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi0.5 solder joint interface aged at 160 °C for 24 h*

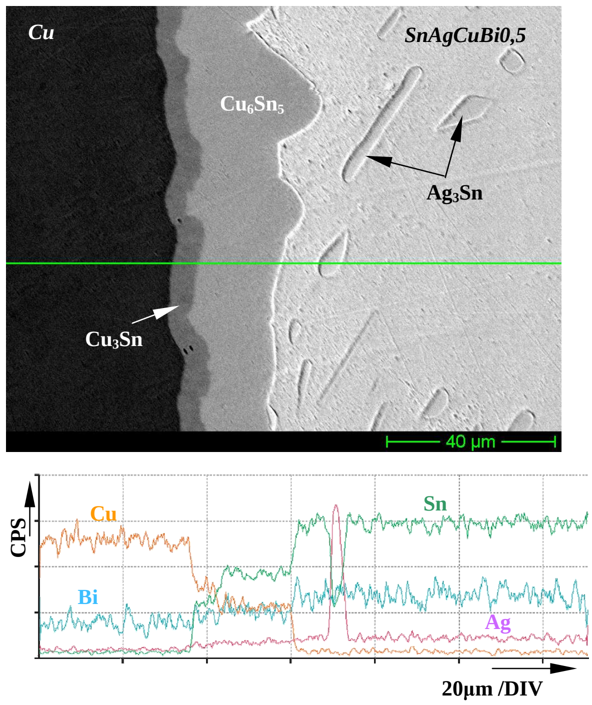

Fig. 3 *Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi0.5 solder joint interface aged at 160 °C for 360 h*

Structure of solder *SnAg1.0Cu0.5Bi1.0* after soldering shows granular structure. Apart from scattered Ag_3Sn phase of various shapes and dimensions, the formation of Cu_6Sn_5 in the form of the letter "F" was observed in the volume of solder. During the annealing of solder joints, there is a change in the growth and shape of IMC.

The sequence of formation at the IMC is the same as in SnAnCuBi0.5 solder, i.e. as the first is the formation of Cu_6Sn_5 phase, and up to the heat affected is the formation of the second phase of Cu_3Sn (Fig. 4b, c). Similarly, during the annealing, the surface of IMC Cu_6Sn_5 also smoothens, but more intensively. It changes from serrated shape to scallop one. "Smoothing" is the most intensive after the longest time of annealing (Fig. 4c).

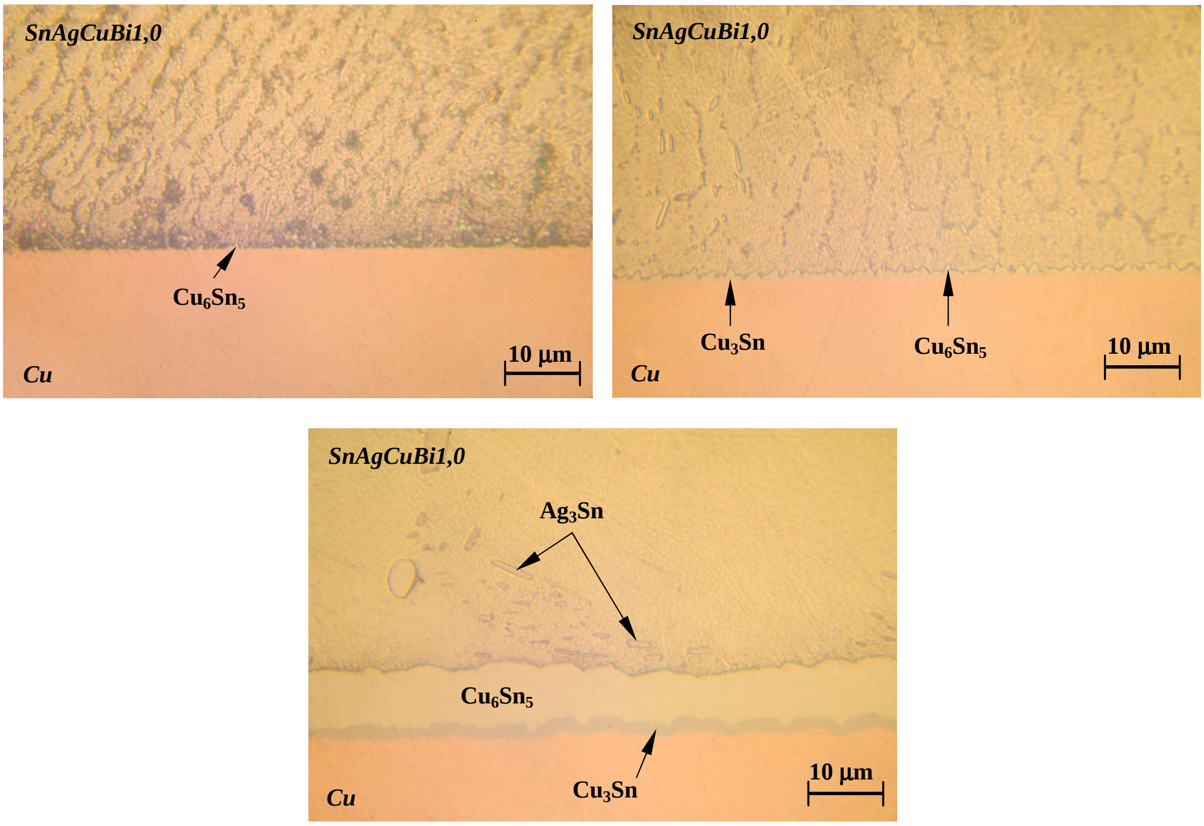

Fig. 4 *Microstructure of the interfacial area of Cu-SnAg1.0Cu0.5Bi1.0 solder joint*

a) after soldering T = 255 °C, t = 5 s

b) aged at 160 °C for 24 h

c) aged at 160 °C for 360 h

When compared with the solder containing less Bi, the thickness of IMC decreased at the interface. SnAgCuBi1.0 solder also varies in the thickness of phases (Ag_3Sn and Cu_6Sn_5) located in the volume and quantity of solders projecting long-scallop skewer (Cu_6Sn_5 phase) of the interface to solders. These changes, microstructure refinement, can be attributed to greater number of particles Bi contained in Sn-rich areas.

The line EDX-microanalysis (Figs. 5 and 6) of Cu - SnAgCuBi1.0 joint confirms the close interface, which is made of Cu_3Sn and Cu_6Sn_5 phases. This was confirmed by the unique occurrence of Ag_3Sn phases in gross IMC Cu6Sn5. As in the solder SnAgCuBi0.5, the presence of Bi precipitates in Sn-rich areas of the EDX microanalysis failed.

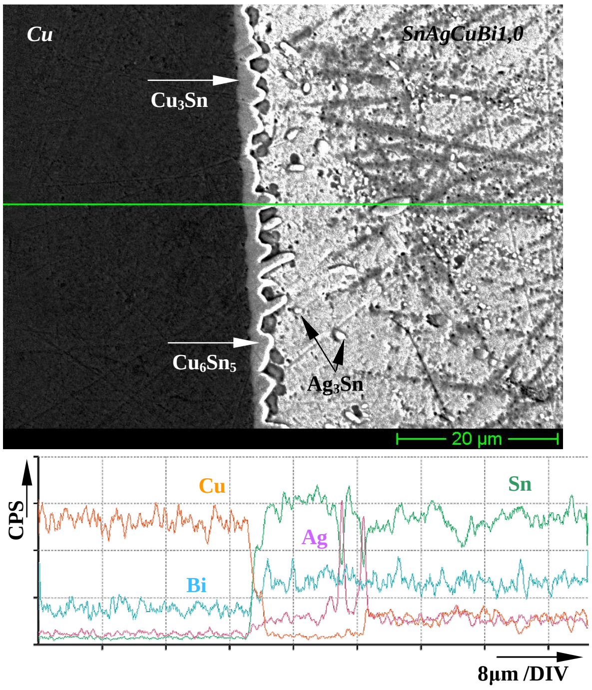

Fig. 5 *Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi1.0 solder joint interface aged at 160 °C for 24 h*

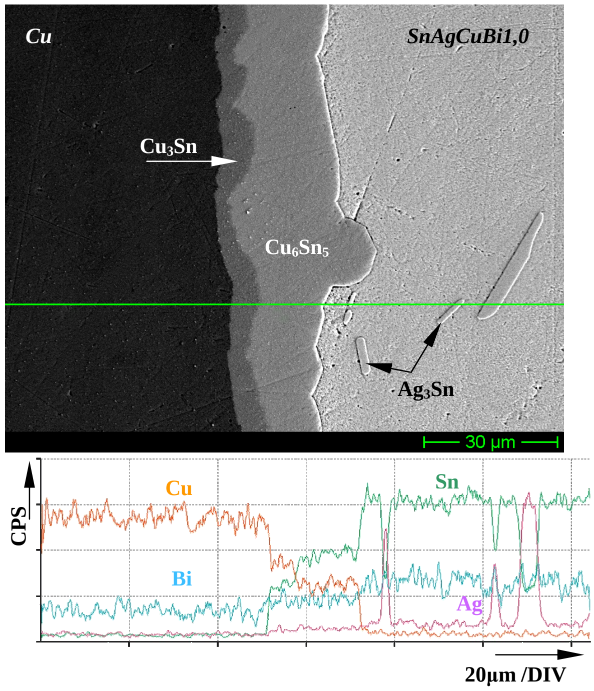

Fig. 6 *Linear EDX microanalysis of Cu – SnAg1.0Cu0.5Bi1.0 solder joint interface aged at 160 °C for 360 h*

Conclusion

From the results of the study of interface the soldering lead-free joints it is clear that, during the annealing (aging) services, there are significant structural changes. Adding 1% Bi to system of SnAgCu alloy leads to refinement of grain size of intermetallic phases in the volume of solders and suppressing the growth layers of intermetallic phases at the interface in soldering joints and thus to the improvement of the reliability of joints. The presence of Bi precipitates owing to the low content (0.5 and 1.0%) of Bi alloys in the systems of SnAgCuBi was confirmed.

Acknowledgement

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References:

[1] LECHOVIČ, E. et al. Spoľahlivosť a životnosť bezolovnatých spájkovaných spojov. In *Zvárač*, 2008, roč. 5, č. 4, s. 10-13. ISSN 1336-5045

[2] MATTILA, T. *Metallurgical Factors Behind the Reliability of High-Density Lead-Free Interconnections*. Helsinki: University of Technology, 2007. ISBN 0-387-27974-1

[3] LAURILA, T., et al. Interfacial reactions between lead-free solders and common base materials. In *Materials Science and Engineering*, 2005, roč. 49. [online]. < http://www.elsevier.com/locate/mser>

[4] SUGANUMA, K. *Lead-Free Soldering in Electronics: Science, Technology, and Environmental Impact.* New York: Marcell Dekker, 2004. ISBN 0-8247-4102-1

[5] SPIŠÁK, E., BEŇO, J., TOMÁŠ, M., VIŇÁŠ, J. *Teória konvenčných technológií*. Košice: SjF TU, 2009, 162 s.

[6] VIŇÁŠ, J., KAŠČÁK, Ľ. Analýza kvality spoja zhotoveného MIG spájkovaním na karosérii osobného automobilu. In *Transfer inovácií,* 2008, č. 11, s. 171-173. ISSN 1337-7094

[7] FREAR D. R. Issues related to the implementation of Pb-free electronic solders. In *Consumer electronics*, Business Media, 2006. [online]. <http://www.tms.org/pubs/journals/JOM/>

[8] LECHOVIČ, E. *Vplyv Bi na životnosť a spoľahlivosť spojov vyhotovených bezolovnatými spájkami*. Diplomová práca. Trnava: Ústav výrobných technológií MTF STU, 2008.

[9] VIŇÁŠ, J., KAŠČÁK, Ľ., DRAGANOVSKÁ, D., ÁBEL, M. Faktory vplývajúce na kvalitu MIG spájkovaných spojov pozinkovaných oceľových plechov. In *Acta Mechanica Slovaca*, 2008, roč. 12, č. 3, s. 501-506. ISSN 1335-2393

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CONTRIBUTION TO THE INVESTIGATION OF SURFACE ROUGHNESS MODELS OF GRINDED PLASMA-JET SPRAYED CERAMIC COATINGS

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Abstract

Ceramic coatings acquired by plasma-jet spraying are considerably rough and inaccurate as for dimensions. To achieve a smooth and accurate surface, it is necessary to shape them and improve their technological properties. The surface roughness is one of these properties.

Key words

ceramic coating, roughness, surface, plasma-jet spraying

Introduction

Real surface can be formed by one or several layers of various chemical compounds or various textures and properties. These layers can originate in natural way as a result of production and utilisation of parts (hardening, oxidation) or in artificial way by deposition. Several techniques of deposition with different structure of layer can be used. These layers on surface can be called surface layers (subsurface layers) or coatings, too.

Properties of coatings

Coatings might have some properties similar to core properties even when coatings' composition does not differ too much from the core´s composition. Other properties might completely differ from the properties inside the part. These properties can be geometrical

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(length parameters), mechanical (e.g. hardness, strength), physical (e.g. thermal and electrical conductivity), chemical (e.g. anticorrosion), technological (e.g. machinability and welding property).

Sometimes, a coating can have inapt geometric and others properties (e.g. high roughness and porosity) and it is necessary to modify them. This can be done by removing a damaged or affected layer. Layers are added and removed by various technologies. When the size of an added or removed layer is in a micrometre scale, then micro technologies can be applied. Similarly, Nano and Pico technologies can be used.

Layers with specific properties are made by Plasma Spraying on material's surface, e.g. wear proof or electrically insulating coatings. Sometimes, mechanical treatment may cause cracks and then local or general unstuck of coating occurs. It is primarily a consequence of the fact that individual characteristics of coatings (e.g. material of coating, its structure and mainly the type of binding between the coating and material) were not taken into account.

Basic characteristics of coating shot plasma arc

Ceramic coating Al_2O_3 + 13 % TiO_2 which was made by plasma spraying of powder AMDRY 6224 compound was chosen, on which intermediate layer NiAl (powder AMDRY 956) was applied. The device used was Plasma – Technic Co SNECMA system at IMMM: Slovak Academy of Sciences and the background material was cylindrical aluminium alloy with dimensions D40x30. The thickness of coating was 0.6mm.

In plasma spraying technology, material is fed into plasma beam in a powder form. In plasma beam, powder particles are heated, melted and accelerated by exhalants of plasma gas and collide with roughed surface of material. After impact, distorting the shape of flat disc, they cool quickly to form a typical layered structure. The temperature in the longitudinal and transverse direction of the plasma beam is not the same, but it decreases with the distance from the beam axis. Individual particles of a different size are moving in the plasma beam using different paths, and heat up themselves to melting and evaporation temperatures. Typical structure of coatings with much non-homogeneity is gradually formed by the deformed particles. Non-homogeneity is caused mainly by non-deformed particles that are formed due to the fact that their heating temperature in plasma beam is low or it dropped before they had rammed the surface. The coating also contains pores, cracks and jet material particles on the surface of the substrate, and the new phases formed during heating or cooling the coating layers.

Those coatings are formed to overlap the different deformed particles distributed unevenly. The result is a film which has a rough surface with pores. This also applies to other types of metallic and ceramic plasma sprayed coatings. Roughness of the coating is mainly dependent on the grain size powders. The surface coating has a roughness which is usually higher than the usual requirements for the quality of surface of mechanical parts. Regarding the dimensional requirements, it is necessary not only to finish (smooth) the surface of coating, but also to machine it to the requested size. Potential ways of coating´s machining are listed below.

Coatings processing

As mentioned above, to perform dimensional correction of a coated part, it is necessary not only to reach requested roughness, but also machine the coating in order to reach requested dimensions. However, adding another layer of coating (plasma spraying) usually does not improve dimensional accuracy; there is a need to find a way how to correct the size by removing a thin subsurface layer of the coating. In case of machining of cylindrical surfaces (in the case of our samples), turning, grinding, polishing and superfinishing can be taken into account. The last two methods require a combination with grinding, as there are stricter requirements for them regarding the previous operations or starting state of the surface. This particularly concerns superfinishing, regardless the needs of a special superfinishing machine and tool, and therefore plasma sprayed coatings are not considered so far.

Subsequent turning of coatings is not taken into account, because the turning of coatings is suitable for coatings with lower hardness and these were not the subject of our investigation. Our interest is focused on the grinding of coatings in particular.

The choice of the method and conditions of machining will depend on the strength of ties in the interface (i.e. when the coating does not peel off), we may seek the conditions for cultivation (mainly cutting rates), making it possible to achieve the desired surface roughness and dimensional accuracy of parts. Cutting process is evaluated by various parameters such as life of the cutting tool, cutting force (or its components), roughness of the machined surface, shape of chips and so on. Basic characteristics of the cutting process in machining coatings are cutting force (components and specific cutting resistance) and the temperature of the cutting. Cutting force and cutting temperature grow with increasing the cutting depth of the layer displacement, the absolute value of a negative angle of the forehead and the hardness of the coating. Cutting speed has a significant influence on the cutting temperature. In addition, cutting force and cutting temperature also affect other properties of the coating (e.g. thermal conductivity), and other machining conditions (cooling, lubrication, etc.). Cutting force has components, which tend to rip lamella coatings from each other or the entire coating from the base. This is true for almost all modes of machining.

Adhesion of coating to the substrate is about ten times lower when compared with the strength of the compact material, and therefore the application of the same machining conditions suitable for compact materials usually leads to success in machining coatings.

Successful machining of plasma spraying coatings primarily depends on:

- the coating material, its structure and physicochemical properties,
- the selection of the way and conditions of machining.

Size of cutting forces and temperature can influence particular choice of cutting ratios (cutting speeds, feed and depth of cutting layer). In their determination, we must take into account the restrictions on the exercise machine, the required durability of the instrument, the required surface roughness and adjustable levels of cutting conditions for the machine. As it is the same group of variable cutting conditions, the determination of the cutting ratios has to be considered as an optimisation issue.

Current plasma spraying coating thicknesses are about 0.6 mm in the light of the necessary layer collected. Considering the functional coating thickness 0.3 mm, total machining allowance is approximately 0.3 mm.

Grinding of plasma sprayed coatings

Ceramic coatings can be machined by super-hard cutting materials such as corundum Al_2O_3, SiC carbon corundum, $_{kub}C$ diamond and cubic boron nitride $_{kub}NB$. These cutting materials are used for grinding tools; therefore, grinding is the main method of machining of ceramic materials.

Grinding is characterized by removing small slits on the cut layer and a large (indefinite but limited) number of teeth in gear (grinding grains) with random geometry. Average value of the instrument´s orthogonal face angles is negative (around-30°). Furthermore, there is a high cutting speed resulting in high cutting temperature. Abrasive grains are gradually worn and abrasive wheel is filled with waste products of grinding which rises the cutting temperature and cutting force. Properties of grinding wheels and grinding conditions should be appropriately determined in order to avoid overheating of the surface layers of the coating, the emergence of crack, or peeling off. Grindstone is characterized by abrasives, abrasives texture, types of links (bonding materials), the hardness of the bonds, the structure (porosity), or impregnation of binder.

Basic recommendations for the choice are:

- Select an abrasive material with low wear rate, is easy to chop and restore cutting edge (diamond, cubic boron nitride, silicon carbide)
- Select granularity according to the type of operation (bigger grain size for roughing and smaller grain size for finishing)
- Hardness of the bonds must ensure release of blunted grains from the grinding disc. Therefore, select soft disks (hardness bond marked J and K)

Metal binding is suitable for diamond grinding wheels for roughing, and bitumen binding for finishing.

Cutting rates should be in the following limits: Depth of the cutting layer should be in the range from 0.002 to 0.02 mm (larger for roughing, smaller for finishing). The feed rate of workpiece should be in the range from 80 to 300 $mm.min^{-1}$. Peripheral speed of grinding disc (cutting speed) should be in the range 15-35 ms-1, while rather lower rates are recommended.

Due to the existence of pores in the coating, the grinded surface is more opaque when compared to the grinded surface of the steel. When grinding, it is recommended to use suitable cooling fluid of 3 to 5% solution of H emulsion.

Mathematical model of experiment

A study of parameter grinded surface coat´s will arithmetic mean deviation of assessed profile Ra. Regarding the circumferential speed of workpiece v_0, feed rate of workpiece v_f and depth of cut, etc., dependence of power type can be assumed

$$Ra = C_{Ra} \cdot v_0^{C_1} \cdot v_f^{C_2} \cdot a_p^{C_3}, \tag{1}$$

which is transformed to a linear formula

$$\log Ra = \log C_{Ra} + c_1 \log v_0 + c_2 \log v_f + c_3 \log a_p, \tag{2}$$

which can be presented as the following linear mathematical model of shape

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 \tag{3}$$

and if x0 = 1, we get

$$y = b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 \quad . \tag{4}$$

The challenge is to determine the coefficients b_0, b_1, b_2, b_3. This must be ascertained experimentally, for example method of planning experiments. The above mentioned variables v_0, v_f, etc. are called the natural factors and variables x_0, x_1, x_2, x_3 are called coded factors. The natural factors determine the upper, lower and middle level setting values for the experiments, ie v0max, v_{0min}, v_{0str}, v_{fmax}, v_{fmin}, v_{fstr}, a_{pmax}, a_{pmin}, a_{pstr}, and transformation

$$x_1 = \frac{2(\log v_0 - \log v_{0\max})}{\log v_{0\max} - \log v_{0\min}} + 1 \tag{5}$$

$$x_2 = \frac{2(\log v_f - \log v_{f\max})}{\log v_{f\max} - \log v_{f\min}} + 1 \tag{6}$$

$$x_3 = \frac{2(\log a_p - \log a_{p\max})}{\log a_{p\max} - \log a_{p\min}} + 1 \tag{7}$$

the received upper, lower and middle levels of the coded factors x1, x2, x3 in the values 1, -1, 0, although fictitious factor x0 is a constant value 1^{st}.

Plan of experiments for the linear model can be illustrated by Fig. 1.

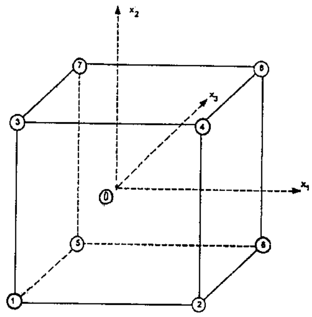

Fig. 1 *Model plan of experiments*

where the set values for the experiment is shown at the top of the cube. Peaks can be numbered as paragraphs 1 to 8, e.g. for point 1, set in the experiment values v0min, v_{fmin}, a_{pmin} for Item 4, set in the experiment values v0max, v_{fmax}, a_{pmin}. Point 0 is at the centre of the plan and shall be subject to the set value v_{0str}, v_{fstr}, a_{pstr}. We developed a matrix plan of experiments using the following Table 1.

Table 1

Point of plan i	$\mathbf{v_0}$	$\mathbf{v_f}$	$\mathbf{a_p}$	$\mathbf{x_0}$	$\mathbf{x_1}$	$\mathbf{x_2}$	$\mathbf{x_3}$	$\mathbf{y_i}$ **log Ra**	$\mathbf{x_{1i},y_i}$	$\mathbf{x_{2i},y_i}$	$\mathbf{x_{3i},y_i}$
1	v_{0min}	v_{fmin}	a_{pmin}	+1	-1	-1	-1	y_1	$-y_1$	$-y_1$	$-y_1$
2	v_{0max}	v_{fmin}	a_{pmin}	+1	+1	-1	-1	y_2	$+y_2$	$-y_2$	$-y_2$
3	v_{0min}	v_{fmax}	a_{pmin}	+1	-1	+1	-1	y_3	$-y_3$	$+y_3$	$-y_3$
4	v_{0max}	v_{fmax}	a_{pmin}	+1	+1	+1	-1	y_4	$+y_4$	$+y_4$	$-y_4$
5	v_{0min}	v_{fmin}	a_{pmax}	+1	-1	-1	+1	y_5	$-y_5$	$-y_5$	$+y_5$
6	v_{0max}	v_{fmin}	a_{pmax}	+1	+1	-1	+1	y_6	$+y_6$	$-y_6$	$+y_6$
7	v_{0min}	v_{fmax}	a_{pmax}	+1	-1	+1	+1	y_7	$-y_7$	$+y_7$	$+y_7$
8	v_{0max}	v_{fmax}	a_{pmax}	+1	+1	+1	+1	y_8	$+y_8$	$+y_8$	$+y_8$
$\mathbf{\sum = 8}$				8	0	0	0	$\sum y_i$	$\sum x_{1i}y_i$	$\sum x_{2i}y_i$	$\sum x_{3i}y_i$

i = 1 to 8, N = 8 (the number of points)

then the coefficients will be:

$$b_0 = \frac{1}{N}\sum x_{0i}y_i = \frac{1}{N}\sum y_i \, , \tag{8}$$

$$b_1 = \frac{1}{N}\sum x_{1i}y_i \, , \tag{9}$$

$$b_2 = \frac{1}{N}\sum x_{2i}y_i \, , \tag{10}$$

$$b_3 = \frac{1}{N}\sum x_{3i}y_i \, . \tag{11}$$

Obtaining the coefficients b_0, b_1, b_2, b_3, and their substitution into (3), which also represents the transformation relations (5), (6), (7) we receive a specific formula (2) and its specific antilogarithm formula (1) for our experiments.

Place of formula (1), which is dimensional non-homogeneous, we can use dimensional homogeneous shape of the equation:

$$Ra = C'_{Ra} \cdot \left(\frac{v_0}{v_{0str}}\right)^{C_1} \cdot \left(\frac{v_f}{v_{fstr}}\right)^{C_2} \cdot \left(\frac{a_p}{a_{pstr}}\right)^{C} \, , \tag{12}$$

here we need to consider the following transformation relations

$$x_1 = \frac{2\left(\log\frac{v_0}{v_{0str}} - \log\frac{v_{0max}}{v_{0str}}\right)}{\log\frac{v_{0max}}{v_{0str}} - \log\frac{v_{0min}}{v_{0str}}} + 1 \, , \tag{13}$$

$$x_2 = \frac{2\left(\log\frac{v_f}{v_{fstr}} - \log\frac{v_{f\,max}}{v_{fstr}}\right)}{\log\frac{v_{f\,max}}{v_{fstr}} - \log\frac{v_{f\,min}}{v_{fstr}}} + 1, \tag{14}$$

$$x_3 = \frac{2\left(\log\frac{a_p}{a_{pstr}} - \log\frac{a_{p\,max}}{a_{pstr}}\right)}{\log\frac{a_{p\,max}}{a_{pstr}} - \log\frac{a_{p\,min}}{a_{pstr}}} + 1 \tag{15}$$

then in Table 1 for values v_0, v_f, then is needed to used denominators v_{0str}, v_{fstr}, a_{pstr}. Calculation of the coefficients b_0, b_1, b_2, b_3, however, will be under (8), (9), (10), (11). Equations (1) and (12) have different constants C_{Ra} and C'_{Ra}.

Eventually we can use standard equation for calculating the physical quantities of Ra, depending on the variables X_1, X_2, X_3, instead of equation (1):

$$Ra = K \cdot X_1^{e_1} \cdot X_2^{e_2} \cdot X_3^{e_3} \ldots \, , \tag{16}$$

where K is a numerical constant dependent on the choice of X_1, X_2, X_3. . . relevant variables, and e_1, e_2, e_3. . . the numerical exponent (integer or fragments).

Then a system of physical units has to be specified so that each relevant variable has a physical dimension. Units can be selected with respect to SI. Then exponents e_1, e_2, e_3. . . should be taken so as the monitored variable gets the dimension with respect to SI. These requirements are rather due to the fact that it is recommended to use the SI, and not because it is the only way possible.

Further on, the procedure well known from the matrix calculus can be used. We can proceed as follows:

- Construct the dimensional matrix so that we will enter the dimensions (length L, mass M, time T, the temperature θ) into the heading of matrix lines, while we will write involved values into the headings of matrix columns.
- The acquired dimensional matrix can be divided into two sub-matrices from the top so that the first sub-matrix (the upper one) will be square and called a basic dimensional matrix P. The other sub-matrix is called an additional dimensional matrix Q. Basic dimensional matrix must be regular (with non-zero determinant), if not, the regularity can be achieved so that one line is replaced by another line of sub-matrix Q. -
- Determine the basic rank-dimensional matrix P.
- According to Buckingham Theorem, dimensional equation with values of X_i:

$$\varphi(X_1, X_2, X_3 \ldots X_n) = 0\, , \tag{17}$$

can be transferred to the formula with non-dimensional parameters π_i:

$$\psi(\pi_1, \pi_2, \pi_3 \ldots \pi_m) = 0 \, , \tag{18}$$

then it is always m <n:

$$m = n - r\,, \tag{19}$$

where r is the rank of the matrix p.

- According to the rules of matrix number, we will find the inverse matrix P 'to matrix P, then we will find the coefficient of matrices QP', then we determine the matrix-QP' to matrix QP,' and after that we will attach a unit matrix Ito the system, obtaining thus the matrix E, which is the exponent matrix of the variables e_{ij} for individual π - parameters.

$$\pi_i = X_1^{e_{i1}} \cdot X_2^{e_{i2}} \cdot X_3^{e_{i3}} ... X_n^{e_{in}} \tag{20}$$

Formulas (5) for individual π – parameters are called primary definition formulas.

- Then write so-called "criterial equation":

$$\pi_0 = \pi_1^{u_1} \cdot \pi_2^{u_2} \cdot \pi_3^{u_3} ... \pi_m^{u_m}\,, \tag{21}$$

where π_0 and u_i are constants to be determined.

- Finally, from criterial equation, we eliminate the searched value, thus getting so called fundamental equation, for example in the form

$$Ra = k \cdot a_p \left(\frac{v_f}{v_0} \right)^e, \tag{22}$$

where vf is the feed rate of the workpiece.

Experimental conditions and results of grinding of ceramic coatings

BUA 16 grinder which had two C 49 80 K 9V and D63/50 K100 B III grinding discs was used for grinding. A modified lathe SV 18 R with abrasive (polishing) Al2O3 grain belts of 120 and 400 (fine) and SiC particle size 240 (rather fine) was used for polishing. Corundum grains (Al_2O_3) size 40, 63, 100 (coarse and fine) were used for blasting.

To detect the surface roughness, Surtronic the 3 + (Rank Taylor Hobson Ltd.) was used.

Grinding conditions were for grinding with grinding disc of silicium carbide as follows:

- Cutting speed (circumferential speed of grinding wheels) v_c = 30 m / s
- Circumferential speed of workpiece = 20 m / min
- Longitudinal feed f = 4.5 mm
- Depth of cutting layer a_p = 0.005 mm

Grinding conditions for grinding diamond grinding wheels were as follows:

- Cutting speed (circumferential speed of grinding wheels) v_c = 30 m / s
- Circumferential speed of workpiece = 20 m / min
- Longitudinal displacement f = 4.5 mm
- Depth of cutting layer a_p = 0.01 mm

Conditions of polishing with the above-mentioned abrasive belts were as follows:

- Polishing speed v = 11.3 m / s
- Longitudinal feed with hand

For a method of planned experiments on grinding dia-disc D 107 C 100 B VII (thicker size, mean concentrations and harder of phenol-formaldehyde bonding) conditions were:

- v_c = 30 m / s
- v_{0min} = 17.59 m / min
- v_{0max} = 35.18 m / min
- v_{fmin} = 750 mm / min
- v_{fmax} = 1500 mm / min
- a_{pmi}n = 0.02 mm
- a_{pmax} = 0.04 mm
- v_{0str} = 25.13 m / min
- v_{fstr} = 1000 mm / min (F_{STR} = 5 mm, $n_{w\ str}$ = 200 min-1)
- $v_f = f.n_w$
- a_{pstr} = 0.025 mm

where n_w is the frequency of rotation of the workpiece.

Results obtained were as follows:

- Arithmetic mean deviation of assessed profile Ra on the basis of AlCu4Mg after spraying plasma showed values of roughness Ra 5.01 ± 0.29 μm
- Interlayer NiAl (0.055 mm) after spraying plasma showed values of roughness Ra = 6.15 ± 0.9 μm
- Ceramic coating Al_2O_3 + 13% TiO_2 (0.5 mm) after spraying plasma showed values of roughness Ra = 3.16 ± 0.29 μm
- Ceramic coating Al_2O_3 + 13% TiO_2 after buffing wheel siliciumcarbid showed values of roughness Ra = 0.83 ± 0.22 μm
- Ceramic coating Al_2O_3 + 13% TiO_2 after diamond grinding wheel showed values of roughness Ra = 0.82 ± 0.23 μm
- Ceramic coating Al_2O_3 + 13% TiO_2 after abrasive belt (which was polished) with Al_2O_3 grains size 120 and 400 showed values of roughness Ra = 1.67 ± 0.46 μm
- Ceramic coating Al_2O_3 + 13% TiO_2 after abrasive belt (which was polished) with Al_2O_3 and SiC grains 120 grain 240 showed values of roughness Ra = 1.23 ± 0.51 μm.
- A method of planning experiments at grinding with by diamond grinding wheel, we found dependence (for Ra_i = 0.9, 0.95, 0.96, 1.00, 1.00, 1.06, 1.17, 1.52 mm)

$$Ra = 0{,}37 \cdot v_0^{0{,}15} \cdot v_f^{0{,}23} \cdot a_p^{0{,}29} \qquad [\mu m]\ , \tag{23}$$

$$\text{resp. } Ra = 1{,}02 \cdot \left(\frac{v_0}{25{,}13}\right)^{0{,}15} \cdot \left(\frac{v_f}{1000}\right)^{0{,}23} \cdot \left(\frac{a_p}{0{,}025}\right)^{0{,}29} \quad [\mu m] \tag{24}$$

and also

$$Ra = 0{,}37 \cdot v_0^{0{,}15} \cdot f^{\,0{,}23} \cdot n_w^{0{,}23} \cdot a_p^{0{,}29} \qquad [\mu m] \tag{25}$$

$$Ra = 1{,}02 \cdot \left(\frac{v_0}{25{,}13}\right)^{0{,}15} \cdot \left(\frac{f}{5}\right)^{0{,}23} \cdot \left(\frac{n_w}{200}\right)^{0{,}23} \cdot \left(\frac{a_p}{0{,}025}\right)^{0{,}29} \quad [\mu m] \tag{26}$$

if h_{eq} is equivalent thickness of chips and formula as follow (for external grinding to round)

$$h_{eq} = \frac{v_0 \cdot f \cdot a_p}{60 \cdot v_c \cdot b_s} = \frac{v_0 \cdot v_f \cdot a_p}{60 \cdot v_c \cdot n_w \cdot b_s} \quad [\text{mm}] \tag{28}$$

b_s is the width of grinding disc [mm] .

Discussion

We have not found the formulas for grinding of coatings similar to ours (formula 23 to 28) in the professional literature, Similar relations are known for grinding the compact materials. Maslov [9] found the relationship:

$$Ra = \left(490 \cdot v_c^{-0,97} \cdot d_w^{-0,15} \cdot b_s^{-0,15}\right) \cdot a_p^{0,56} \cdot f^{\,0,75} \cdot v_0^{0,68} \quad [\mu\text{m}]\ . \tag{29}$$

The term in parentheses is based on the variability of the cutting speed v_c, workpiece diameters d_w and width (thickness) grinding disc b_s, and f is axial displacement. When considering the frequency of rotation of the workpiece nw, the relationship (41) can be rewritten using the formula

$$Ra = \left(490 \cdot v_c^{-0,97} \cdot d_w^{-0,15} \cdot b_s^{-0,15} \cdot n_w^{-,075}\right) \cdot a_p^{0,56} \cdot v_f^{\,0,75} \cdot v_0^{0,68} \quad [\mu\text{m}]\ , \tag{30}$$

while the expression in brackets is replaced by the constants in our formula (23) to (28). Formula (29) resulted from the experiments. In larger scale experiments, more values can be considered, however in equation (29) they are taken into account by the constant 490. These values can be: the coefficient of rigidity of grinding machine tool and tool holder, the coefficient of the properties of grinding wheel (multiplication of abrasive coefficient, binding type coefficient, binding hardness coefficient, binding impregnation coefficient, granularity coefficient and coefficient of porosity of grinding wheel), the coefficient of cutting fluid properties, the coefficient of grinding time (number of strokes) and the coefficient of spark-out time (number of spark-out strokes).

Values of exponents of cutting conditions' parameters are more interesting than the above mentioned constant. Formula (29) also says that roughness of grinded surface is affected mostly by feed velocity (in axial direction), and then by tip velocity of work piece, and finally by the depth of the cut (stroke, feed, etc.). However, experiments brought the following rate: depth of cut, feed velocity and at least tip velocity. This can be justified as follows:

When grinding very hard materials (including coatings), grinding wheel is markedly worn, the rate material removal declines and more material is pushed away. Feed and particularly infeed (stroke, depth of cut) can be used to overcome the deformation forces by cutting forces. Infeed can therefore substantially influence the material removal rates and also roughness of the grinded surface.

Conclusion

The achieved results can be taken into account for coatings' machinability, also called micro-machinability. At present, it can be considered as absolute micro-machinability according to the achieved surface roughness (absolute micro-geometric micro-machinability), because we did not define standard conditions including standard instrument, and so we could not yet determine the relative machinability achieved by buffing the surface roughness (relative micro-geometric micro-machinability grinding). If machinability by grinding we called grindibility, we could talk about the absolute or relative micro-geometric micro-grindibility.

Ceramic and hard metal coatings obtained by plasma spraying exhibit high roughness, porosity, and indeed cannot always meet the requirements of the manufacturer on the quality of the surface. It must therefore be carefully grinded to avoid overheating of the surface layer coating (may cause cracks) and possibly to avoid possible peel off coating from the substrate and to prevent the deterioration of the bearing curve profile, which should result in a decrease in carrying capacity of the surface coating, increased friction and wear in the possible exploitation of a coated part.

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References:

[1] PÁLKA, V. Machining plasma arc sprayed coatings. In *Zváranie,* 1997, č. 4, pp. 73-76.

[2] PÁLKA, V., POŠTRKOVÁ, E., KRSEK, A., LIPA, Z. Surface roughness of coatings plasma spraying after grinding. In *Nové smery vo výrobných technológiách*. Prešov: 1998, s. 285-287.

[3] PÁLKA, V., LIPA, Z., CHARBULA, J., GŐRŐG, A. Machining of hard metal coatings, plasma spray coated. In *Technológia´99*. Bratislava, 1999, pp. 563-565.

[4] CHANDLER, P.E. *Improving the bonding of plasma sprayed coatings*. Marchwood Engineering Laboratories, 1985.

[5] BUMBÁLEK, B., NOVÁK, Z., VALA, D. *Rating of ceramic coating surface roughness after grinding*. Brno: Výskumná správa VÚ 070, 1989.

[6] BÉKÉS, J. *Analysis and synthesis of engineering objects and processes*. Bratislava: ALFA, 1986.

[7] BUDA, J., BÉKÉS, J. *Theoretical foundations of metal cutting*. Bratislava: ALFA, 1977.

[8] LIPA, Z., PÁLKA, V., JANÁČ, A. Dimensional analysis as a means of investigation of cutting forces and surface roughness. In *Zborník medzinárodného kongresu MATAR 2000, sekcia 4, Technologie obrábění a tváření*. Praha: 2000, pp. 69-73.

[9] MASLOV, J. N. *Theory of metal grinding*. Praha: SNTL, 1979.

[10] INASAKI, I. I. Surface Grinding Machine with lin. mat. driven. In *CIRP Annuals*, 1999, pp. 243-246.

[11] PETERS, J. Contribution of CIRP research to industrial problem in grinding. CIRP Annuals 33, č. 2, 1984. Saljé, E – Damlas, H. H.- Mőhlen, M.: Interval grinding of high strength ceramic with diamond. CIRP Annuals 1985, pp. 263-266

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PROCESS CENTERLESS RECESS GRINDING

Andrej MALÍK, Augustín GÖRÖG

Abstract

The article deals with special centerless grinding using various methods, particularly the centerless grinding recess methods. The results of measuring the surface roughness of frontal and cylindrical areas of a workpiece, as well as the roundness of the cylindrical surface of the workpiece are presented in the paper. Qualitative parameters of the machined surfaces are supplemented by the course of the grinding process. The change in the shape of the workpiece in the process of grinding causes also the change of position of the workpiece in the work zone.

Key words

centerless grinding, quality parameters, the grinding process

Introduction

The principle of each method of grinding is withdrawal of material by abrasive grain. Abrasive grain is a cutting wedge with random geometry and orientation. When grinding, the workpiece material is removed by a hard flint grinding wheel at high cutting rates. [1]

Centerless grinding is used for grinding smooth cylindrical components, which are inserted between two discs. One of them is a grinding wheel and the other a regulating wheel. Workpiece rotates at a peripheral speed of the rotating regulating wheel.

Centerless radial grinding (Recess)

Recess grinding is used for machine parts that have a recess, shaped or conical surfaces, or, where appropriate, more coaxial cylindrical surfaces without centres. Workpieces are inserted into the backstop between the grinding and regulating wheels, the axes of which are parallel [1].

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Specific features of centerless recess grinding

Specific features of centerless grinding recess method are:

1. Movement (feed) of one of the discs in the radial direction of grinding. At the end of this movement (feed), the workpiece receives the final dimension;
2. Axis of the wheels are parallel with the surface of the leading slide;
3. Smooth procedure, since there is no axial movement of the workpiece.

However, in the real procedure, the regulating wheel forms a minute angle (0.5 °) with the surface of the leading slide. This arrangement, which is typical for this method, is here to prevent the workpiece from oscillating in the axial direction. The inclined axis of the regulating wheel is pressed against the front of the piece backstop.

Wheels are converging either manually or automatically. In this method, we can grind the parts of various shapes to a certain length and $l_{max} \leq H$, where l_{max} is the maximum length of the piece of ground. Workpieces are inserted and removed manually or by using tanks.

Grinding process is usually carried out with a surface of the workpiece pressed to surface of the leading slide and regulating wheel. The change of the shape of the workpiece in grinding leads to the change of the location of this workpiece in the work zone.

Recess grinding process

In Fig. 1 is a scheme of instant positioning the workpiece during a single revolution when in-feed grinding.

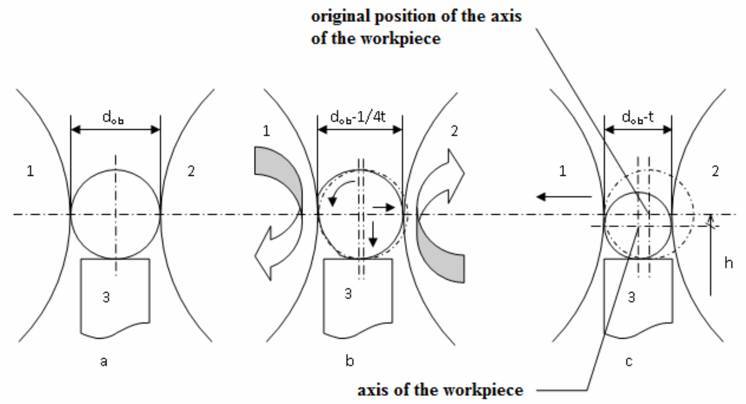

Fig. 1 *Scheme of instant positioning of the workpiece when in-feed grinding*
a – starting the process; b – intermediate position of the workpiece; c – position after one revolution of the workpiece; 1 – grinding wheel; 2 – regulating wheel; 3 – leading slide. [2]

The tool path feed rate is marked t.

If allowance is taken with certain parts of the surface, the workpiece decreases and is shifted to the regulating wheel Fig. 1 b).

Thus, the workpiece does not have a correct cylindrical shape after one revolution, because the depth of grinding over the turn varies. To receive the workpiece of a precise circular shape, it must be kept rotating without lateral feed.

When grinding, the geometrical axis of the workpiece position is constantly changing while remaining parallel to its initial position Fig. 1 c).

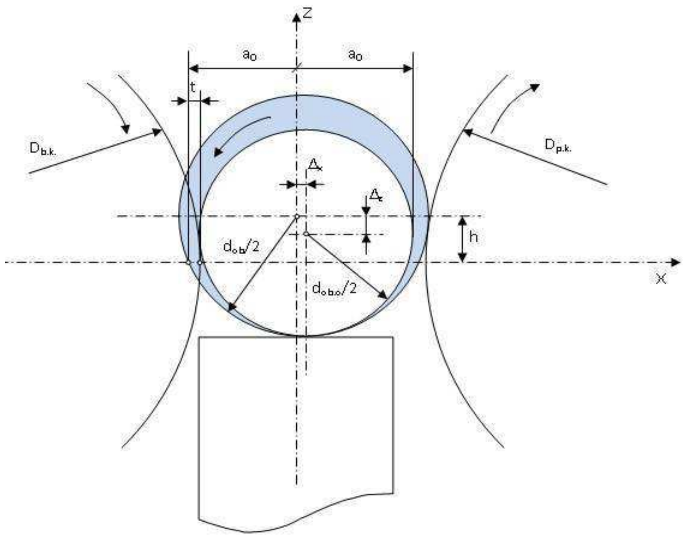

Fig. 2 *The ratio of diameters of the workpiece before and after grinding [2]*

$D_{b.k}$ – grinding wheel diameter, $D_{p.k}$ – regulating wheel diameter, d_{ob} – workpiece diameter before, $d_{ob.o}$ - workpiece diameter after, h – height of the workpiece axis connecting the wheels centers, a_0 – half of a chord limited by an intersection line between the centers of wheels with the outer surface of the workpiece, Δ_x – center displacement of the workpiece axis X, Δ_z – center displacement the workpiece axis Z.

$$a_0 = a_0 \tag{1}$$

$$\sqrt{\left(\frac{D_{p.k}+d_{ob}}{2}\right)^2 - h^2} = \sqrt{\left(\frac{D_{p.k}+d_{ob.o}}{2}\right)^2 - (h-\Delta_Z)^2} + \Delta_X \tag{2}$$

$$\Delta_Z = \frac{1}{cos\varphi}\left(\frac{d_{ob}-d_{ob.o}}{2}\right) + \Delta_X \frac{sin\varphi}{cos\varphi} \tag{3}$$

$$\left(\frac{D_{b.k}+d_{ob.o}}{2}\right)^2 = (h-\Delta_Z)^2 + \left(\frac{D_{b.k}}{2} + (a_0 - t) + \Delta_X\right)^2 \tag{4}$$

The system of equations (2), (3), (4) must be solved wit regard to $d_{ob.o}$, Δ_X ,Δ_Z. In a special case when φ = 0, h = 0, the system takes the following shape:

$$\frac{D_{p.k}+d_{ob}}{2} = \sqrt{\left(\frac{D_{p.k}+d_{ob.o}}{2}\right)^2 - \Delta_Z^2} + \Delta_X\,; \tag{5}$$

$$\Delta_Z = \frac{d_{ob}-d_{ob.o}}{2}\,; \tag{6}$$

$$\frac{D_{b.k}+d_{ob.o}}{2} = \sqrt{\Delta_Z^2 + \left(\frac{D_{b.k}+d_{ob}}{2} - t + \Delta_X\right)^2}\,. \tag{7}$$

When substituting the expression for Δ_Z in equation (6) in equations (5) and (7), and take them to the power of two, we get:

$$\left(\frac{D_{p.k}+d_{ob}}{2} - \Delta_X\right)^2 = \left(\frac{D_{p.k}+d_{ob.o}}{2}\right)^2 - \left(\frac{d_{ob}-d_{ob.o}}{2}\right)^2\,; \tag{8.1}$$

$$\left(\frac{D_{b.k}+d_{ob.o}}{2}\right)^2 = \left(\frac{D_{b.k}+d_{ob}}{2} - t + \Delta_X\right)^2 + \left(\frac{d_{ob}-d_{ob.o}}{2}\right)^2 . \tag{8.2}$$

After further adjustments, we will have a system of equations (8) in the form:

$$\frac{d_{ob}-d_{ob.o}}{2} = \Delta_X - \frac{\Delta_X^2}{D_{p.k}+d_{ob}} ; \tag{9.1}$$

$$\frac{d_{ob.o}-d_{ob}}{2} + t - \Delta_X = \frac{(t-\Delta_X)^2}{D_{b.k}+d_{ob}} . \tag{9.2}$$

When omitting the members $\frac{\Delta_X^2}{D_{p.k}+d_{ob}}$ a $\frac{(t-\Delta_X)^2}{D_{b.k}+d_{ob}}$ in the system (9) , which do not affect the required accuracy of calculation, from equations (3) and (9) we get:

$$d_{ob.o} \cong d_{ob} - t ; \tag{10}$$

$$\Delta_X \cong \frac{t}{2} ; \tag{11}$$

$$\Delta_Z \cong \frac{t}{2} . \tag{12}$$

It is evident that dependences (10), (11), (12) are valid for the addition of the removal of any thickness, however only with the difference that variable *nt* will be substituted for *t*, where *n* is the number of revolutions of the workpiece within the period of removing the allowance.

The property of centre workpiece displacement is taken into account when setting the grinders. It should be noted that with increasing *h*, difference d_{ob} - $d_{ob.o}$ is also growing fast. Line height *h* can be determined from the geometrical relationships.

Similarly, this applies to centerless grinding-through manner, yet the nature of the workpiece movement is much more complex. Workpiece is rotated and thus its axis stops to be parallel with its original position.

These movements in the piece-through grinding lead to reducing the workpiece diameter approximately by variable *t*, which was previously set up in the grinding machine. With the same setup in center grinding, the workpiece diameter would decrease by *2t*.

In centerless grinding, the variable-through d_{ob} - $d_{ob.o}$ is usually called the *depth of cut*. A double depth of cut for grinding center is indicated *t*, respectively *2t*.

To avoid misunderstanding, variable *t*, which can only be regarded an instantaneous depth of cut will called allowance of angle [2].

Change profile and qualitative parameters surfaces workpieces

To determine the impact of in-feed centerless grinding on a circular profile and the parameters of the surface (roundness and surface roughness), we carried out a series of experiments within which the parts shown in Fig. 3 were manufactured. Components were made of ST 37 - 2K. Their diameter was ø $9.96^{-0.01}$ (diameter of semi-product before grinding ø$10.04^{+0.06)}$. Grinding was made on MULTIMAT 208 machine while using the grinding wheel 400x30x203 99BA/96A 60N7V (STROH flat diamond), regulating wheel 300x30x127 A120RL152R7 and leading slide was straight. Grinding machine working time was 9.8 sec.

a) b)

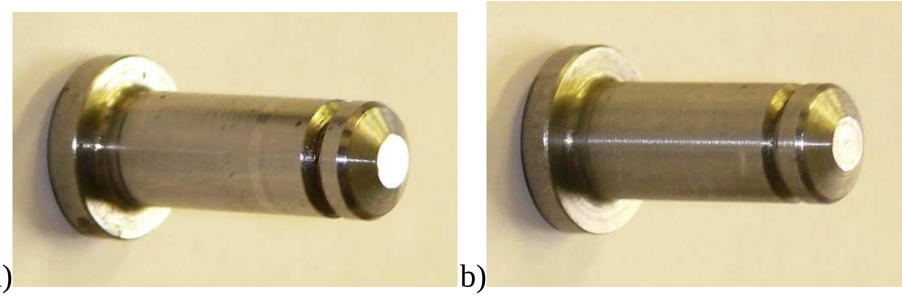

Fig. 3 *Workpiece a) before and b) after grinding*

Fig. 4 shows the round profile section measured for a selected part before grinding. Below the picture, specific parameters of measured round profile and surface roughness are listed.

For comparison, Fig. 5 shows one of the measured profiles after grinding and the measured parameters.

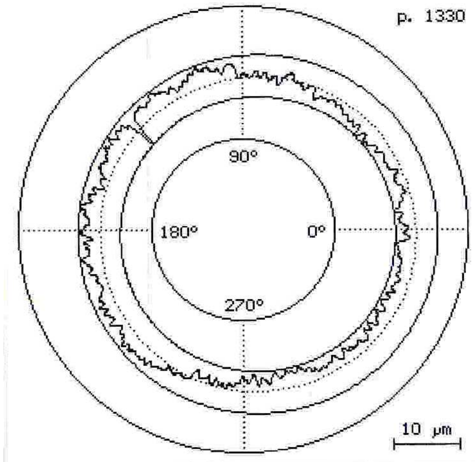

Fig. 4 *Profile before grinding*

ΔZ 6.34µm; P 3.28µm; V 3.05µm; R_R 7,03µm

Roughness before grinding: Ra 1.59µm; Rz 8.99µm; Rq 1.97µm

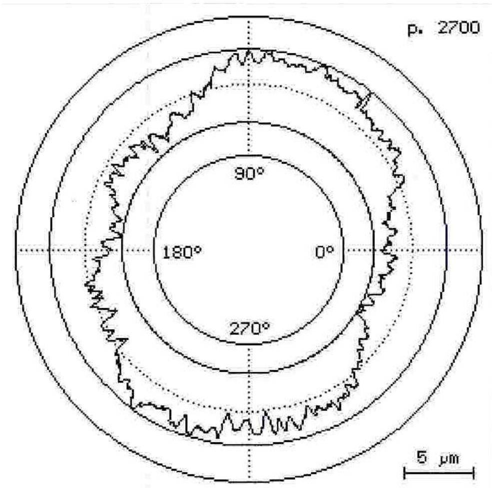

Fig. 5 *Profile after grinding*

ΔZ 5.25µm; P 2.50µm; V 2.74µm; R_R 5.79µm

Roughness after grinding: Ra 0.55µm; Rz 4.37µm; Rq 0.70µm

Both displayed profiles (Figs. 4, 5) have representation parameters – the parameter values are the closest to the average values. Roundness (ΔZ) was reduced by grinding in average by 17%, while the part in the region of mounts (P) was reduced by 24% and the depressions (V) by 10%. Radial wheel run-out (R_R) was reduced in average by 17%. All the surface roughness parameters observed were reduced significantly (different parameters of 51 to 65%).

Conclusion

The experiments proved that the centerless plunge grinding improves the parameters of circular profile and surface roughness. However, there are cases where grinding can worsen a qualitative parameter. It concerns particularly an accurate mutual positioning of the workpiece surfaces. For example, in a way-through centerless grinding of outer surfaces (especially with a small of length/diameter ratio of a component, i.e. ring-shaped components) nonuprightness of the cylindrical surface of the workpiece regarding its face can be a bit bigger. This will not happen with plunge grinding.

All the methods of centerless grinding may cause that the outer (grinding) surfaces and the inner surfaces of the workpiece are not exactly in alignment. Coaxiality of surfaces is changed by pass-through grinding along the length of the workpiece.

This abaxial is usually considered a *random deviation*. In fact, this phenomenon is caused by specific features of centerless grinding and it can be affected. If the grinder is properly adjusted, a larger amount of appliance is used and the optimum allowance of grinding is retained, it is possible to achieve the accuracy to the extent of the prescribed tolerances after grinding.

References:

[1] KOCMAN, K., PROKOP, J. *Machining technology.* Brno: Academic publishing CERM. ISBN 80-214-3068-0

[2] SLONIMSKIJ, V. I. *Theory and practice of centerless grinding* second edition. Moscow: National Scientific and technical literature publishing machine, 1952.

[3] STN EN ISO 1101: 2006, Geometrical product specifications (GPS). Geometrical tolerancing. Tolerances on shape, orientation, location and runout (ISO 1101: 2004).

[4] DOVICA, M., KAŤUCH, P., KOVÁČ, J., PETRÍK, M. *Metrology in engineering.* 1. edition. Košice: Series of scientific and technical literature – Faculty of Mechanical Engineering TU Košice. Tlač: EMILENA s.r.o., Košice, 2006. 351 p. ISBN 80 – 8073 – 407 – 0.

[5] PERNIKÁŘ, J., TYKAL, M. *Engineering metrology II.* 1. edition. Brno: Publisher: University of Technology in Brno, Faculty of mechanical engineering. Publishing: ACADEMIC PUBLISHING CERM, s.r.o., 2006. 180 p. ISBN 80–214–3338–8

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USING ARAMIS FOR MEASUREMENT OF DEFORMATION OF THIN-WALLED PARTS DURING MILLING

Jozef PETERKA, Ivan BURANSKÝ

Abstract

This paper describes deformation measurement of thin-walled parts by ARAMIS measuring system. During the milling, machine and workpiece may deviate from required geometry. Thin-walled parts are primarily used in automotive, aerospace and energy industries. ARAMIS is a system for optical 3D deformation analysis for static or dynamically loaded specimens and components. ARAMIS measuring system can be used for determining the deformation of thin-walled parts during milling.

Key words

ARAMIS, deformation, milling, thin-walled parts, measuring deformation

Introduction

Peripheral milling of flexible thin-walled parts is a commonly required operation. Thin-walled parts are used primarily in automotive, aerospace and energy industries. During the milling, tool and workpiece are in contact. The effect of cutting forces is a deflection from the ideal component shape. The problem during milling of thin-walled parts is chatter. The flexibilities of the cutter and plate produce severe forced and self excited vibration during peripheral milling. Self-excited chatter vibrations occur due to dynamic interactions of the cutting process and structure. Chatter vibrations are initiated by transient vibrations, and their stability depends on the axial and radial depth of cut, cutting speed, workpiece material hardness and structural properties of both tool and workpiece [3].

The peripheral milling of very flexible plate structures made of aluminium alloy is studied in this paper. Some authors have presented the results about milling thin-walled parts. *Budak* and Altintas presented a dynamic model for peripheral milling of very flexible plates [1]. *Ratchev* presented his paper on error compensation strategy in milling flexible thin-wall parts [2].

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Optical measuring system ARAMIS

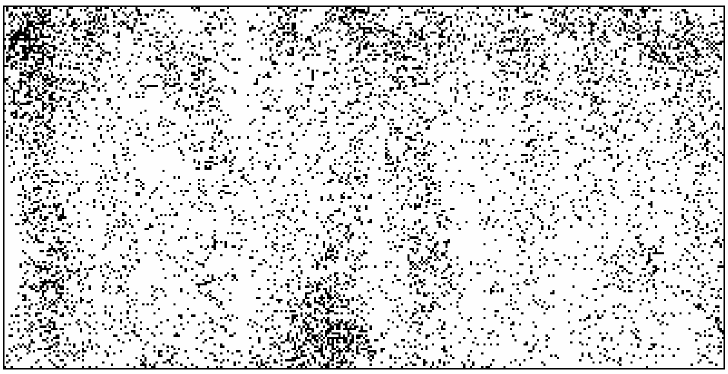
ARAMIS (Fig. 1) is the system for optical 3D deformation analysis [4]. It is ideally suited to measure, with high temporal and local resolution as well as with a high accuracy, three-dimensional deformation and strain in real components and material specimens. For static or dynamically loaded specimens and components, ARAMIS allows for non-contact and material independent determination of 3D coordinates and 3D displacements, 3D speeds and accelerations, plane strain tensor and plane strain rate, material characteristics.

BASIC DATA OF OPTICAL MEASURING SYSTEM ARAMIS [4] Table 1

System Configuration	**5M**
Frame Rate	15 Hz up to 30Hz
Camera Resolution	2448 x 2048 pixels
Measuring Area	mm² to > m²
Strain Measuring Range	0.01 % up to > 100%
Strain Measuring Accuracy	up to 0.01 %
Sensor Dimensions	510 x 230 x 200 mm³
Weight	3 kg

Fig. 1 *Optical measuring system ARAMIS [4]*

For the 3D deformation and strain measurements, the object to be loaded is viewed by a pair of high resolution, digital CCD cameras. 3D image correlation photogrammetry technology is a unique combination of two-camera image correlation and photogrammetry. A random or regular pattern with good contrast is to the surface of the test object, which deforms along with the object. The deformation of this thin-walled part under different load conditions is recorded by the CCD cameras and evaluated.



Random pattern on surface

Milling thin-walled part and deformation measurement

Milling is a multiple point, interrupted cutting operation. Because of the multiple teeth, each tooth is in contact with the workpiece for a fraction of the total time [3]. The finished surfaces, therefore, consist of a series of elemental surfaces generated by the individual cutting edges of the cutter. Due to the nature of relative contact between the workpiece and the tool, the chip thickness is not constant but starts with a zero thickness and increases in up-milling and starts with a finite thickness and decreases to zero in down-milling. The down-milling (Fig. 3) of thin-walled parts is better than up-milling.

The dimension of workpiece was 100x80x10 mm. The shape of thin-walled part is show in Fig. 2. Material of workpiece was EN-6082 AlMgMnSi1 aluminium alloy which has good machinability.

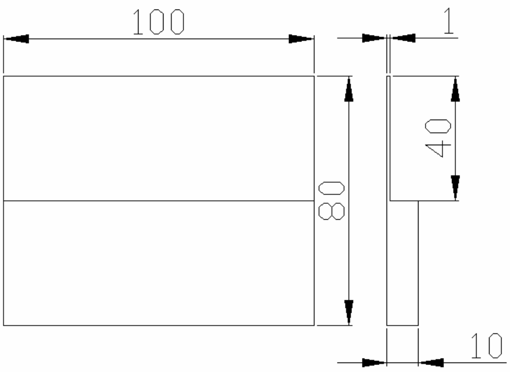


Fig. 2 *Shape of thin-walled part*

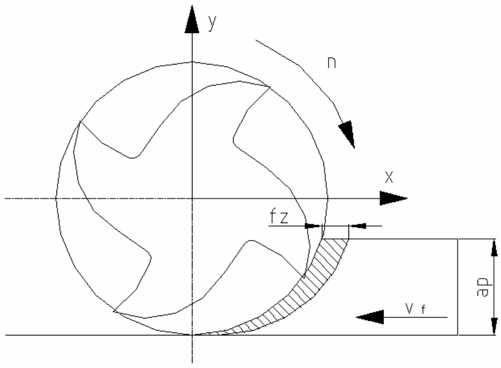


Fig. 3 *Down-milling*

The workpiece is a 10 mm thick aluminium plate. It was cantilevered by clamping one end in a vice with a clamped length of 27 mm and a width of 100 mm. The cutting tests were carried out on a 5-axis high-speed milling centre HSC 105 linear. The free-end was down-milled **(**Fig. 3) using a bull nose end mill, helical 30°, two-flute tool with a diameter of 20 mm with MEGA-T coating. Overhang of tool was 55 mm. For the experiment, the following parameters were used: depth of cut (DOC) 10 mm, cutting speed 314 m/min, width of cut (WOC)1 mm without cutting fluids. 3D optical measuring system ARAMIS was used for deformation measurement.

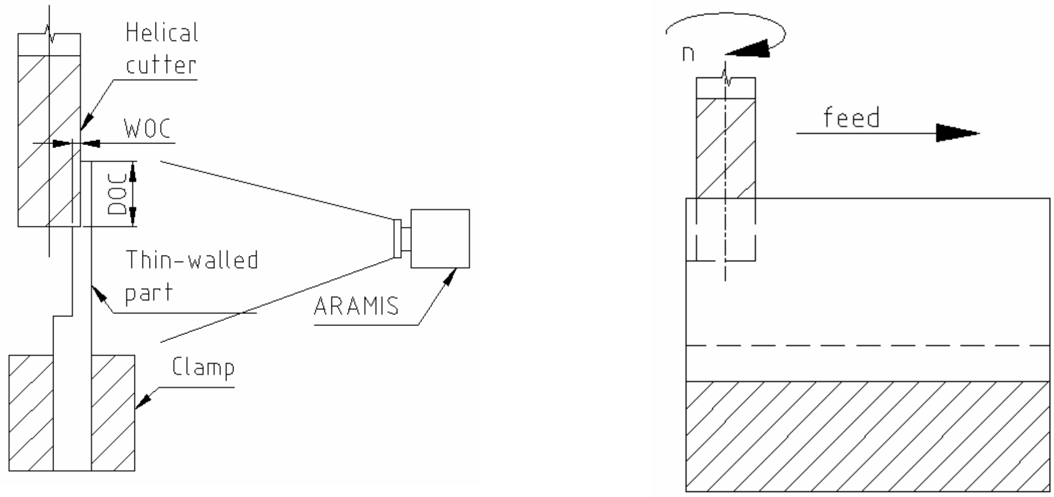


Fig. 4 *Measurement set-up*

Experimental results

Figures 5, 6, 7 shown colour deviations maps in various positions of cutters. At the first immersion, the deformation of parts at the beginning can be seen. The maximum deviation during milling was 2.5 mm. The maximum deviation was caused by the parts vibration, this vibration was accompanied by unpleasant sound. This deviation of parts was changed during cutting, just moves with the cutter. After milling, the maximum deviation was to a value of 0.01 to 0.05 mm.

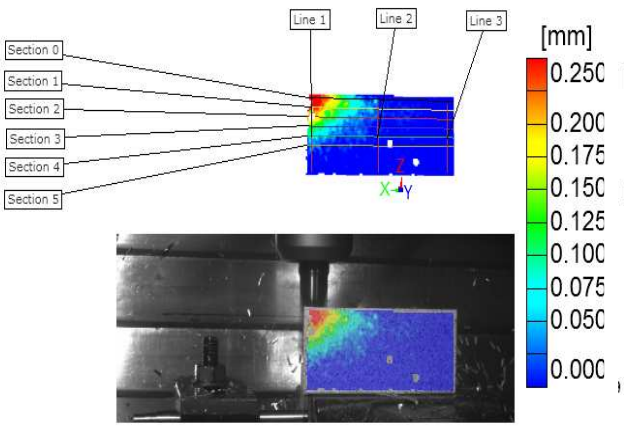


Fig. 5 *Colour deviation map of thin-walled part when tool is in starting position on part*

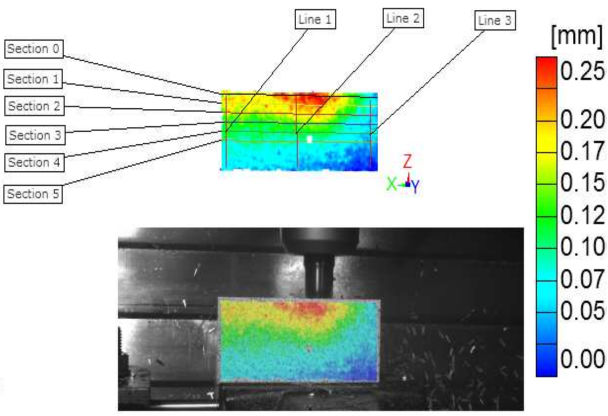


Fig. 6 *Colour deviation map of thin-walled part when tool is in middle position on part*

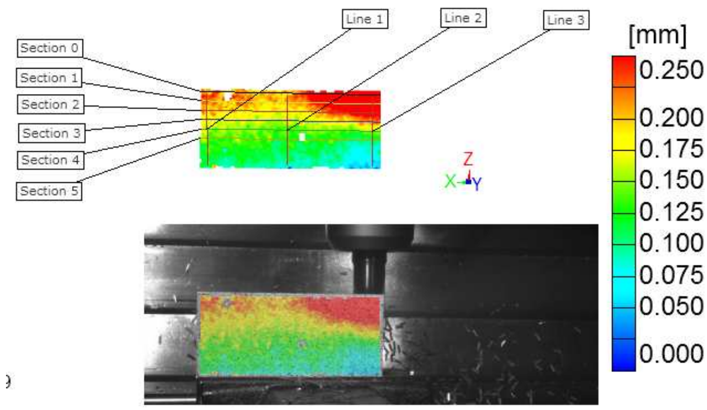


Fig. 7 *Colour deviation map of thin-walled part when tool is in end position on part*

From the measured data, displacement of points in parts can be graphically evaluated. Chosen points and their layout are shown in Figure 8. The result of the experiment was the graph of displacement of measured points (mm) and time (s) shown in Figure 9. Displacement measured points were evaluated with regard to the fixed points. Colours of points correspond to colour curves measured by determining the change in position of point in time. The maximum deformation reached endpoints (red and blue points). These are places where the cutter enters and exits from thin-walled parts. Prerequisite for the experiment was that the greatest deformation will be around the end points.

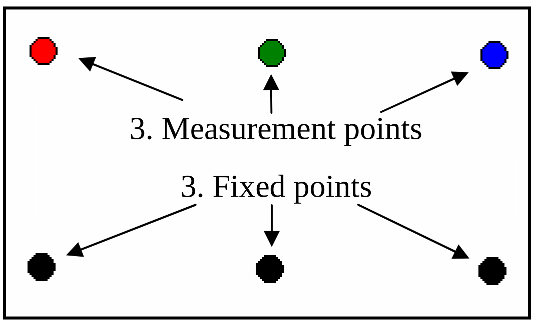


Fig. 8 *Position of measurement points and fixed points*

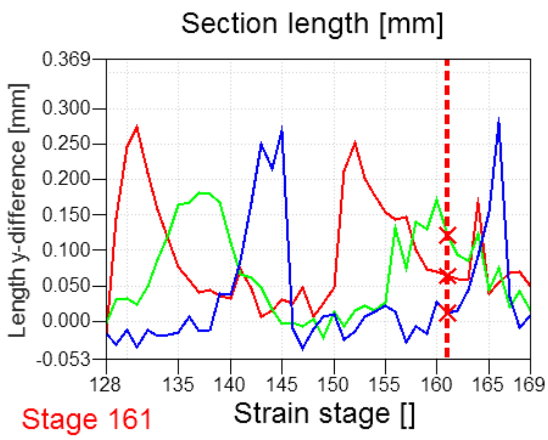


Fig. 9 *Result from ARAMIS software*

Scientific asset

The asset of this paper is the presentation of the new method of measuring deformation of thin-walled parts. This method is used for real-time measurement. It is possible to compare the results from ARAMIS with FEM analysis.

Conclusion

The issue of thin-walled milling is very extensive. The article deals with one of the main aspects of the production of thin-walled parts, and especially with their deformation during milling. Method of monitoring strain components in real-time using 3D optical system ARAMIS was first used in experiment. The results of the experiment make it possible to better understand the behaviour of thin-walled components during milling.

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Európska únia
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Operačný program
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Podporujeme výskumné aktivity na Slovensku/
Projekt je spolufinancovaný zo zdrojov ES

References:

[1] BUDAK, E., ALTITAS, Y. Modeling and avoidance of static form of static form errors in peripheral milling of plates, internet source: http://www.sciencedirect.com, [on-line 25.4.2008]

[2] Ratchev, S. Liuand, BECKER, A.A. Error compensation strategy in milling flexible thin-wall parts., internet source: http://www.sciencedirect.com, [on-line 25.4.2008]

[3] BUDAK, E. *Mechanics and dynamics of milling thin walled structures*. PhD Thesis, The university of British columbia, 1994, internet source: https://circle.ubc.ca/

[4] GOM optical measuring techniques, Industrial 3D Measurement Techniques, internet source: www.gom.com, [on-line 25.4.2008]

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2010 Number 28

INFLUENCE OF CUTTING MEDIUM ON DEFORMATION OF THIN RIBS

Jozef PETERKA, Ivan BURANSKÝ, Eva KUCHÁRIKOVÁ

Abstract

Influence of cutting medium on tool life or quality of workpiece is well-known. This paper deals with the influence of cutting medium on deformation of thin ribs made by milling. The machining of thin ribs exhibits various problems. The paper describes some of these problems and contains basic information on several types of cutting media used in machining. Chatter is generated by machining of thin ribs. This chatter causes surface waviness. If the chatter is oversized, it is possible to measure the deformation. In the experiment, TRITOP noncontact measuring system for measuring thin ribs' deformation was used.

Key words

cutting medium, deformation, thin ribs, non contact measuring, milling

Introduction

Machining can be defined as the process of removing material from a workpiece in the form of chips. This process is performed within MTWJ (M - machine, T- tool, W- workpiece, J – jig) system. The cutting media are integral parts of this system. In general, the cutting medium can be divided into the following categories [2]: gaseous, liquid and solid.

Cutting medium has influence on dimensional accuracy and surface quality of workpiece, especialy in case of thin ribs. This type of workpiece is used particularly in aircraft industry, as well as energetic and automotive industry mainly because of weight decrease of final product (e.g. aircrafts, turbine, etc.). Thin ribs are made by milling.

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Milling is a multiple point, interrupted cutting operation. Because of the multiple teeth, each tooth is in contact with the workpiece for a fraction of the total time [3]. The finished surfaces, therefore, consists of a series of elemental surfaces generated by the individual cutting edges of the cutter. Due to the nature of relative contact between the workpiece and the tool, the chip thickness is not constant, but starts with a zero thickness and increases in up-milling and starts with a finite thickness and decreases to zero in down-milling. The peripheral milling of flexible thin-walled parts is a commonly required operation. During the milling, tool and workpiece are in contact. The effect of cutting forces is that there is a deflection from the ideal component shape.

Cutting medium characteristics

The prime functions of cutting fluid are effective cooling and lubrication. With the supply of cutting fluids, the friction is also reduced. These functions and effects require the cutting fluids to be in a fluid form. There are also consistent media such as fats or powder lubricants. Though the friction can be reduced, they are not able to decrease the heat in cutting area and that is the reason why they are not used so frequently. The main application fields for these lubricants are thread cutting or special forming operations [4]. Only the gas media have not been employed in manufacturing so far, because their application is difficult. If particular gases are applied properly, they can remove the heat and also reduce the friction if their chemical properties are suitable [8]. Nowadays, the air-mist cooling is also expanding but the cutting fluids are still the most applicable cooling medium in metal machining. Besides cooling and lubrication effects, they also have other functions [4]. Main functions of cutting fluid involve [1]: cooling, lubrication, removing chips and metal fines from the tool/workpiece interface, flushing and prevention of corrosion.

Thin ribs

Thin rib can be described as a workpiece consisting of very thin plates. Thin plate in machining is that, even at a minimum cutting forces, is so deformed, that the local thickness in critical place is different, such as guide value after milling or surface waviness are formed due to chatter. The concept of a thin wall component means that it consists of walls; the thickness is extremely small compared with other dimensions such as wall height and wall length. The shape of thin-walled parts can vary. Thin-walled parts can be divided into single-walled parts and thin-shape complex parts. Deformation of thin-walled parts in the machining process is shown in Fig.1. Material ABCD (Fig. 1) should be ideally cut, but, due to the oscillation, A'BCD material is cut. After milling, the machined surface material passes back and BDB 'material which should be removed is cut off. This causes, that the wall thickness is thinner at the top and wider at the bottom of the wall.

3D Coordinate measuring system TRITOP

TRITOP^{CMM} (Fig.2) is an industrial, non-contact optical measuring system for exact 3D coordinate acquisition of discrete object points. As shown in Fig. 2, the system consists of a laptop including the evaluation software, the digital TRITOP camera, coded and uncoded reference points and a scale bar set with accessories [6]. Coded reference points ensure an image set that can be evaluated and allow for automatic calculation of the camera positions. In addition, so-called orientation crosses are available which are factory-equipped with several coded points. Uncoded reference points are used to determine the 3D coordinates of the measuring object and are identified automatically by TRITOP software. In each TRITOP measuring project, the scale bars are the reference for determining the dimensions. We used photogrammetry camera system with resolution of 12.32 million pixels. The cameras are based on professional digital reflex camera housings (e.g. Nikon, Canon, Fuji) in connection with a manual fixed focus lens and a ring flash. Each TRITOP camera system is factory-verified and certified in order to guarantee the measuring accuracy.

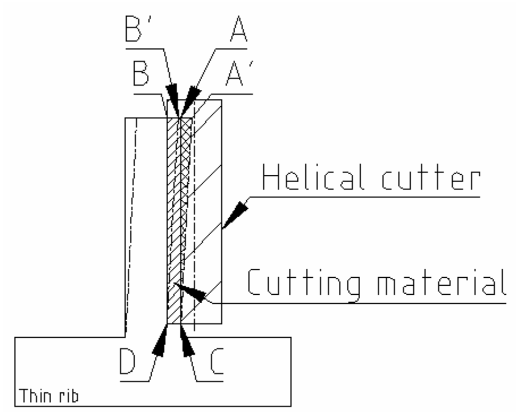

Fig. 1 *Thin rib milling*

Fig. 2 *Non-contact optical measuring system TRITOP*

This mobile technology supports time-optimized measurements for on-site quality control and deformation analysis. All relevant object points are marked and, using a photogrammetric camera, images of the object to be measured are recorded from various angles of view. Then, the TRITOP software automatically calculates the 3D coordinates of the adhesive markers and object characteristics from these digital images [7]. Photogrammetric is the technique of measuring objects (2D or 3D) from photo-grammes.

Experiment

The cutting tests were carried out on a 5-axis high-speed milling centre HSC 105 linear, with a 42 000 rpm spindle. The tool was a carbide cylindrical end mill with two cutting edges, 16 mm diameter, 30° helix angle, 0.5 mm corner radius, and L= 50 mm overhang (L/D=3). A small overhang is necessary to consider a rigid cutter on the spindle. The cutter was mounted in a HSK 50A thermal holder. The workpiece was made of 6082 aluminium alloy. The machining of the thin wall starts from a solid plate of the dimension 100x80x10 mm. Deformations of the part were measured in the x direction, the perpendicular feed direction, by TRITOP, a non-contact optical measuring system. In addition to parts deformation, average surface roughness Ra was measured. As the coolant, 5% emulsion Blasocut BC25 was first used and then air. Cutting conditions were as follows: depth of cut – 5 mm, width of cut – 2 mm, cutting speed – 301.44 m/min, milling method - down milling.

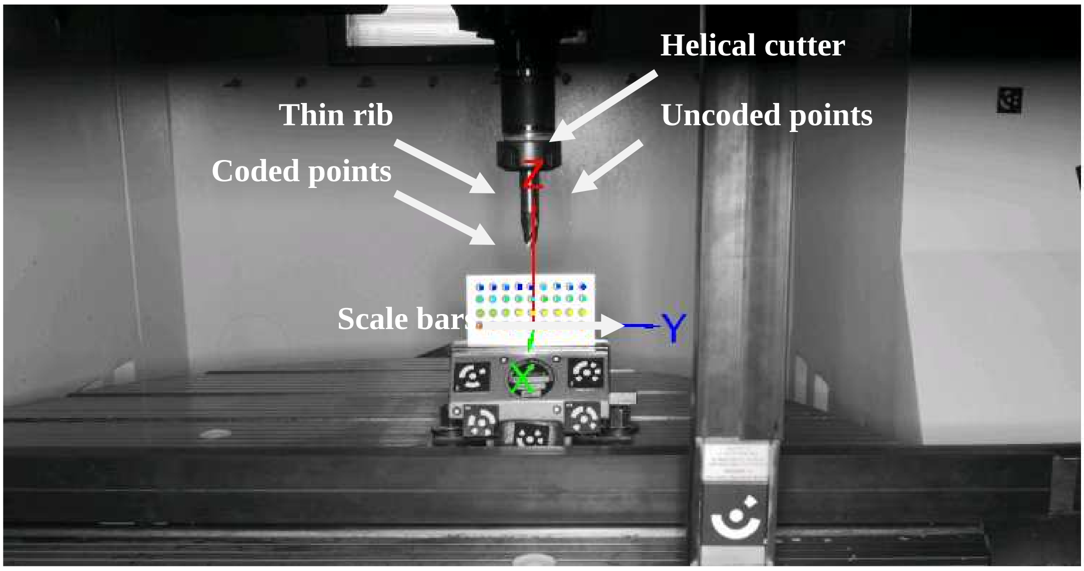

Fig. 3 *Machining set-up*

Results

The deformation of thin ribs is shown in a deviation colour map. The results of deformation at different cutting medium are shown in Figures 4-5. The difference in deformation was minimal. The deformation components occurred mainly at the top of the wall in both cutting media, about the same as can be seen in Fig.4 and Fig.5. We can say that cutting medium (air, emulsion) has a significant impact on the deformation of thin wall milling. Cutting medium is reflected more on the quality of the surface.

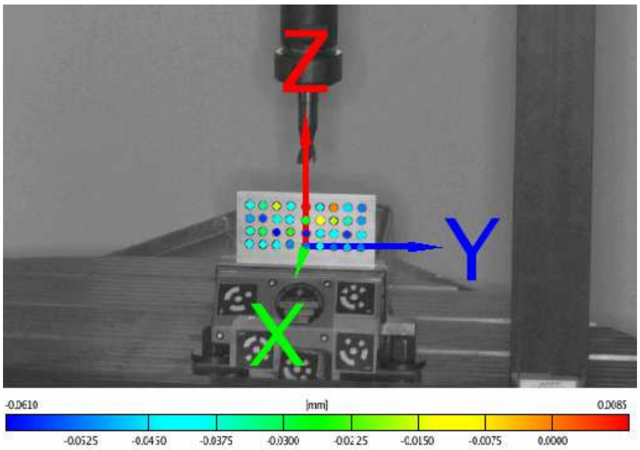

Fig. 4 Colour deviation map of thin rib using air

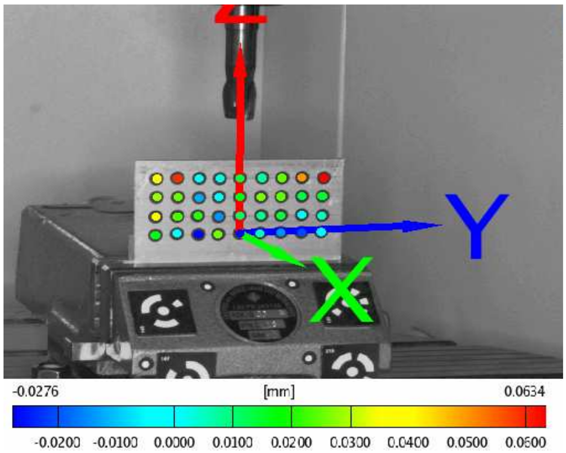

Fig. 5 Colour deviation map of thin rib using emulsion

Roughness was measured by using Surtronic 3 +. The measuring positions are shown in Figure 6. Surface roughness of thin ribs is given in Table 1.

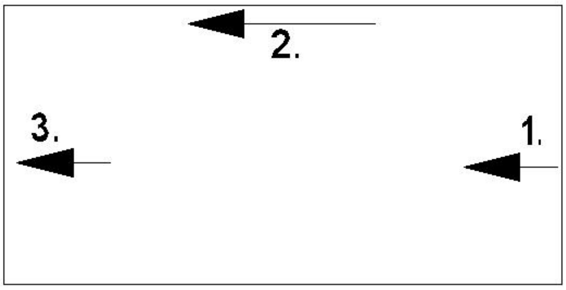

Fig. 6 *Measuring position*

ROUGHNESS OF THIN RIBS SURFACE Table 1

Measuring position	**Roughness Ra [µm]**	
	Air	**5% emulsion Blasocut BC 25**
1.	0.46	0.32
2.	1.22	0.34
3.	1.26	0.58

Scientific asset

Asset of this paper is pointing out the importance of cutting medium in milling the thin ribs. Contribution is a summary of basic cutting fluid characteristics; it describes problems with thin ribs and noncontact measuring method of deformation by TRITOP optical measuring system. Experimental results proved the influence of cutting medium on deformation and surface quality of thin ribs.

Conclusion

Cutting medium plays an important role in machining operations and has impact on productivity, tool life and quality of work. The high-speed machining of aluminium and its alloys does not use emulsion, but only air. However, at the speed of 10,000 min^{-1}, it is recommended to use emulsion, since, in addition to better lubrication, cooling and removing chips and metal fines from the tool/workpiece interface, which has no significant effect on the deformation of thin-walled parts, it leads to higher surface quality. Cutting conditions (particularly the depth of cut) remain the most important parameters influencing the deformation of thin ribs.

Contribution was prepared thanks to the support of VEGA project No. 1/0130/08.

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Operačný program
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Podporujeme výskumné aktivity na Slovensku/
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References:

[1] ZAJAC, J. *Trends in the research process liquid*. In *Manufacturing engineering,* FVT TU Košice located in Prešove, 2007, č.2, pp. 36-38, [online]. [cit.2008-01-08]. internet source: http://web.tuke.sk/fvtpo/casopis/skindex.htm

[2] LIPA, Z., PETERKA, J., POKORNÝ, P. *Collaboration of cutting medium.* In Proceedings of International Conference *TOP 2002,* Častá – Papiernička: 2002, pp. 335-339.

[3] BUDAK, E. *Mechanics and dynamics of milling thin walled structures, PhD Thesis.* The university of British Columbia, 1994, internet source: *https://circle.ubc.ca/*

[4] KOCMAN, K. *Special Machining Technology*. Brno: VUT, 2004, pp. 151-161. ISBN 80-214-2562-8

[5] *Introduction to Photogrammetry*, [on-line] ,[12-12-2007]. internet source: http://www.univie.ac.at/Luftbildarchiv/wgv/intro.htm

[6] Measuring Characteristic Features Using the Optical Measuring Machine TRITOP CMM, [on-line], [12-12-2007]. internet source: http://www.gom.com
[7] *TRITOP v.6 User Manual*, GOM mbH, Germany, 2006
[8] SHAW, MILTON C. *Metal cutting principles.* New York: Oxford University Press, 2005, pp. 651. Zv. II. ISBN 0-19-514206-3

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2010 Number 28

SELECTION OF MATERIALS AND TECHNOLOGY FOR FORMING THE LAYERS RESISTANT TO ABRASIVE WEAR

Silvia REVESOVÁ, Pavel BLAŠKOVITŠ

Abstract

This article deals with the selection of materials for forming wear resistant layers within agricultural machine parts wear. We can achieve required hardness, wear resistance and life extension of agricultural machine parts and tools by the selection of a suitable material and surfacing technology.

Key words

tribology, abrasive wear resistance, electric arc surfacing, filler material for abrasive wear

Introduction

Studying wear is characterised by many different aspects and it is mostly influenced by the complexity of materials interaction on a functional surface as well as by operation conditions. In machine elements, there is a gradual wear in the result of friction. This is considered to be an undesirable effect in most cases. Therefore, we have to search for the possibilities to prevent it thus extending the technical life of a component. Surfacing presents one of these possibilities. Searching for the possibility of cutting the costs of changing the worn or damaged machine elements has led to the development of a wide range of surfacing technologies. Increasing the safety and extending the technical life of machines and devices are important requirements of modern technology. We can also add the requirement for simple maintenance, as well as simple and less time-consuming repairs in solving the random failures or operation accidents.

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Wear is the (permanent) change of shape, size or features of material layers that usually form the surface of solids. It occurs as a result of friction and out of technologically required shaping or required change of material characteristics [3].

Slovak technical standard 01 5050 classifies wear as follows: adhesive, abrasive, erosive, fatigue, cavitation and vibration wear. Wear can have many forms that depend on the surface topography, contact conditions and environment.

Abrasive wear

Abrasive wear belongs to such wear types that can occur most frequently in machine elements of industrial installations and it presents up-to 80% of overall volume [4]. It can also originate from other wear types in the course of which the free particles are being formed. These particles are becoming stiffer than the parent material. This happens under the influence of either intensive plastic deformation, or air oxygen oxidation. Abrasive wear rate can be reduced by:

- load reduction – particles will not be imprinted so deeply into the material surface and the riffles will be shallower
- hardening – with the same effect as it is in previous possibility [6]

Abrasive wear consists in separation of surface parts by undulation of another surface or particles that are situated between the friction areas. It mainly depends on load, slide-way length and hardness. The influence of number, size and shape of the particles is also very important [5]. Riffles belong to typical surface damages in abrasive wear.

In abrasive wear, it is necessary to distinguish between two critical phases, namely the process of imprinting the abradant into the surface where the imprint hardness and destruction process are the limiting factors. Interatomic bond force and the composition strength between structural components reciprocally at the borders of grains play a decisive role [4].

Experimental programme

Subject of this experimental programme presented the choice and evaluation of surfacing (Fig. No. 1, Fig. No. 2, Fig. No. 3) made out using the technology of hand arc surfacing with using of filler materials by Welco Company (Welco electrodes 1702 S, 1707 S, 1709) for surfacing layer resistant to abrasive wear. On the parent material S 355J0 (constructional steel according to Slovak Technical Standard 11523), we welded the filler materials to three layers. We were searching for such sample that would be hard enough, resistant to abrasive wear and contain minimum amount of chrome at the same time, so it would not burden the welder’s health and the environment. Chemical composition of the filler material is presented in the table No. 1.

Fig. 1 ***The surfaced sample No. 1***

Fig. 2 ***The surfaced sample No. 2***

Fig. 3 ***The surfaced sample No. 3***

CHEMICAL COMPOSITION OF APPLIED FILLER MATERIALS Table 1

Parent material 11523	Chemical composition (%)									
Electrode	C	Mn	Si	S	P	Cr	Ni	Mo	V	W	Fe
No. 1 – 1702 S	0,75	11.7	0.15	0.002	0.02	4.2	3.1	0.35	-	-	79.728
No. 2 – 1707 S	0.4	0.3	0.8	-	-	8	-	1	0.6	-	88.9
No. 3 – 1709	0.6	0.5	0.4	-	-	4	-	8	1.1	1.7	83.6

This type of surfacing belongs to plainer and nowadays also the most widespread ways of surfacing concerning the availability of devices and their undemandingness in handling. Heat needed for the parent material and electrode melting, including the cover, generates in the electric arc. Fusion metal can be alloyed through the electrode cover and corestock. In surfacing, it is necessary to keep the arc short, so it is possible to provide the protection of the metal pool against the air atmosphere and not to stove the alloying elements [1]. Surfacing is carried out by laying down weld beads using the longitudinal or transversal method and covering the beads by 1/4 up-to 1/3. Surfacing is rarely made on a vertical plane. Thickness of a surfacing layer is usually of 2 or more millimetres and it can be resistant not only to wear, but also to collision, pressure, corrosion etc. [2].

One of the important aspects in the surfacing process is the choice of the electrode. Correct choice of the electrode can improve the properties of a surfacing layer, increase hardness, toughness and stretch out the life of functional area.

Sample preparation

Three types of surfacing were selected for the experimental testing. Sample No. 1 surfaced by 1702 S electrode without pre-heating, sample No. 2 surfaced by 1707 S electrode and No. 3 surfaced by 1709 electrode with pre-heating up- to 200 °C following the producer's recommendation.

Surfacing parameters:
Welding current intensity: I = 120 A (all samples)
Welding voltage: U = 22 V (all samples)
Direct current of reversed polarity was used.
Diameter of electrodes: 3.2 mm
Electrodes were dried at 300 °C for 2 hours before use.

Testing methodology

Aim of this testing was to determine the most suitable surfacing layer resistant to abrasive wear. We selected three basic tests for evaluation:
1. metallographic testing (macroscopic and microscopic);
2. hardness testing (microhardness measuring – microhardness attests mainly to the character of the structure and its homogeneity. At the layer-underlayer interface, it attests to the character of the weld and the amount of mixing the filler and parent material);
3. testing of the abrasive wear resistance according to Slovak technical standard 01 5084.

Experimental programme evaluation

Metallographic testing

a) Macrostructural analysis results – macroscopic observation was carried out with naked eye and a magnifying glass. We were observing different damages of the welded-on material surface as well as the equality and thickness of the surfaced layer. At the meltdown border line in sample No. 1 (Fig. 4) we observed a slag. In sample No. 2 (Fig. 5) in the third surfacing, it is possible to observe disintegrity of the size 0.5 mm. Heat affected zone is indistinctive. In sample No. 3 (Fig. 6), there was no disintegrity compared by sight such as lack of inter-run fusion, cavities or pores.

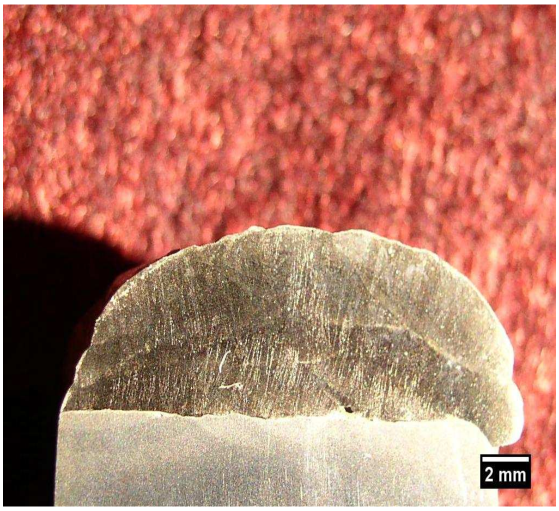

Fig. 4 *Macrostructure of the sample No. 1 (1702 S)*

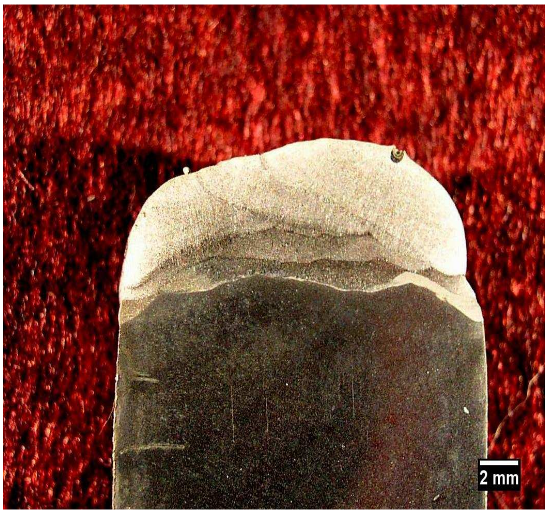

Fig. 5 *Macrostructure of the sample No. 2 (1707 S)*

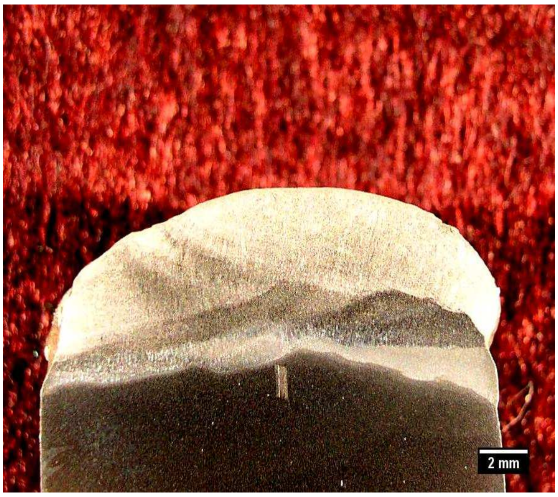

Fig. 6 *Macrostructure of the sample No. 3* (1709)

b) Microstructural analysis results – we used light microscopy for prepared cross-sections, according to the sample preparation procedure for metallographic testing. Selection of the corrosive depended on the chemical composition of analysed sample. Sample No. 1 surfaced by 1702 S electrode was corroded by 3 % of natal, and samples No. 2 and 3 surfaced by 1707 S and 1709 electrodes were corroded by 10 % of CrO_3. Analysis was focused on the evaluation of the surfacing integrity, buttering microstructural analysis, and heat affected zone of the base material. In Figure No. 7, we can see the parent material – surfacing transfer. The surfacing layer is of a cast character and the parent material is of ferritic - pearlitic structure and polyendric morphology. Bainitic structure occurs here and it causes the fact that the melted parent material is alloyed from the filler material of the electrode and carbidic particles originate consequently. At the interface, there is formation of a fine-grained structure in the result of recrystallization process within the surfacing of another layer.

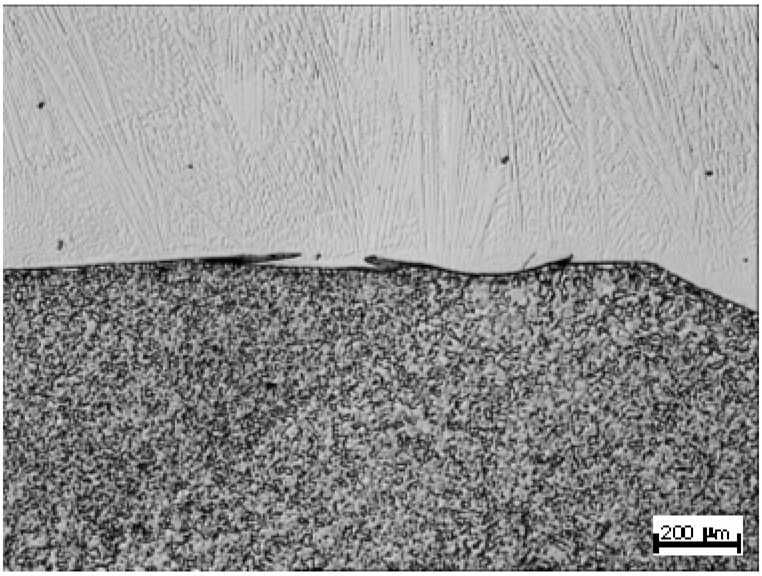

Fig. 7 *Microstructure of a transition zone, parent material – surfacing of a sample no. 1 (1702 S)*

Transition zone (Fig. 8) consists of a dendrite mixed with the parent material. We assume high density of precipitates and carbides within the alloying elements (Cr, Mo). Heat affected zone, which is now indistinctive, has grain that has not coarsened and it comprises polydedric morphology of ferrite and secreted pearlite along the borders of ferritic grains.

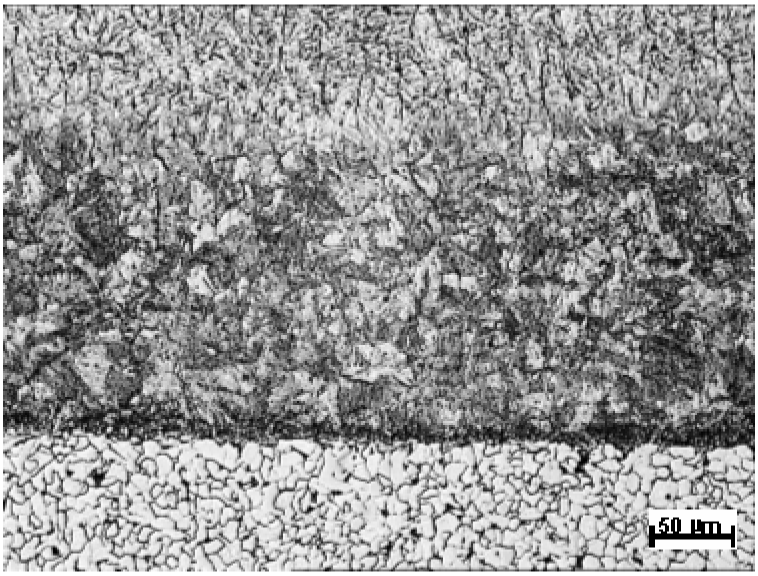

Fig. 8 *Microstructure of a transition zone, parent material – surfacing of a sample No. 2 (1707 S)*

Figure No. 9 shows a detail of the surfacing microstructure. The surfacing microstructure is characterized by similar dendrite morphology in all samples. The surfacing microstructure character around the heat affected zone – dendrite morphology is not distinctive, borders of columnar grains are markedly corroded, and this can be caused by precipitation of secondary phases. On the basis of the surfacing chemical composition, we assume that these are the carbides of alloying elements.

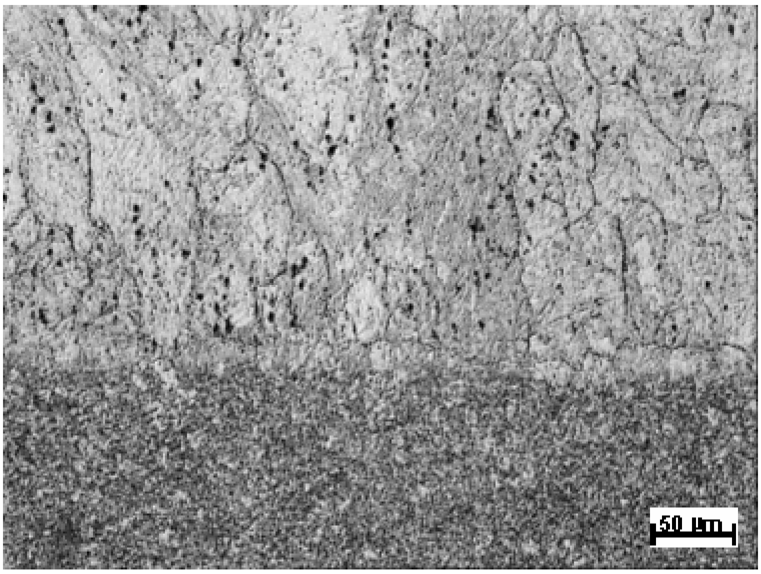

Fig. 9 *Microstructure of a transition zone, parent material – surfacing of a sample No. 3 (1709)*

Microhardness measurement

Microhardness of individual samples made out by a hand arc-drop surfacing technology was measured in 15 places of sample cross-section. In sample No. 1 (Fig. 10), the lowest average value of microhardness was measured and this was probably caused by the chemical composition of parent material (1702 S). The surfacing hardness in samples No. 2 (Fig. 11) and No. 3 (Fig. 12) changes from 262 to 762 $HV_{0,01}$ (Tab. 2). In these locations, the concentration of chrome probably rises. The measured surfacing microhardness is presented in Figure No.13.

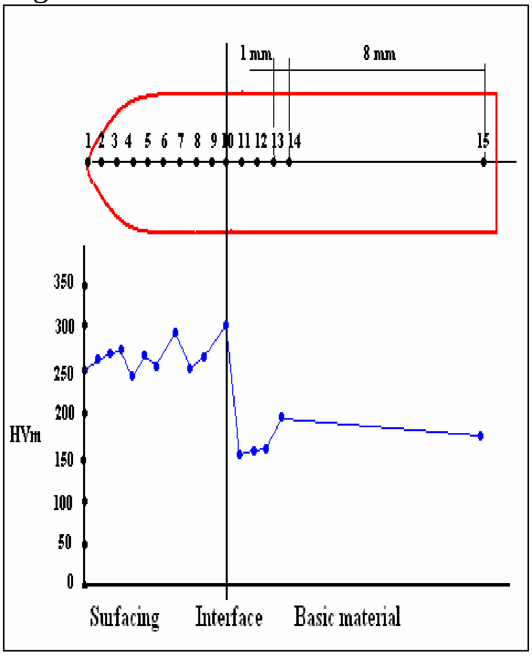

Fig. 10 *Measuring the microhardness on the sample No. 1 – 1702 S*

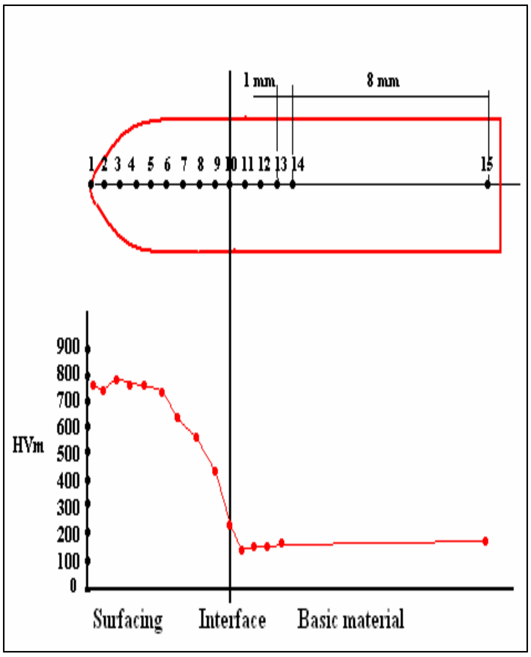

Fig. 11 *Measuring the microhardness on the sample No. 2 – 1707 S*

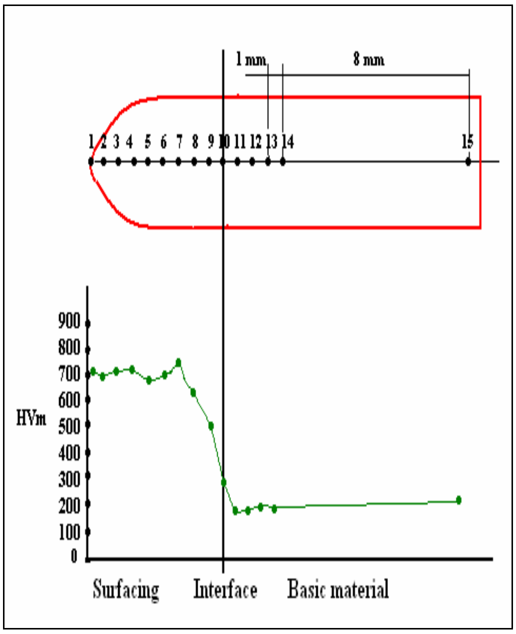

Fig. 12 *Measuring the microhardness on the sample No. 3 - 1709*

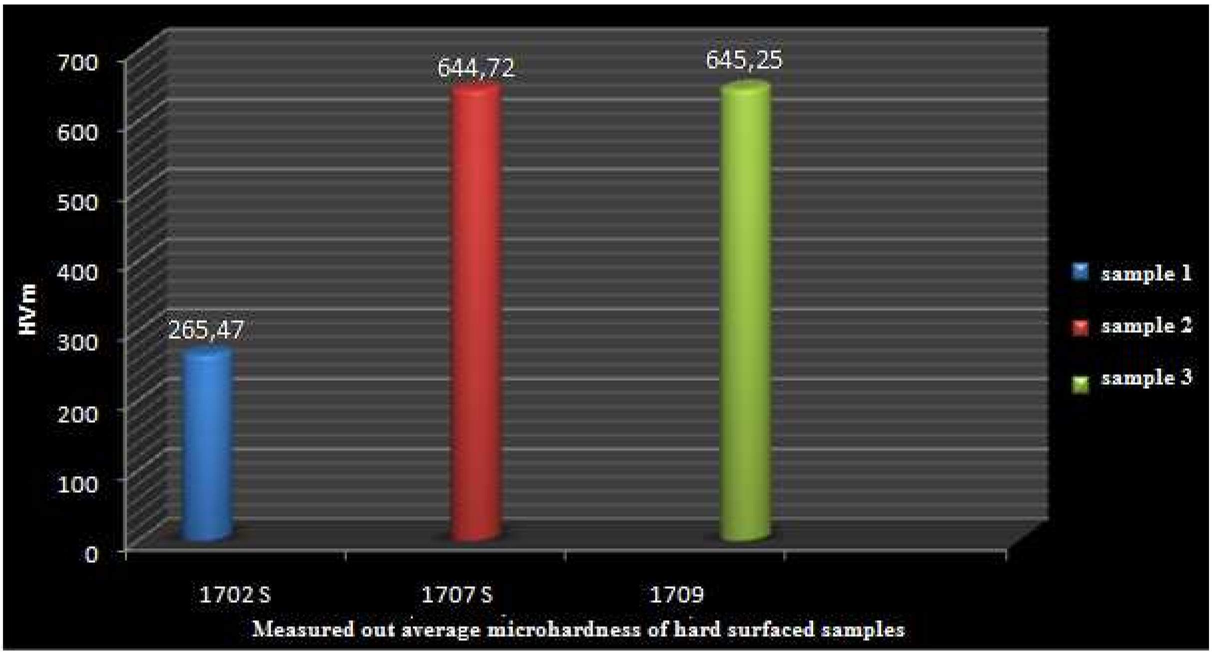

Fig. 13 *Measured out average microhardness of hard surfaced samples*

Test of resistance to abrasive wear according to the Slovak technical standard 01 5084

Before measuring the wear resistance, we weighed the samples individually on the electronic weighing machine with an accuracy of 10^{-3} g. After weighing, we tightened the sample into the holder of the tester and loaded by compressive force of 0.25 N. The sample was moving radially from the edge to the middle where it automatically stopped. Thereafter, we picked it and cleaned it. Abrasive cloth was replaced and we put on another sample. Reference indicator W_{opz} = 0,35715 g was obtained after the abrasive wear of the sample from the material 12 014.20 in such way that is specified in the Slovak technical standard 41 2014. After testing, we weighed the samples again and, using the measured values, we figured out the weight reduction and relative resistance to abrasive wear.

In the compared surfacing types, the relative resistance to abrasive wear is different. In order to find out which surfacing is the most resistant to abrasive wear, we calculated the average relative resistance for each sample.

- for surfacing 1702 S................................Ø Ψ_{abr} = 1,8183
- for surfacing 1707 S................................Ø Ψ_{abr} = 2,4600
- for surfacing 1709 ....Ø Ψ_{abr} = 2,6955

The best resistance to abrasive wear was again reached by the sample No.3. It is suitable for cutting tools of all types. Surfacing is characterized by high resistance to abrasive wear but it also has the advantage in terms of economic availability and mainly in terms of chrome content which was the lowest, especially in this sample. Thanks to the Cr content reduction in the layer, Cr content in welding fumes reduces and simultaneously it does not pose a burden to the environment and the welder’s health.

Discussion on the results

Applied filler materials were selected on the ground of chemical composition and the recommendation according to the company catalogue. Chrome content in the filler material increases toughness, oxidative resistance of the weld, transit temperature of notch toughness and notch sensitivity. Chrome and carbon form chromium carbides that are characterised by high wear resistance, but even small amounts of these elements unfavourably influence the man's health and the environment. The advantageous combination to chrome is molybdenum. Their content increases hardeability of steel and hardness at higher temperatures, which was also proved in the sample No. 3 hardfaced by 1709electrode. Despite the lowest content of chrome and the highest content of molybdenum, it reached the best results (the highest level of microhardness and abrasive wear resistance). During the macrostructure observation, we did not notice any lack of inter-run fusion, cavities or pores. Sample No. 2 also reached high level of hardness and abrasive wear resistance. However, the content of chrome was at the highest level in this sample. Weld beads forming after surfacing is regular. In sample No. 1, we recommend to change the surfacing parameters, because it reached the lowest level of hardness, and abrasive wear resistance. By visual control, we found some surfacing defects. These were probably caused by the low molybdenum content in the surfacing material.

Conclusion

Present spurt technical development imposes increasing requirements on the quality of manufactured machine components. The requirements comprise particularly the operational reliability, component life, but also the requirements for precise parameters and quality, adequate toughness, corrosion resistance, resistance to individual types of wear such as collision, pressure etc.

All these requirements imposed on machine components cannot be, in most cases, secured by only one kind of material. Also by this reason, individual layers are coated onto the parent material of a component by surfacing technology. These layers mainly function as a protection, but they are also resistant to corrosion, pressure, collision and other individual wear types. The component is renovated in this way, or a new component is then hardfaced.

Following this knowledge, the development of new filler materials is very important. These materials should reduce chrome content in the surfacing so that their ability to reduce the resistance to given wear types does not decrease.

References:

[1] BLAŠKOVITŠ, P., ČOMAJ, M. *Renovation of the surfacing and thermal spraying*. Bratislava, 2006. 204 p.

[2] BALLA, J., *Tribology and tribotechnique*. Nitra: VŠP, 1987. 129 p.

[3] Dostupné na internete: http://www.strojarstvo.sk/docwww/SK/284/284.pdf [cit. 2008-04-28]

[4] Dostupné na internete: http://www.stifner.sk/skola/doc/afm/texty_AFM_2004.doc [cit. 2009-11-12]

[5] Dostupné na internete: http://www.mtfdca.szm.sk/subory/opotrebenie.pdf [cit. 2009-04-28]

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EFFECT OF REDUCTION IN THREE-DRAWN AND TWO-DRAWN SINGLE-RUN TECHNOLOGY ON ROUGHNESS OF INNER SURFACE OF TUBES

Martin RIDZOŇ, Ľubica ELEKOVÁ, Jana LIŠKOVÁ, Jozef BÍLIK

Abstract

The paper deals with the production of could drawn precision seamless steel tubes with three-drawn and two-drawn single-run technology.. The aim of experiment is to verify the possibility of drawing rolled tubes of size ∅ 70 x 6.3 mm (material E355) with three-draw single-run technology without intermediate recrystallising annealing on the final size ∅ 44 x 3 mm in the fixed reduction and two-draw single-run technology∅ 70 x 6.3 mm without intermediate recrystallising annealing on the final size ∅ 50 x 3.75 mm in the fixed reduction and with size ∅ 70 x 6.3 mm without intermediate recrystallising annealing on the final size ∅45 x 3.75 mm in the fixed reduction. Advise the impact choice of the reduction on roughness of inner surface of tubes.

Key words

reduction, three-draw and two-draw single-run technology, roughness of surface

Introduction

Under the name of drawing tubes, cold-forming means, during which the original material (tube) forms in beams, its cross-section shrinks, thins up or the thickness of wall of pipe enlarge and length increases. The process of forming moves in several draws, depending on the original and final size of the tube. The important task is the choice of proportional reduction for the particular cross-sections because the unbalanced decomposition of reduction results into tension and deformation or cracks during the pulling, that will consequently influence the roughness of tubes' surface.

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Experiment

The experimental material is non-alloy structural steel grade E355 (see tab.1) which was used to produce hot rolled tubes' size ∅ 70 x 6.3 mm.

CHEMICAL COMPOSITION OF EXPERIMENTAL MATERIAL E355 Table 1

C	0,1800	Mn	1,1800	Si	0,2300	P	0,0150	S	0,0140	Cr	0,0500
Ni	0,0800	Mo	0,0200	Ti	0,0020	V	0,0030	Nb	0,0010	N	0,0090
Al	0,0230	Zr	0,0020	Ca	0,0022	As	0,0060	W	0,0100	Zn	0,0040
Cu	0,2000	Sn	0,0160	Pb	0,0010	O	0,0032	Sb	0,0040	Ce	0,0010

The experiment was contucted to the following technological process:
Deburring → chemical treatment → drawing tube at a fixed mandrel roller → other operations. Detailed view of the internal tube surface is shown in Fig.1., Fig. 2., and Fig. 3.

Fig. 1 *Detail of the inner tubes' surface material E355 a) Ø57x5, first- draw, b) Ø50x3.75, second- draw c) Ø44x3, third- draw*

Fig. 2 *Detail of the inner tubes' surface grade OR-3) Ø55x4.75, first- draw, b) Ø50x3.75, second- draw*

Fig. 3 *Detail of the inner tubes' surface grade and OR-3) Ø55x4.35, first- draw, b) Ø45x3.75, second- draw*

Determining of the final reduction:

- Specified final reduction with three-drawn single-run technology of drawing tubes from ∅70 x 6.3 mm to final diameter ∅44x 3mm is 69.35 % which was consequently divided into three draws.
- Specified final reduction with two-drawn single-run technology of drawing tubes from ∅ 70 x 6.3 mm to final diameter ∅50x 3.75 mm is 56.78 % which was consequently divided into three draws.
- Specified final reduction with two-drawn single-run technology of drawing tubes from ∅ 70 x 6.3 mm to final diameter ∅45x 3.75mm is 61.45 % which was consequently divided into three draws.

Experiment evaluation

After various draws in the samples was measured roughness of the inner surface of tubes and was considered whether the sample properties are according to EN 10305-1. Surface roughness was measured by Taylor Hobson touch profilometer Surtronic 3 + (Fig.4), in according to STN EN ISO 4287. Principle of measurement: the sensing tip of the arm moves at a constant speed across the surface and picks up his inequality. The device provides output numerical values for the standard characteristics of surface roughness on the display or graphical output (measured profile and curve of the material profile share) in the monitor.

Fig. 4 *Touch profilometer Surtronic 3 +*

For the experiment were monitored and measured values of the arithmetic mean deviation Ra considered profile. The measured values were constructed in following charts:

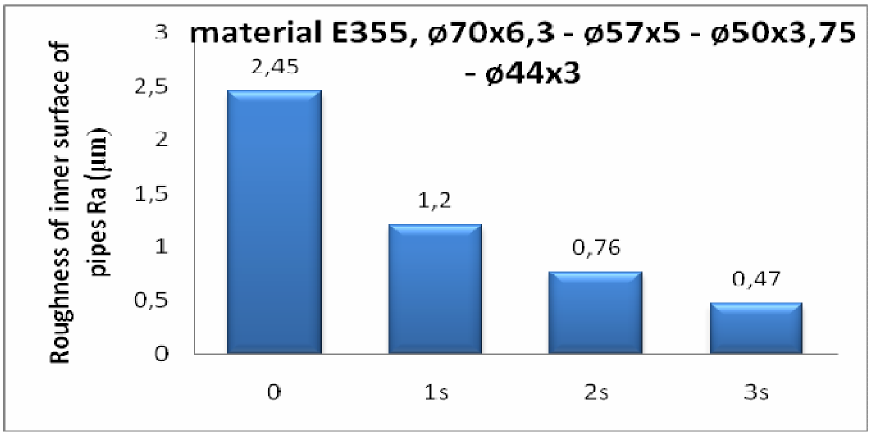

Fig. 5 *The resulting roughness values of tubes Ra [μm]*
0 – rolled tube (intermediate input), 1s – first drawn, 2s –second dawn, 3s – third drawn

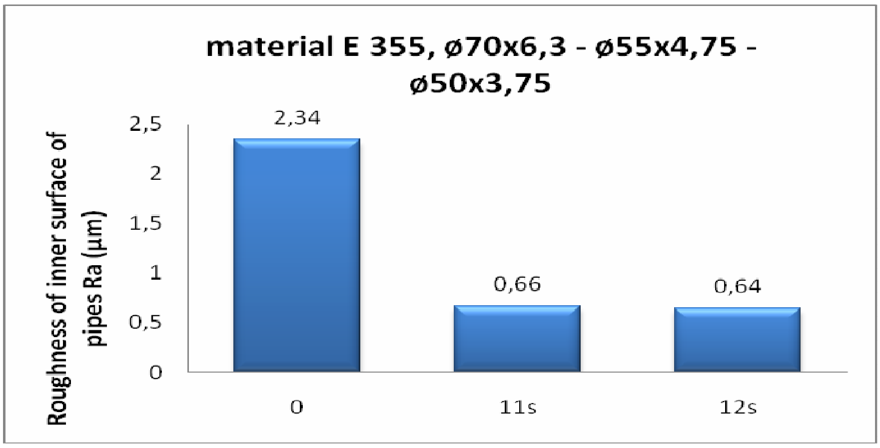

Fig. 6 *The resulting roughness values of tubes Ra [μm]*
0 – rolled tube (intermediate input), 11s – first drawn, 12s –second drawn

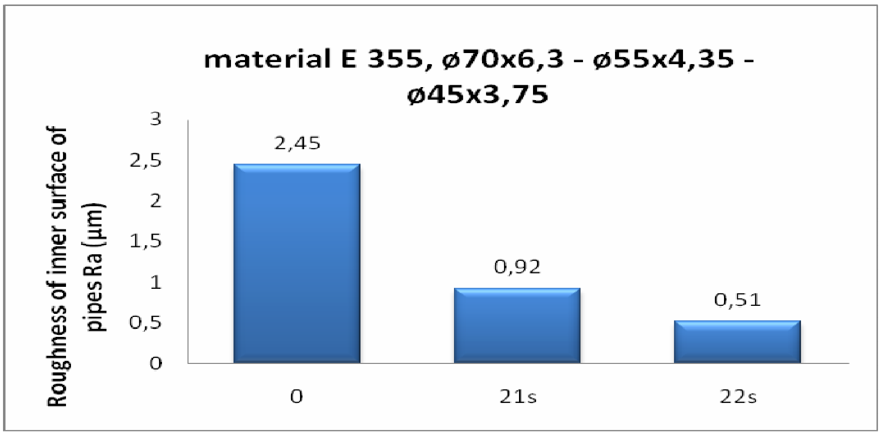

Fig. 7 *The resulting roughness values of tubes Ra [μm]*
0 – rolled tube (intermediate input), 21s – first drawn, 22s –second drawn

The required roughness Ra value according to EN 10305-1 and formed by heat-treated steel E355 + C (symbol + C means - no heat treatment after the last cold forming) Ra is 4 μm.

Conclusion

The consequential roughness of inner tubes' surface has large influence on the choice of a proportional reduction in the individual sections. By mistaken determining of reduction would be express to roughness of surface and the Ra value would be greater than according to EN 10305-1. According to this standard is given by max. arithmetic mean value of deviation Ra = 4 μm, while the charts show that these samples by three-drawn single-run technology was roughness after third drawn Ra 0.47μm and by two-drawn single-run technology was roughness with reduction 56.78 % after second drawn Ra 0.64 μm and with reduction 61.45 % was after second drawn Ra 0.51 μm. It follows that the material in terms of roughness verifies the requirements in standard to EN 10305 is suitable for forming other operations related to roughness of surface.

References:

[1] BAČA, J., BILÍK, J. *Technology of forming*. Bratislava: STU, 2000. 242 p. ISBN 80-227-1339-2

[2] ELEKOVÁ, Ľ. *Mathematical expression of the material ratio curve of the profile.* Written thesis of disertation exam. Trnava, 2009.

[4] RIDZOŇ, M. *Research of technological parameters affecting the production and properties of steel tubes*. Written thesis of disertation exam. Trnava, 2009.

[5] EN 10002-1 : 2001 *Tensile testing of metallic materials. Method of test at ambient temperature.*

[6] LIŠKOVÁ, J. Research of influence technological parameters on cold drawn wires. Written thesis of disertation exam. Trnava, 2009.

[7] EN ISO 4287 : 1997 *Geometrical Product Specifications (GPS) - Surface Texture: Profile Method – Terms, Definitions and Surface Texture Parameters.*

[8] PERNIS, R. *Theory of metal forming.* Trenčín: TnU AD, 2007. 168 p. ISBN 978-80-8075-244-6

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ELECTRON BEAM WELDING OF DUPLEX STEELS WITH USING HEAT TREATMENT

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Abstract

This contribution presents characteristics, metallurgy and weldability of duplex steels with using concentrated energy source. The first part of the article describes metallurgy of duplex steels and the influence of nitrogen on their solidification. The second part focuses on weldability of duplex steels with using electron beam aimed on acceptable structure and corrosion resistance performed by multiple runs of defocused beam over the penetration weld.

Key words

duplex stainless steel, electron beam welding, heat treatment

Introduction

Duplex stainless steels are very attractive constructional materials for service in aggressive environments. Their physical properties are between those of the austenitic and ferritic stainless steels, but tend to be closer to those of the ferritics and to carbon steel. Such steels offer several advantages over the common austenitic stainless steels. The duplex grades are highly resistant to chloride stress, corrosion cracking, have excellent pitting and crevice corrosion resistance and are about twice as strong as the common austenitic steels.

The first-generation duplex stainless steels provided good performance characteristics, but had limitations in the as-welded condition. These limitations confined the use of the first-generation duplex stainless steels, usually in the unwelded condition, to a few specific applications. The heat-affected zone of welds had low toughness because of excessive ferrite and significantly lower corrosion resistance than that of the base metal. Nitrogen alloying of

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duplex stainless steels enhances HAZ toughness and corrosion resistance, which approaches that of the base metal in the as-welded condition. Nitrogen also reduces the rate at which detrimental intermetallic phases are formed.

Normally, duplex steels are weldable using welding procedures generally used for high alloyed steels. The experience with such comparatively new welding method like electron beam welding is still limited. However, there have been a few successful applications and there is every reason to expect that procedures will be developed more fully.

Chemical composition and metallurgy of duplex stainless steel

Duplex stainless alloys have 18 % to 28 % chromium, 2.5 % to 7.5 % nickel and low carbon contents. Some of the alloys will also have additions of nitrogen, molybdenum and copper. Chemical composition of some duplex, superduplex and hyperduplex steels are given in Table 1 [8].

The second-generation duplex stainless steels are defined by their nitrogen alloying. It is generally accepted that the favourable properties of the duplex stainless steels can be achieved for phase balances in the range of 30 to 70 % ferrite and austenite. Fig. *1*1 shows the typical microstructure of duplex stainless steel.

Dark phase = ferrite

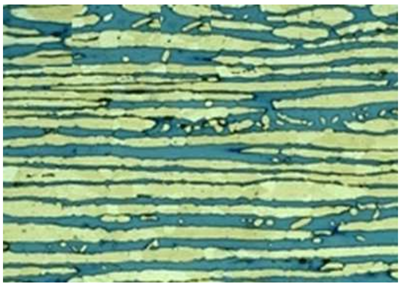

Fig. 1 *Typical microstructure of duplex stainless steel*

The interactions of the major alloying elements, particularly chromium, molybdenum, nitrogen, and nickel, are quite complex. To achieve a stable duplex structure that responds well to processing and fabrication, care must be taken to obtain the correct level of each of these elements.

Mechanical properties of duplex stainless steels are excellent in the temperature range from - 50 °C to 300 °C. When steel is subjected to elevated temperatures, numerous different solid state reactions can take place. These lead to the formation of different precipitates resulting in detrimental changes in the properties of the material, especially in its toughness. When duplex steels are exposed to temperatures over 300 °C they are susceptible to 475 °C embrittlement. During heat treatments in temperature range 500 °C – 900 °C, duplex stainless steels are prone to microstructure changes and precipitation of intermetallic phases.

CHEMICAL COMPOSITION OF SOME DUPLEX STEELS SANDVIC SAF Table 1

Steel grades	**EN**	**ASTM**	***Chemical composition (%)***					**PRE**
			C max.	***Cr***	***Ni***	***Mo***	***N***	
SAF 2205 (duplex)	X2CrNiMoN22-5-3	S32205	*0,02*	*22*	*5,7*	*3,1*	*0,17*	35
SAF 2507 (super duplex)	X2CrNiMoN25-7-4	S32750	*0,03*	*25*	*7*	*4*	*0,3*	42
SAF 2707 HD (hyper duplex)	X2CrNiMoN27-6-5	S32707	*0,03*	*27*	*6,5*	*5*	*0,4*	49

PRE *– Pitting Resistance Equivalent*

The iron-chromium-nickel ternary phase diagram is a roadmap of the metallurgical behaviour of the duplex stainless steels.

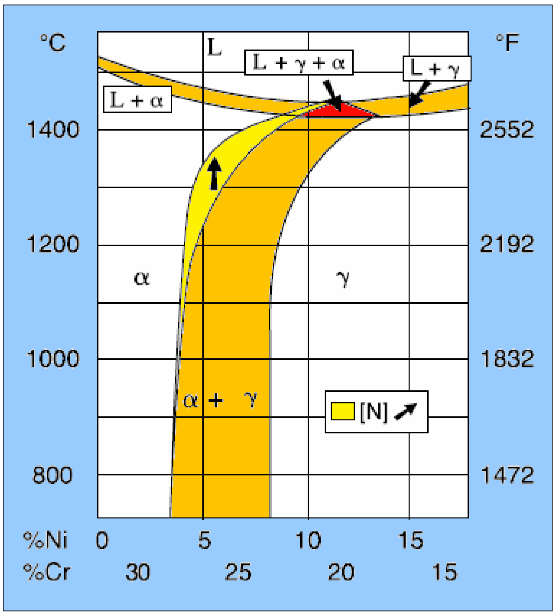

Fig. 2 *Section through the Fe-Cr-Ni Ternary Phase Diagram at 68 % Iron*

A section through the ternary at 68 % iron (Fig. 2) illustrates that these alloys solidify as ferrite. As temperature decreases (*to 1000 °C*), austenite develops. For cast duplex, a structure of austenite islands in a ferrite matrix can be observed. For wrought alloys, the microstructure has morphology of laths of austenite in a ferrite matrix. Thermodynamically, because the austenite is forming from the ferrite, it is impossible for the alloy go past the equilibrium level of austenite. However, as cooling proceeds to lower temperatures, carbides, nitrides, sigma and other intermetallic phases are all possible microstructural constituents [1, 2].

The effect of increasing nitrogen is also shown in Fig. *2*. Another beneficial effect of nitrogen is that it raises the temperature at which the austenite begins to form from the ferrite. Therefore, even at relatively rapid cooling rates, the equilibrium level of austenite can almost be reached. In the second-generation duplex stainless steels, this effect reduces the problem of excess ferrite in the HAZ [5].

Electron beam welding of duplex stainless steels

Electron beam welding uses energy from a high velocity focussed beam of electrons made to collide with the base material. When electrons in a focused beam hit a metal surface, the high energy density instantly vaporizes the material, generating a so-called key hole (Fig. 3).

A characteristic of this phenomenon is that it allows the unique capability for deep, narrow welds with very small heat affected zones (HAZ) and minimized thermal distortions of welded assemblies.

Depth-to-width ratios of up to 40:1 have been achieved in production for many years. With high beam energy, a hole can be melted through the material and penetrating welds can be formed at speeds of the order of 20 m/min.

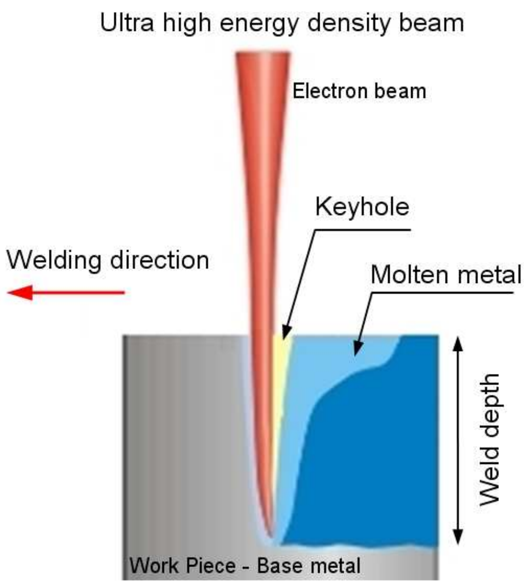

Fig. 3 *Schematic illustration of the Electron beam welding process*

Welds are made in vacuum, which eliminates contamination of the weld pool by gases. The vacuum not only prevents weld contamination but produces a stable beam.

The concentrated nature of the heat source makes the process very suitable for stainless steels. The available power can be readily controlled and the same welding machine can be applied to single pass welding of stainless steel in thicknesses from 0.5 mm to 40 mm [4, 5].

Characteristic of a problem

Electron beam welding process is used without the addition of filler metal and is not very suitable for the welding of duplex stainless steels as the welds will be very high in ferrite. Such a weld must be quench-annealed in order to get the correct structure.

Electron beam welding is especially suited to produce joints of heavy section materials in one or two passes. Unfortunately, it tends to produce rapid cooling rates and therefore highly ferrite in the melt zone, particularly in thin sections. Nevertheless, the toughness remains high which can be attributed to the very low oxygen content in the weld. Still the qualification of the procedure must be alert to the possibility of excessive ferrite in the HAZ and even in the weld when the high speed welding capabilities of these methods are considered.

The cooling rate has a considerable impact on the austenite-ferrite ratio developing at ambient temperature. This means that slow cooling causes a higher austenite content than rapid cooling, during which approx 60 to 90 % ferrite is to be expected (Fig. 4). In this way it is possible to influence the ferrite-austenite ratio, depending on the weld process and weld geometry.

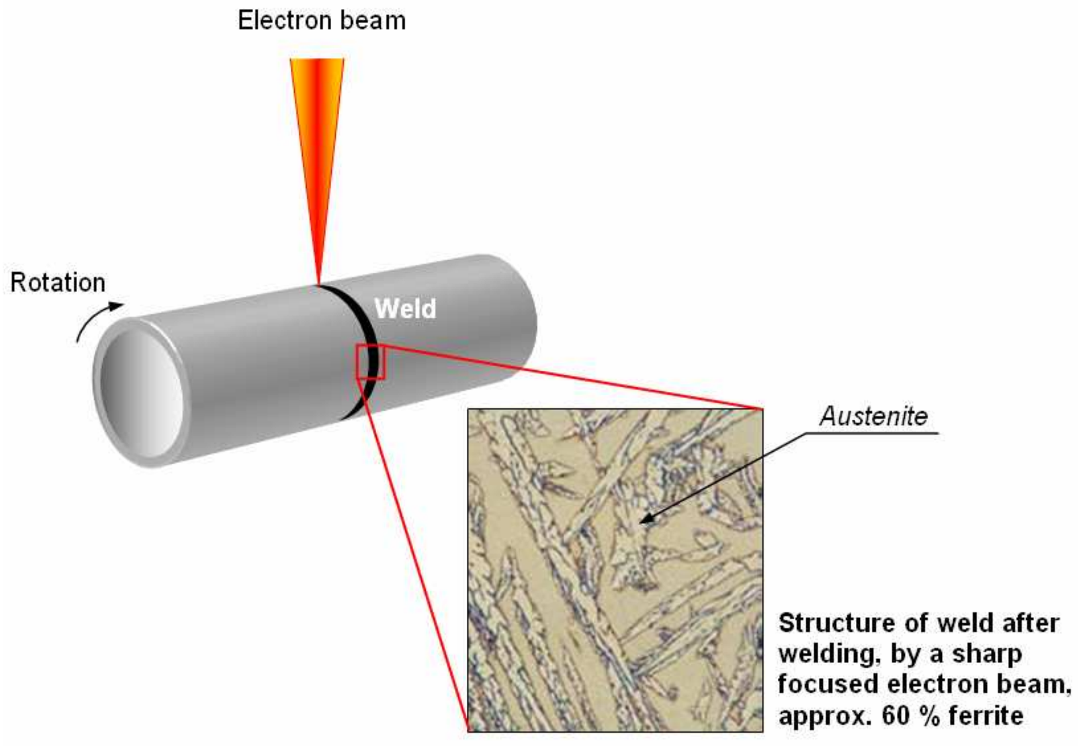

Fig. 4 *Welding of duplex steel by a sharp focussed electron beam*

In order to guarantee a balanced ferrite/austenite ratio of the weld, heat treatment after welding, and solution annealing is recommended, what however represents an undesired operation increasing the welding costs. Solution annealing temperature should be approx. 1,080 °C and holding times of around 2 – 3 min / mm wall thickness, followed by a rapid water quench. In order to avoid the development of a sigma phase, the cooling time from 950 °C down to 700 °C should not be more than 2 minutes.

Low heat input may result in undesirable proportion of ferrite in weld and in the heat affected zone and in corresponding loss of toughness and corrosion resistance. Maximum average ferrite content should be within 40 to 50%.

We try to solve the mentioned drawbacks of beam welding duplex steels application of post-heat after welding by a defocused beam with several passes along the weld zone (Fig. *5*).

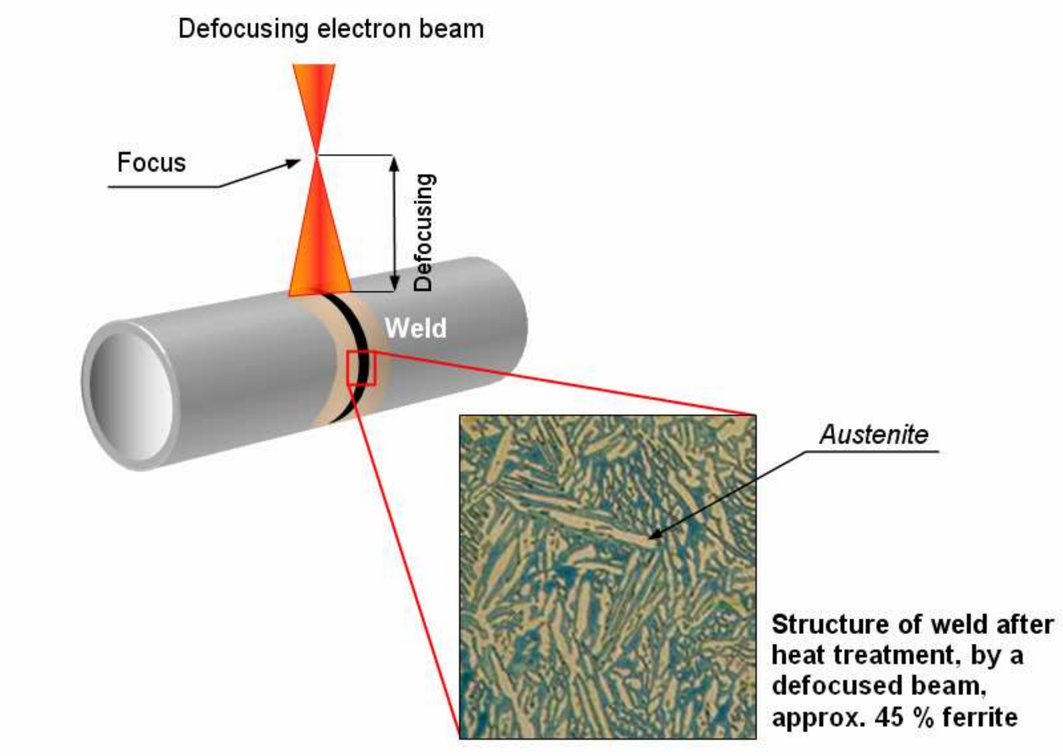

Fig. 5 *Heat treatment by a defocused electron beam*

The post heat is realized by a combination of defocusing (*defocusing current*) and oscillation of electron beam with a certain swap – generation of alternating course set on generator with subsequent cooling down in vacuum.

Parameters of post heat:

- acceleration voltage,
- electron beam current,
- defocusing current,
- oscillation of electron beam by generation of sine course with 90° phase shift,
- number of passes after welding [3].

Own contribution

Our own contribution to this article is a theoretical overview of solution to the problem of weldability of duplex stainless steels. This article describes technology of heat treatment after welding for the purpose of acquisition of desired properties. The paper defines the parameters of heat treatment after welding by electron device.

Conclusion

Exceedingly low heat input may result in fusion zones and HAZ which are excessively ferritic with a corresponding loss of toughness and corrosion resistance. Exceedingly high heat input increases the danger of forming intermetallic phases. It is generally agreed that the characteristic benefits of duplex stainless steels are achieved when there is at least 35% ferrite with the balance austenite. The heat input introduced by the controlled post heat, applied after welding, enabled to affect the proportional volume of ferrite in weld metal. These results suggest that such a procedure leads to positive results.

References:

[1] LIPPOLD, J, C., KOTECKI, D,J. *Welding Metallurgy and Weldability of Stainless Steels*. New Jersey: WILEY-INTERSCIENCE, 2005. 357 p. ISBN 0-471-47379-0

[2] HRIVŇÁK, I. Dual-Phase Stainless Steels – material of pipelines for aggressive media. In *Corrosion of Underground Structures 2003. Proceedings of the 13th International Conference Corrosion of underground structures 2003*, 27 and 28 may 2003. Košice: Technická univerzita v Košiciach, 2003. pp. 54-59. ISBN 80-7099-251-4

[3] KOLENIČ, F., IŽDINSKÁ, Z., FODREK, P. Influence of EB Welding Parameters on Properties of Welded Joints in Duplex steel type SAF 2205. In *60th Annual Assembly and International Conference: Proceedings of the IIW International Conference Welding and Materials. Technical, Economic and Ecological Aspects*. 01-08 July 2007 Dubrovnik & Cavtat. Croatia, Zagreb: Croatian welding society, 2007. pp. 1-13. ISBN 978-953-7518-00-4

[4] Dr. G. SCHUBERT. Electron Beam Welding – Process, Applications and Equipment. In *Proceedings of the IIW International Conference on Advances in Welding and Allied Technologies*, Singapore: Published by Singapore Welding Society, 2009, ISBN 978-981-08-3259-9, pp. 283 – 288.

[5] Available on internet: <http://www.euro-inox.org.>

[6] Available on internet: <http://www.imoa.info.>

[7] Available on internet: <http://www.stainless-steel-world.net.>

[8] Available on internet: <http://www.smt.sandvik.com.>

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THE ASSEMBLY OPERATION SEQUENCE MODEL

Štefan VÁCLAV [1], Katarína SENDERSKÁ [2]

Abtract

The research within the development of digital factory concept concerns also the assembly process as an important part of the production. This paper presents an assembly operations sequence model as a part of design and planning method for the assembly process. This model enables to obtain a precise graph presentation as a tool for computer support.

Key words

assembly, assembly operation sequence, oriented graph

Introduction

Digital factory is a new concept based on the application of digital models, modelling and simulation. This concept has a great potential to rapid and effective solving of the products and production systems. The assembly as a part of the production processes requests a systematic consideration owing to the processes' complexity and lower level of development.

Assembly operation sequence planning

One of the important approaches is the development of the theoretical and methodical procedures of assembly process formalization and its exact description. The increased possibility of computer support in the assembly design process requires the new CA-oriented models for various design and planning tasks.

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The main goal in the developed integrated methodical procedure for assembly process design was to create a scope in which the designer can move in a large knowledge base and to use relatively independent methodical tools. The assembly operation sequence planning is a part of a complex system of assembly process and system design. All approaches in this filed use some types of graph presentation [1], [9].

Model of assembly operation sequence planning

The general scope of the proposed model of assembly operation sequence planning is a hierarchical division of the assembly operation planning into three levels minimum. These levels come out from the assembly operation definition. In this model, there is the assembly operation defined as a process of joining of minimum 2 parts or product components that must be carried out at one place and must be finished, since the division of this joint process into "smaller entities" can cause a failure of position, orientation or other requested parameters. After finishing the assembly operation, the assembled product can be stored, positioned, clamped, tested etc. without any impact to the quality.

This definition defines three main levels of planning the assembly operation sequence. The basic level is planning the assembly operation according to the above-mentioned definition. The lower level is planning and analysing the assembly actions contained in the operation. The higher level is oriented to analysing and planning the operation aggregations. This level is very useful for more complex products (with number of parts about 30 and more) and by generating the assembly operation sequence variants. All this three levels are in correlation. The analysis can be carried out on any level. The transfer between the levels is simple.

The methodical procedure of assembly operation sequence planning – basic level (Fig.1) supposes the integration of product structure and assembly operation sequences into one unit that represent the process nature, i.e. gives into the relation the objects (assembled product parts and assembly results) with the performed activity (assembly operations).

Identification of the assembly operation inputs

The first step is the decomposition of the product into "the parts" e.g. inseparable items from the point of view of assembly, and the definition of the set of product parts.

The second step is the identification of the set of assembly operation.

The set of assembly operations $M_o = \{O_1, O_2, O_3...\}$ and the set of a product parts $M_S = \{S_1, S_2, S_3...\}$ are in correlation than can be expressly formalized. The elements of both sets are in graphical representation graph tops and the relations between them are the graph edges. The elements of the set M_S "put into" the set $M_{o.}$ The main parameters of this relation are input part number and the order of their input.

Identification of the assembly operation outputs

After performing every assembly operation, an assembly point is defined. The set of the assembly operation results can be written as $M_v = \{V_1, V_2, V_3 ... V_n\}$, where V_n is the final product and $_n$ is the number of assembly operations.

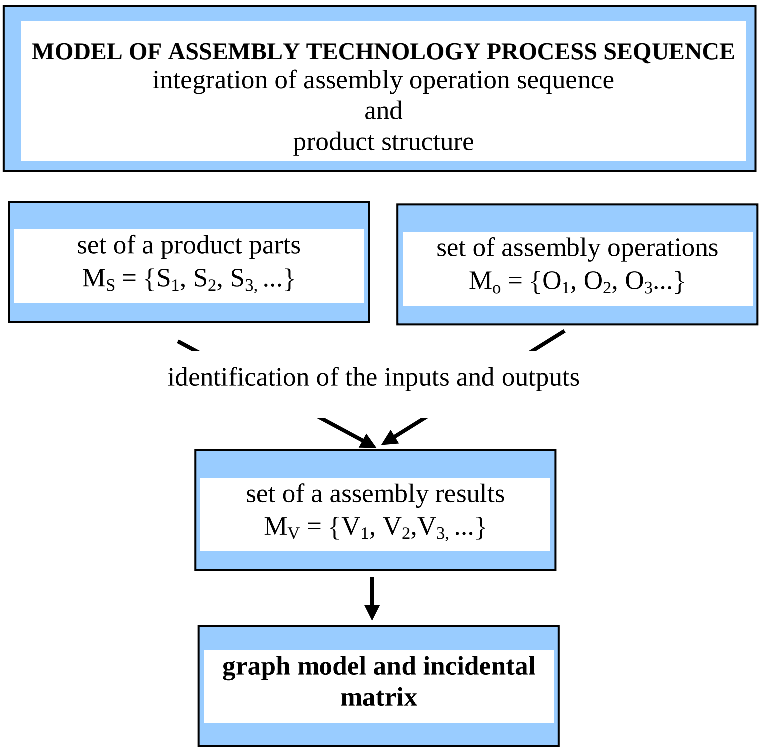

Fig. 1 *Analysis steps of assembly technology process model*

Graph of assembly operation sequence

Graph model of assembly operation sequence (Fig.2) with inputs and outputs and with several parameters is implemented under the following conditions. The graph tops are the elements of part set M_S and elements of the assembly operation result set M_v, e.g. inputs and outputs of assembly operations. In the graph is also listed the number of the parts. This data gives an answer to the question, whether all parts were used. The elements of assembly operation set M_o are represented by a rectangle. The relations are represented by an oriented graph edge, which is described as **(i, j),** where **i** is the number of elements put into assembly operation and **j** is the order of their input.

It is possible to describe the graph model in the form of incidental matrix. The incidental matrix contains the same information as that contained in the graph.

The model application

The presented model was applied for a large number of different product types in the Slovak companies as well as in the university training and research. The analysis enables for instance to create a technologically correct assembly sequence from a 3D model of the product (Fig.3). Fig. 4 shows a 3D model of a personal car - ventilating grid. By the analysis of the assembly technology process sequence for this product, the above described approach was used. Fig. 5 shows the result, a model of assembly technology process sequence for one sub-assembly of the ventilating grid. Incidental matrix for this graph is presented in Fig. 6.

On this basis, type technological assembly sequences of various assemblies and products as gear pump, water pump, ventilating grid, buffer cylinder, wiper mechanism, door hanger etc was designed. The model of the assembly sequence was successfully applied for all these products or assemblies with the result that the description of the assembly sequence by this model is correct and it can express all possible variants of the assembly process.

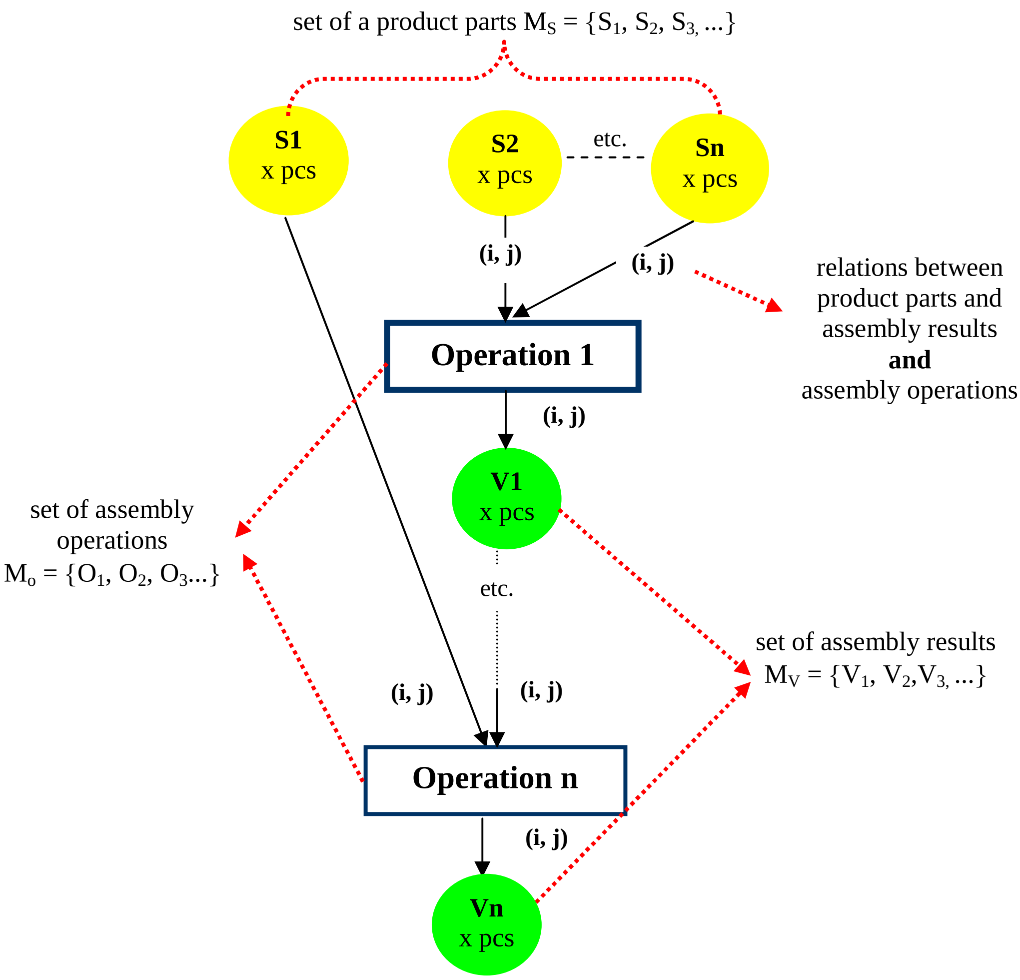

Fig. 2 *Principle of assembly operation sequence model*

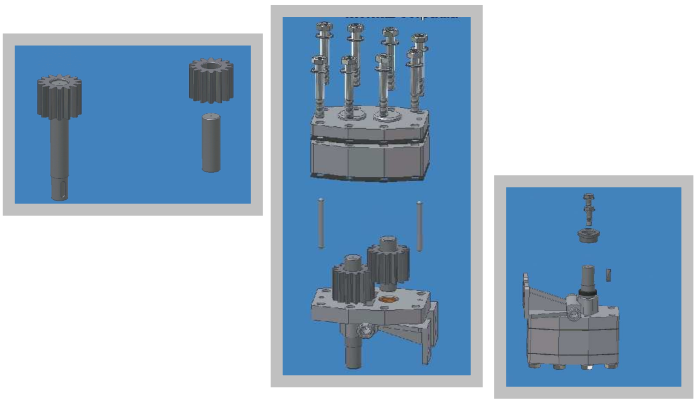

Fig. 3 *Printscreens of the assembly sequence created from a 3D model of the product*

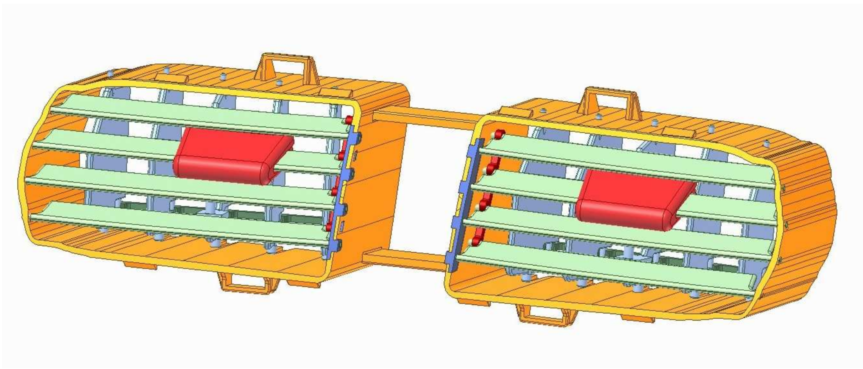

Fig. 4 *Analyzed product - ventilating grid of personal car*

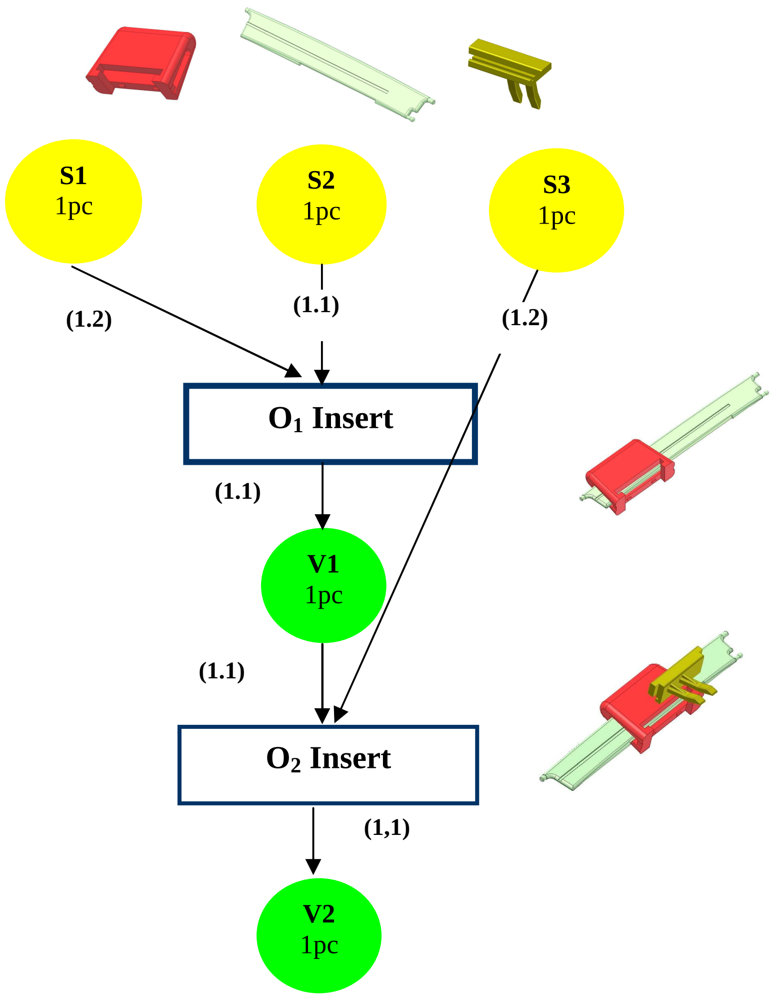

Fig. 5 *Model of assembly technology process sequence for one sub-assembly of the ventilating grid*

set of a product parts $M_S = \{S_1, S_2, S_3, ...\}$ and set of a assembly results $M_V = \{V_1, V_2, V_3, ...\}$

+ input, - output

Operations	**S1**	**S2**	**S3**	**V1**	**V2**
O_1 Insert	**+(1,2)**	**+(1,1)**		**-(1,1)**	
O_2 Insert			**+(1,2)**	**+(1,1)**	**-(1,1)**

set of assembly operations $M_o = \{O_1, O_2, O_3 ...\}$

description of the relations between product parts and assembly results **and** assembly operations

Fig. 6 *Incidental matrix for assembly technology process sequence graph*

Conclusion

On the basis of the obtained results, we can say that the great advantage of this approach is the possibility to obtain a logical linear formal description. Defined model can use the computer support. This concept enables also to analyze more complex products and to express parallel operations. The possibility of viewing angle selection enables individual application, modular implementation and interconnection. The model is precise, can be simply stored and repetitively used for standard components. This makes possible to develop a standard or unified model of the assembly operations sequence for the standard or unified components.

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References:

[1] LOTTER B., WIENDAHL H.P. *Montage in der industriellen Produktion*. Berlin: Springer, Heidelberg, New York, 2006. p. 531. ISBN 13978-3-540-21413-7

[2] MADARÁSZ, L. *Inteligentné technológie a ich aplikácie v zložitých systémoch*. Košice: Vydavateľstvo Elfa, s.r.o., 2004. p. 349. ISBN 80-89066-75-5

[3] PETERKA, J. Simulácia v montáži. In *Automation in production planning and manufacturing, 8-th International Scientific Conference*. Žilina: University of Žilina, Faculty of Mechanical Engineering 2007, pp. 191-195. ISBN 978-80-89276-03-5

[4] SENDERSKÁ, K., KOVÁČ, J., MADARÁSZ, L., ANDOGA, R. The assembly technology process and part-feeding model. In *SAMI 2005, 3-th Slovakian-Hungarian joint symposium on applied machine intelligence*. Herľany, 2005, pp. 415-423. ISBN 963-7154-35-3

[5] SENDERSKÁ, K., KOVÁČ, J., MAREŠ, A. Videoanalýza montáže vetracej mriežky. In *Nové smery vo výrobných technológiách : 9. medzinárodná vedecká konferencia*. Prešov: FVT TU v Košiciach, 2008, pp. 499-502. ISBN 978-80-553-0044-3

[6] SENDERSKÁ, K., KOVÁČ, J., STRAMA, M., TOBÁK, J. Analiza struktury montowanego wyrobu i konstrukcijne uzasadniona kolejnošč operacji montažowych. In *Technologia i automatyzacja montažu*, 1997, no. 1, pp. 2-3. ISSN 1230-7661

[7] VÁCLAV, Š. The grade of intelligence of assembly works. In *Annals of MTeM for 2005 & Proceedings, International Conference Modern Technologies in Manufacturing.* 7th. Cluj-Napoca, 6th-8th October 2005, Cluj-Napoca (Rumunsko), Technical University of Cluj-Napoca, 2005, pp. 407-410. ISBN 973-9087-83-3

[8] VÁCLAV, Š., VALENTOVIČ, E. OMA-objective method for assembly. In *RaDMI 2006, Proceedings on CD-ROM. International Conference*. Budva, Montenegro, 2006, Trstenik, High Technical Mechanical School of Trstenik, 2006, pp. 1-6. ISBN 86-83803-21-X

[9] WHITNEY, Daniel. *Mechanical Assemblies. Their design, manufacture, and role in product development*. New York: Oxford university press, 2004. pp. 517. ISBN 0-19-515782-6

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RESEARCH PAPERS
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IMPORTANCE OF PROJECTS IN AUTOMOTIVE INDUSTRY

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Abstract

For automotive companies, research and development is the key to success for new generation of products. The aim of this article is to accent the importance of innovations and innovations-focused projects in automotive industry. Relevance of co-operation between automotive industry and educational institutions is noticed in the article, too. Furthermore, history of automotive industry in Slovakia is outlined in the article. Main part of the article is focused on project AUTOCLUSTERS.

Key words

automotive, industry, innovation, project, clusters

Introduction

Automotive industry is one of the most important ones not only in Slovakia but in the region of South East Europe as well. This industry develops continually and belongs to the most quickly advanced sectors. Automotive industry poses claims to many areas and industry segments. An ever-present competition forces the automobile factories to strive be the best in order to keep their market shares. It gives vehemence on innovations and looking for new ways of co-operation.

Automotive industry in Slovakia

The first automobile factory in Slovakia was established relatively early in Bánovce nad Bebravou. The largest expansion of large-scale production for automobiles Tatra was

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registered in the 70's of the 20th century. Later, after the changes in socio-political situation, Volkswagen, an international corporation, entered the Slovak market in 1991. Furthermore, after the Slovak government introduced regulations in area of income tax from 1998, a stream of new investment started to pour into the automotive industry in Slovakia. Qualification, labourers' workmanship as well as low labor costs meant an attractive opportunity for investors. Besides main component suppliers for automotive industry, there were also suppliers of spare parts as new investors, who decided to invest in Slovakia. In 2003, the headstone of the technologically newest automobile factory PSA Peugeot Citröen Corporation was established in Trnava. Last year, this automobile factory became the biggest producer of automobiles in Slovakia. In 2004, the building work of Kia Motors Slovakia plant began in Teplička nad Váhom near Žilina. Kia Motors Slovakia is the first production factory of company Kia Motors Corporation in Europe. These projects attracted many other investors and thereby stimulated the establishment and development of new industrial parks.

Co-operation with educational institutions

High technologies used in automobile industry put demands on people working in this industry. That is why the co-operation of automotive industry with educational institutions is so vital. Such cooperation presents potential advantages for all co-operative partners. Some educational institutions provide methodical and technical support for laborer/employee trainings for particular jobs and work positions. Closer co-operation enables educational institutions transmit up-to-date knowledge from automotive industry to the students. Up-to-date knowledge, applicable study programmes and the hands-on approach enable to educate students whose profile will meet the requirements of the automotive industry. The agreement between the Slovak University of Technology in Bratislava and Volkswagen Slovakia Corporation is one of the most significant projects. The co-operation agreement between the Faculty of Mechanical Engineering of the Slovak University of Technology in Bratislava and Volkswagen Slovakia Corporation was signed in September 2009. The co-operation agreement involves development of the study programmes "Automobile production" and co-operation in the areas of science and research and development. The "Automobile production" programme will be the first study programme with focus on this area in Slovakia. The first applicants for this study programme can apply in the academic year 2010 – 2011. Mutual co-operation should enable to involve students and scientists to do the research and development activities in the area of technologies and production methods.

Increasing requirements in automotive industry

Increasing requirements in automotive industry are typical for their interdisciplinary nature. These demands stem from the area of technologies, performance, safety, environment and many others.

The current focus in the automotive industry is the area of environmental technologies, their development, application and adaptation to the current system. It brings to the fore green innovation and new environmental standards in cars production in order to develop cleaner, more economical and attractive cars. Supply companies must respond flexibly to the development in automobile factories which links strongly to the green car, increasing rate of electronic and software components, requirement for greater security in vehicles, integrated traffic management, navigation systems, networking and linking intelligent vehicles, reducing vehicle weight and other areas. [1]

Permanent impulses form consumers and competitors call for new technologies, new functions and further implementation of innovations. These demands concern not only automobile factories themselves, but their suppliers as well. That is because the automobile factories derive benefits from using suppliers not only for requested components delivery, but also for development of these components. Automobile factory can thus confide not only in factory development platform but also in development workrooms of factory suppliers. Providing such a development has many requirements, which need to be performed complexly. That is the reason why it is helpful for interested participators to create networks which enable to perform these requirements. Therefore, there is a growing importance of projects, which facilitate establishment of such networks and clusters focused on knowledge transfer to particular subjects in automotive industry.

South East Europe Transnational Cooperation Programme AUTOCLUSTERS

Project "The international co-operative network of educational and research institution with subcontractors and other bodies active in automotive industry" started in 2009 and this project will continue until 2012. Project logo can be seen in Figure 1.

Fig. 1 *Project logo*

The Project brings together Universities, R&D institutions, SME support facilities from EU-15, NMS as well as IPA to prepare and create the first automotive network in SEE. The second level clustering activities proposed by the project are strictly oriented on the activities which are improving the innovation capacities in the region and improve technology and know-how transfer – improving the innovation circle. The project in the first stage analyses the cluster's development and best practices across the regions as well as sets up the connection with other existing European activities in the automotive clustering. The second stage of cluster activities in the project is consistently focused on improving the innovative capacity in the region and improving the technology and knowledge transfer, which contributes to the innovation cycle.

The project is focused highly towards producing concrete results, and addresses the main challenges that are specific for both SEE region and across the whole EU territory.

Project aims and schedule

Clustering in automotive industry is at a great level in comparison to some other industries in the SEE region. The clusters identify the issues in innovative capacities and in the innovation cycle, by identifying which project to address by proposing specific second level clustering activities based on the long time experience in auto industry of some partners and capacities of others. Activities are based on the partner's experience in previous projects in auto-industry and clustering.

Aims

There are three main issues we would like this project to focus on:

- Requirements for implementations of new technologies, particularly according to the new European strategies and policies.
- Innovation capacities - Lack of labour on the market mainly in the area of highly qualified workforce for automotive industry.
- Innovation circle - Lack in co-operation between R&D (universities), SME's and car (part producers).

In case of NMS (New Member States), candidate countries, potential candidate countries and neighbouring countries, co-operation between industries and universities is still at lower level, which is negatively affecting the sustainable development of the automotive industry in SEE.

Primary objectives

The project is built up on the experience from previous activities in Automotive industry (NEAC, Automotive Clusters, Belcar, TCAS, I-CAR-O) and in line with EU policies, especially in clustering and automotive industry. The framework's project aims to:

- Create the first sustainable network in automotive industry in SEE region with specific focus on innovation activities.
- Create partnerships which consist of institutions from New Member States, non-EU members as well as well experienced institutions from EU-15.
- Invite in the network not just clusters and other SME supporting facilities but directly also R&D institutions and universities.
- Improve innovative capability by carrying out the studies of innovation capacities, exhibitions in universities and dissemination outputs of our activities, exchange studies and networking activities.
- Prove the concept by carrying out the project samples and by generating the proposals to FP7.

Secondary objectives

The secondary project objectives are to:

- Speed up the usage of NMS potential (as well as candidate's countries, potential candidate and neighbouring countries.
- Identify the conditions for more efficient technology transfer as well as to prove the concept by pilot project implementations.
- Promote automotive industry to universities and in other R&D institutions.

- Increase competitiveness between institutions in SEE region to focus on and contribute in finding of solutions for global problems in Industry.
- Create conditions for networking in finding solutions to global problems in Industry.
- Identify available opportunities for further development of co-operation through community or national programmes and other funding sources.

Expected outputs of the project and project contribution

The project aim is to develop cooperation among the existing SMEs with research institutes and universities in the automotive industry sphere. This is the second level of implementation of cluster activities in order to enhance innovation capacity, the effectiveness of technology transfer - to improve the innovation cycle in the automotive industry and through projects clearly address global objectives - facilitation of innovation, knowledge economy and information society. The project contribution to the attractiveness of the region has to be also taken into account. Taking the partners of the European Fifteen, the new Member States and candidate countries, together with the proposed activities, including intensive cooperation and exchange will lead to reducing disparities between regions and cooperating significantly contribute to the policy of cementing Europe.

The main project output involves:

- Permanent network of co-operation in the automotive industry of South East Europe.
- Continuous exchange programme activities as a part of a co-operation network.
- Confirmation of the concept through financing small projects from three specified areas.
- Preparation of three proposals for 7th RP and the other three projects from specified areas.
- Preparation of three studies and one methodology, the results can be taken in different industries and regions.

Other results and outputs with highly positive impact on the innovation capacities and innovation circle worth to mention involve ten exchange study visits (with 200 participants), 10 exhibitions at universities (with 3000 visitors), one exchange experience seminar (with invitation of other relevant stakeholders), and two educational seminars in each region.

Project focus on innovation

The project's aim is to develop the network of existing SME facilities together with R&D or universities in automotive industry. The purpose of the project is to realize the second level clustering activities with the objectives to increase innovation capacities, increase effectiveness of technology transfer – improve the innovation circle in automotive industry, and through the project clearly address the global objectives – facilitating innovation, knowledge economy and information society. The contribution into improving the attractiveness of the region should be taken in account as well. The invitation of the partners from EU-15, NMS and IPA countries together with proposed activities including intensive cooperation and knowledge-exchange is a clear contribution to the EU cohesion policy by diminishing the gap between participating regions.

Conclusion

Integration of the Slovak research capacities into the projects focused on automotive industry will secure retention of high skilled labour with high added value in Slovakia. The only chance for Slovakia is innovation, research and development, in case of removing the manual assembling in automotive industry towards East. This is the reason why it is important to focus on high tech laboratories and innovation projects. There is no other way than to prepare people for automotive industry and involve them into the productivity development.

This article is an output of "Project AUTOCLUSTERS – The international co-operative network of educational and research institution with subcontractors and other bodies active in Automotive industry", which is funded by the EU under the SEE Programme.

Fig. 2 *Logo of SEE and projects co-funded by the European Union*

References:

[1] ŠVAČ, V., KOVÁČOVÁ, Ľ. Rastúce požiadavky na dodávateľov v automobilovom priemysle. Increasing demands on suppliers in the automotive industry. In *AI Magazine*, 2010,1, s. 46-47. ISSN 1337 – 7612

[2] URDZIKOVÁ, J. Ľudia - rozhodujúci faktor úspešnosti nielen projektov európskeho sociálneho fondu. People - critical factor for successfulness not just of European social found projects. In *Znalostní ekonomika - trendy rozvoje vzdělávání, vědy a praxe: Mezinárodní vědecká konference*. Recenzovaný sborník příspěvků. Luhačovice, 2007. Zlín: Univerzita Tomáše Bati ve Zlíne, 2007. ISBN 978-80-7318-646-3

[3] VIDOVÁ, H., MOLNÁROVÁ D. Automobilový priemysel na Slovensku. Automotive industry in Slovakia. In *Fórum Manažéra*, 2005, Vol. 1, č. 1, s. 7-8. ISSN 1336-7773

[4] http://www.kia.sk/index.php?context=208 (cit. 3.3.2010)

[5] http://www.psa-slovakia.sk/sk/o_nas/automobilka_trnava.php (cit. 3.3.2010)

[6] http://www.volkswagen.sk/sk/tlacove-centrum/tlacove-spravy/2009/univerzity.html (cit. 25.1.2010)

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CLAIM AND CONTINUOUS IMPROVEMENT

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Abstract

The claim will always represent the kind of information that is annoying to recipients. Systematic work with claims has a positive value for the company. Addressing the complaint has a positive effect on continuous improvement. This paper was worked out with the support of VEGA No.1/0229/08 Perspectives of quality management development in coherence with requirements of Slovak republic market.

Key words

claim, continuous improvement, customer

Introduction

There is no need to say, that claimed or returned products are always **the less *welcomed forms of feedback from customers.*** Claims and complaints will, however, remain a standard part of our lives, organizations, and that is why it is logically expected that the organization establishes procedures and mechanisms to work effectively with complaints and claims. Senior management is responsible for assurance that the organization has created a process for handling complaints and identifies its objectives. It must be satisfied that ***the complaint handling process is planned, designed, implemented, and that it is maintained and continuously improved in line with the complaint of the organization.*** Selecting the suitable claim system can be a significant task due to the risks involved in going with the wrong decision [5]. Learning by doing can be costly, the more so the more complex the systems involved – just think of products such as space shuttles and organisations such as big supplier networks [6].

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Claim and continuous improvement

The complaint and the claim will always represent the kind of information that is annoying to recipients. But this may be the reason that we should prevent them. Systematic work with complaints and claims is in fact a positive charge [1].

What is meant by the concept of positive charge? *Every complaint is a communication with the customer in which an organization can find a source of guidance and information.* Through transparent and systematic record thoroughly examined failures of the product, a wide base of information can be created, that is an invaluable tool in the ongoing filling of such amendments and actions that lead to continuous increases product reliability. Claim enables to gain ideas for improvements in measuring and analysing the customer's needs, its own product quality control, technology supply and distribution organization.

Dissatisfied customer may not always be in the role of adversary. ***His disagreement points to weaknesses in the organization and allows him to remove*** and it is in the interest of the organization to keep him. This method of communication with customers will often detect small defects of the product before they become major deficiencies, which are removed with high costs and may also lead to a significant loss of customers in favour of competition [2]. Claims and detailed analysis of their causes are very valuable information for future improvement of all activities of the manufacturer, respectively suppliers. Although they mean more effort and additional costs, they have negligible potential for future savings, as long as the causes of negative perceptions in projects are permanently eliminated [1].

In short, we will define what we mean by ***continuous improvement***. Improving quality by today's terminology is seen as a part of quality management focused on increasing capacity to meet quality requirements. These are activities aimed at achieving a higher level of quality compared to the previous situation [4].

Now, we would like to point out to address complaints from the field and then implemented corrective and preventive measures in the process of cables in the company. The company offers complete energy solutions and services for global IT and telecommunications market. The production of energy products and systems, the company produces cable sets, entering into manufactured products.

Accrued claims NC 5984 and NC 6008 is a serious problem related to cable eyelets, see Figures 1 and 2.

Fig. 1 *Claim NC 5984 of BMK 445 905/ 6R1A product*

Fig. 2 *Claim NC 6008 of BMK445 011/ 6R1A product*

In dealing with both claims, we followed the methodology 8D. After the identification of the problem, the establishment of the team (Quality department) and precise definition and quantification of the problem, we started to take an immediate action.

Regarding NC 5984, we found the basic information. Thirty-one systems were ordered by customers, 5 pcs of BMK 445 905/ 6R1A were checked with the customer and the 3 pc had a problem with cable eye, i.e. loose cable eye. In the latter case, the NC 6008, it was found that in one cabinet BMK 445 011/ 24R1A, a cable eye is released (dropped) from battery cable during installation. In both cases, the cable having a cross section of 70 mm^2.

In the first step and the primary information that we found, product number "cable problem" NTM 445 905/ 6R1B - TFL 103 107 / 08 was identified. An immediate 100 % check of cable in stock was carried out, see Table 1.

SELECTED CABLE FOR 100 % INSPECTION

Table 1

Selected items	Pieces
NTM 2110 000/ 4R1A	20
TRE 211061/ 1003R1A	61
TRE 211061/ 1004R1A	107
TRE 211061/ 1005R1A	110
TRE 211061/ 1006R1A	107
TRE 211061/ 901R1A	274
TRE 211061/ 925R1B	276
TRE 211061/ 927R1B	494
TRE 211061/ 975R1A	37
TRE 211052/ 1	80
TRE 211052/ 2	96
TRE 211052/ 4	84

After 100 % of control cables and cable sets, it was found that all the items were in order. **In the second step** we took control of all manufactured and finished products in stock, entered into with "cable problem", see Table 2.

SELECTED PRODUCTS FO R 100 % INSPECTION

Table 2

Selected items	Pieces
BMK 211 0000/ 4R1A	12
BMK 211 0000/ 7R1A	1
BMK 447 905/ 27R1A	2
BMK 447 905/ 28R2A	1
3/ BKY26104R1B	36
BMY 201 301/ 1R1A	5
BMK 445 901/ 73R2A	10
BMK 447 085/ 312R1A	2

After 100 % inspection of selected items, all types except the cabinet BMK 2110000 / 4R1A were all right. Cabinet BMK 2110000 / 4R1A was immediately corrected. It should be noted that *the principle of the control was manual pulling of the cables.*

In the third step, we focused on the cable shop, where we found some interesting facts:

- Discrepancy between the used crimping machine Klauke (Press) and tool Chamber,
- Cable lugs Chamber and machine Klauke were not applicable in this combination,
- Cable lugs Chamber were thin – walled with difference 1.6 mm (external diameter) towards Cable lug Klauke,
- Most suitable combination is Chamber crimping machine and Chamber tool,
- Pull test in cable shop area is missing,
- Cable lugs which are used in Cable shop area Chamber,

- This issue occurred when previous Ericsson cable was exchanged for Top Cable (new supplier from April 2009).

In the fourth step, we took immediate remedial action:

- Tool Klauke was taken from Cable shop area,
- Tool Klauke was changed on Chamber tool.

In the fifth step, we provided a pull test conducted with the assistance of other divisions. Samples were prepared in our cable shop with diameters of 35, 50 and 70 mm^2 for each type of 5 pcs. After the tensile test, we obtained additional observations, see Table 3.

RESULTS OF PULL TEST Table 3

Record of pull test			
Date	Number of cable	Tool	Result
2.12.2009	1.1	KM 051	90
2.12.2009	1.2	KM 051	90
2.12.2009	1.3	KM 051	90
2.12.2009	1.4	KM 051	73
2.12.2009	1.5	KM 051	90
2.12.2009	2.1	KM 051	90
2.12.2009	2.2	KM 051	90
2.12.2009	2.3	KM 051	90
2.12.2009	2.4	KM 051	90
2.12.2009	2.5	KM 051	90
2.12.2009	3.1	KM 051	90
2.12.2009	3.2	KM 051	90
2.12.2009	3.3	KM 051	90
2.12.2009	3.4	KM 051	90
2.12.2009	3.5	KM 051	90

Table 3 shows that cable No. 1.4 withstands only 73 kilogram, while other cables withstand the maximum value (90 kilograms). It should be noted that the test check was regarded only as a reference for us because the machine on which we performed the test is used for much smaller diameters.

Conclusion

Root cause was that the machine tool was from another manufacturer. After an exchange of the Chamber instrument type, claims of a similar nature have not occurred. Within a frame of preventive measurements, we found a company that is able to practise the testing procedures of cables. Each cable has a diameter of the minimum size by a force that must be met. For each diameter 3pcs are made, where 1pcs is tested up to its destruction and the other 2 pcs are tested up to their minimum power the cable has to withstand. We sent all of our manufactured types of cables to the companies to find out the 100 % satisfaction and the promise that no similar case will be repeated in future.

Complaints and claims set a detailed analysis of their causes and are very valuable information for future improvement in all activities of the manufacturer. They are a fair mirror of how the delivering organization systematically examines perception and sells the needs of its customers as a part of its quality management system.

Professionally selected claim management system affords the opportunity to retain customers in the case of a complaint and to improve customer loyalty.

References:

[1] GOODMAN, J. *Manage Complains To Enhance Loyality*. Quality Progress, 2006, pp. 28-33. ISSN 003-524X

[2] ŠALGOVIČOVÁ, J. a kol. *Meranie spokojnosti zákazníka z pohľadu manažérstva kvality a marketingu*. Trnava: Tripsoft, 2006, 214 p. ISBN 80-969390-6-8

[3] STN EN ISO 9000:2005 *Systém manažérstva kvality*. *Základy a slovník*. Bratislava: Slovenský ústav technickej normalizácie.

[4] STN ISO 10002:2004 *Manažérstvo kvality, Spokojnosť zákazníka. Návod na vybavovanie sťažností v organizáciách.* Bratislava: Slovenský ústav technickej normalizácie.

[5] ZGODAVOVÁ, K., SLIMÁK, I. Advanced Improvement of Quality. In *Proceedings of the 19t International DAAAM Symposium "Intelligent Manufacturing & Automation: Focus on Next Generation of Intelligent Systems and Solutions"*.Vienna, 2008. ISSN 1726-9679, ISBN 978-3-901509-68-1

[6] ZGODAVOVÁ, K., KOŠČ, P., KEKÄLE, T. Learning Before Doing: Utilising a Co-operative Role Play for Quality Management in a Virtual Organisation. In *Journal of Workplace Learning*, 2001, Volume 13, Issues 3rd and 4rd, pp. 113 – 118.

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GLOBALIZATION EFFECTS ON SPECIFIC REQUIREMENTS IN AUTOMOTIVE PRODUCTION

Yulia ŠURINOVÁ, Iveta PAULOVÁ

Abstract

Currently, there is worldwide overcapacity in the industry - and this has forced manufacturers to contain and even reduce costs. Globalization makes it possible to use the world best improvement techniques in order to reduce costs and satisfy customer.

Key words

customer specific requirements, customer satisfaction, globalization, tools and methods of quality management

Introduction

As the automobile business grows, it is also becoming more competitive. Competitive pressures have forced most companies to increase their focus on using world best improvement techniques. A major benefit of globalization is an access to improvement techniques being developed around the world.

Automotive companies are finding that globalization offers many challenges and opportunities. By establishing an integrated management system, companies can manage the complexity of a global operation so that they can leverage these opportunities where it makes sense for their business.

Customer special requirements versus ISO and other standards

Automotive production is one of the key branches of the Slovak economics. Plenty of world automotive suppliers have come to Slovakia to open their production factories. There were also new Slovak factories opened to meet the needs of the automotive giants [1]. At the

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time of economic crises, each organization makes its best to effectively manage its internal and external processes. It finally leads to setting their specific requirements for suppliers.

Nowadays, high quality of products and affordable price are important, yet not enough to succeed on the global market. Personal relations, specific requirements and knowledge are very important too. Satisfaction of customers' needs should be the primary organizational goal. If the organization wants to be successful, it must follow customers' needs and satisfy these needs as soon as possible. In order to satisfy customers' need in all processes, the organization should establish the management system and make it work for the customer.

It is not enough to build the quality management system according to ISO 9001:2009, not even enough to meet the requirements of ISO TS 16 949:2009 developed especially for automotive production. It is important nowadays to meet the specific requirements of each customer. Different customers have their specific requirement based on their special market strategy in order to satisfy customers' needs better than the competitive organizations do. These special requirements are often based on the manuals of the American quality management standards QS 9000 or the European standards for quality management VDA.

The American organizations often require that their suppliers use QS 9000 manuals such as APQP (Advances Products Quality Planning), PPAP (Production Part Approval Process), MSA (Measurement system analysis), SPC (Statistical Process Control), FMEA (Failure Modes and Effects Analysis) and others. The European automobile producers usually require from their customers to meet for example VDA 4.2 for FMEA, to meet VDA 6.1 in terms of audits and EMPB products approval process. These are just some of the basic customer requirements for automotive production. Besides these requirements, automotive producers often have some special needs which they want their suppliers to fulfil (Fig. 1).

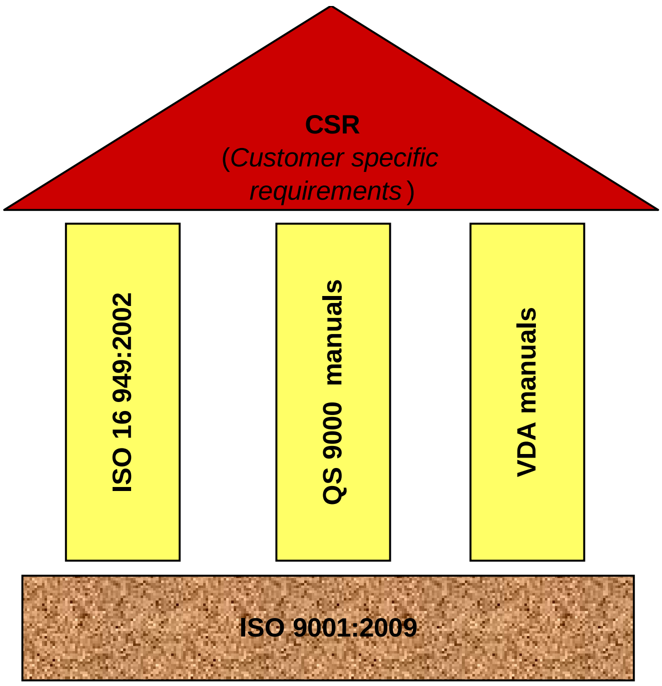

Fig. 1 *Quality management system structure in supply house for automotive production*

To be successful, the organization should flexibly react to satisfy customers' needs. Financial success is contingent on reaction time and outlays amount. It is important to adapt organizational strategy to this trend.

Application of new trends in tools and methods of quality management

Globalization brings the application of new tools and methods in different factories all over the world. There are quality management tools and methods which used to be applied only in particular countries. Nowadays, those methods are widely used all over the world in different production branches.

Product development process is one of the key production processes. Each development system has its advantages and disadvantages. That is why the American automobile producers such as Ford, Daimler Chrysler and General Motors developed an integrated system for product development. Since that time, Advanced Product Quality planning (APQP) and Production Part Approval Process (PPAP) are widely used not only in America, but also by the Korean and Japanese automobile producers. Even some European automobile producers prefer APQP and PPAP instead of VDA standards.

Advanced Product Quality Planning is a formal standardized and structured method of defining and implementing steps to produce a product that satisfies the customer. PPAP is a part of approval process within APQP. APQP is a framework of procedures and techniques used to develop products in industry, particularly the automotive industry. It is quite similar to the concept of Six Sigma.

The Production Part Approval Process (PPAP) is used in the automotive supply chain to establish confidence in suppliers and their production processes, by demonstrating that"....all customer engineering design record and specification requirements are properly understood by the supplier and that the process has the potential to produce a product consistently meeting these requirements during an actual production run at the quoted production rate." Version 4, March 1st 2006 [1].

Japanese are famous for their statistical methods. **7 basic (Japanese) tools** of quality managements are widely used all over the world. Since that time, one more Japanese method has become famous. **5S** (Seiri – Chipping, Seiton – Visual disposition, Seiso – Clearance, Seiketsu – Standards building, Shitsuke – Improvement) is a method which has to bring tidiness and discipline to the workplace. Many organizations have started to use this method even though discipline is the traditionally Japanese feature. 5S brings systemization to the workplace, making subsequently the management system easier. It saves time and money. This is one of the most often used tools for housekeeping, standardization and continuous improvement.

5S method the G8D method has become extremely important for many organizations in the world as well. The 8D methodology is a tool for problems root causes analysis, corrective actions definition and problems of repetitive occurrence elimination. The 8D is a technique for products and processes improvement. 8D methodology is a team-oriented problem solving tool, which consists of 8 basic steps. Team work is considered to be much more efficient then individuals' efforts subtotal. This tool prevents the common mistakes made by individuals or problem solving teams, who frequently develop elegant solutions to the wrong problem - or disguise the evidence of failure with quick fixes without finding the root causes [2].

The 8D methodology comes from the USA. The U.S. government first used the 8D-like process during the World War I, referring to its military standard 1520 (Corrective action and disposition system for non conforming material). Ford Motor Company first documented the 8D method in 1987 in a course manual entitled “Team oriented problem solving”. This course was written at the request of senior management of the Power Train organizations of the automaker facing growing frustrations of the same problems that were recurring year after year [3].

There are also many new tools and methods of quality management which have become widely used together with the 8D. They are for example *Is / Is not analysis* and *5Why* tools. Is / Is not analysis is very easy to implement and represents an efficient method to analyze process shortcomings. It is usually used in terms of step 4 Root Cause Analysis of the 8D tool. Is a very efficient way of how to define what had not been done in order to prevent the analyzed problem occurrence.

“If you don't ask the right questions, you don't get the right answers. A question asked in the right way often points to its own answer. Asking questions is the ABC of diagnosis. Only the inquiring mind solves problems." said Edward Hodnett.

Another globalized Japanese tool is **5 Why**. The methodology was designed by Sakichi Toyoda and was first implemented in Toyota Motor Corporation. The architect of the Toyota Production System, Taiichi Ohno, described the 5 whys method as "... the basis of Toyota's scientific approach ... by repeating why five times, until the nature of the problem as well as its solution becomes clear [4].

Globalization effects on specific customers’ requirements

Specific customer’s requirements are a component of ISO/TS 16949:2009 that cannot be ignored. In fact, customer’s specific requirements are more important in ISO/TS 16949:2009 than they were in QS-9000 and VDA standards, which considered them as part of the standard. Detailed customer specifications can be implemented into the processes by following a documentation strategy. Mapping the specific customer’s requirements to processes is the least risky, and so the best, documentation strategy. Adopting a common process for the entire organization and clearly indicating different ways should be performed to satisfy different customers [5].

Globalization brings the best improvement tools and methods which have been developed in different countries and companies throughout the world. Organizations help each other to improve their internal and external processes. Using the same tools for the same processes in different organizations in the world helps the suppliers who can use familiar techniques to communicate with different customers and satisfy different customers’ needs.

Despite the globalization advantages, modern organizations make their best to develop unique products and services to satisfy their customers. Modern organizations want to offer their customer something more than the competitive organizations do. In this manner, specific customers’ requirement phenomenon develops.

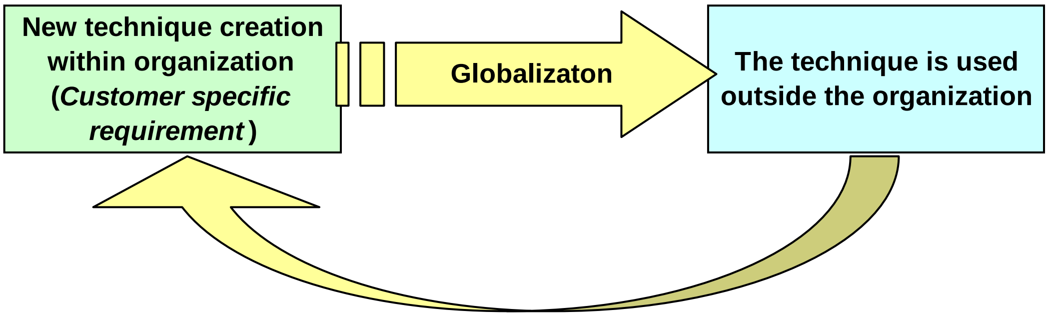

Fig. 2 *Globalization vs. Specific customer requirements*

Thus the globalization phenomenon in fact generates new specific customer's requirements. These specific requirements will soon become globalized and used in competitive organizations (Fig. 2). This may be called global continuous improvement spiral.

Summary

Globalization is a process which, in terms of quality management, introduces the application of similar improvement techniques in different organizations in the world. On the ground of the particular tool efficiency, it becomes a famous methodology which is used in different organizations all over the world. The techniques such as APQP, PPAP and 8D are the example of the quality management technique globalization. However, in order to satisfy customers' needs and to offer the customer something extraordinary, the organizations continuously specify their special requirements. It actually drives the global continuous improvement process.

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References:

[1] FORD MOTOR COMPANY - *APQP Status Report Version 3.1 (Pan Brand)*, Ford Motor Company 1996-2006, 58 p.
[2] Explanation of 8D Problem Solving online http://www.12manage.com/methods_ford_eight_disciplines_8D.html
[3] ŠURINOVÁ, Y.: *Positives and negatives of 8D method application in terms of claims disposal process.* In *Kvalita* 3/2008, ISSN 1335-9231
[4] [4] TAIICHI OHNO; foreword by Norman Bodek (1988). Toyota production system: beyond large-scale production. Portland, Or: Productivity Press. ISBN 0915299143.
[5] Customer Specific Requirements online (10.4.2010) http://www.omnex.com/consulting/customer_specific_requirements.aspx
[6] PAULOVÁ, I. et al. *Methods of TQM efficiency and effectivity improvement.* STU 2008, 304 p. ISBN 8022728577

[7] ZGODAVOVÁ, K., KOŠČ, P., KEKÄLE, T. (2001): Learning Before Doing: Utilising a Co-operative Role Play for Quality Management in a Virtual Organisation, Journal of Workplace Learning, Volume 13 Issues 3rd and 4th 2001, pp. 113 – 118.

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CRITICAL RATE OF THERMAL DECOMPOSITION OF PURE AND IMPREGNATED LIGNOCELLULOSIC MATERIALS

Tomáš CHREBET, Karol BALOG

Abstract

Contribution deals with monitoring the impact of airflow velocity around the sample, the oven temperature during thermal decomposition and nature of the sample for the minimum mass flux rate needed to initiate flame combustion. We used the samples of lignocellulosic materials, particularly spruce wood, pure cellulose, flax, cellulose impregnated by 5%, 10%, 15% water solution of $KHCO_3$ and by 5%, 10%, 15% water solution of $(NH_4)_2HPO_4$.

Key words

critical mass flux rate, air-flow, lignocellulosic materials

Introduction

Based on experimental observations, the criteria of ignition were set up in order to determine the moment of ignition. The idea of using critical rate of flammable gases generation in critical conditions was first proposed by Bamford. On the base of experimental results of convection thermal stress of defined geometry wood samples and numerical solutions of conduction heat transfer equation, Bamford et al. identified critical rate of fuel transfer from condensed phase in the gas phase for selfsustained process of flame combustion after forced ignition. The minimum rate of formation of volatile combustible products $2.5.10^{-4}$ $g.cm^{-2}s^{-1}$ near the surface of the condensed phase of wood was determined [1, 2, 3].

Used materials

To verify Bamford criteria, we selected a sample of spruce wood. Cellulose is the main component of wood and the most flammable products are released from it. $KHCO_3$ and

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$(NH_4)_2HPO_4$ were used as the flame retardants witch cause modification during active thermal decomposition and catalyze the reaction going at lower temperatures (dehydration, thermal-oxidation) [4]. The following concentrations of retardants were used: 5%, 10% and 15%. Flax is not a well explored cellulosic material, so we focused on it.

Equipment and measurement procedure

The basis of the test equipment (Fig. 1) is electrically heated hot-air furnace according to ISO 871 standard [5] (Setchkin furnace) (1). A sample in a steel sieve is placed into the furnace (2), to better monitor the airflow effect. In the furnace, there are two thermocouples (3), one is about two centimetres above the sample and the other approximately a centimetre below the sample. Air is forced to the furnace by air pump; the flow is regulated by flowmeter (4). Under the furnace, there is a weight (KERN PLT 450-3M) (5). Sieve with the sample in the furnace is linked with the weight using a glass rod (6), which is flat extended on both sides, for stability. Four centimetres above the sample, there is a source of ignition. An electric coil of kanthal wire was used as a source of ignition (7).

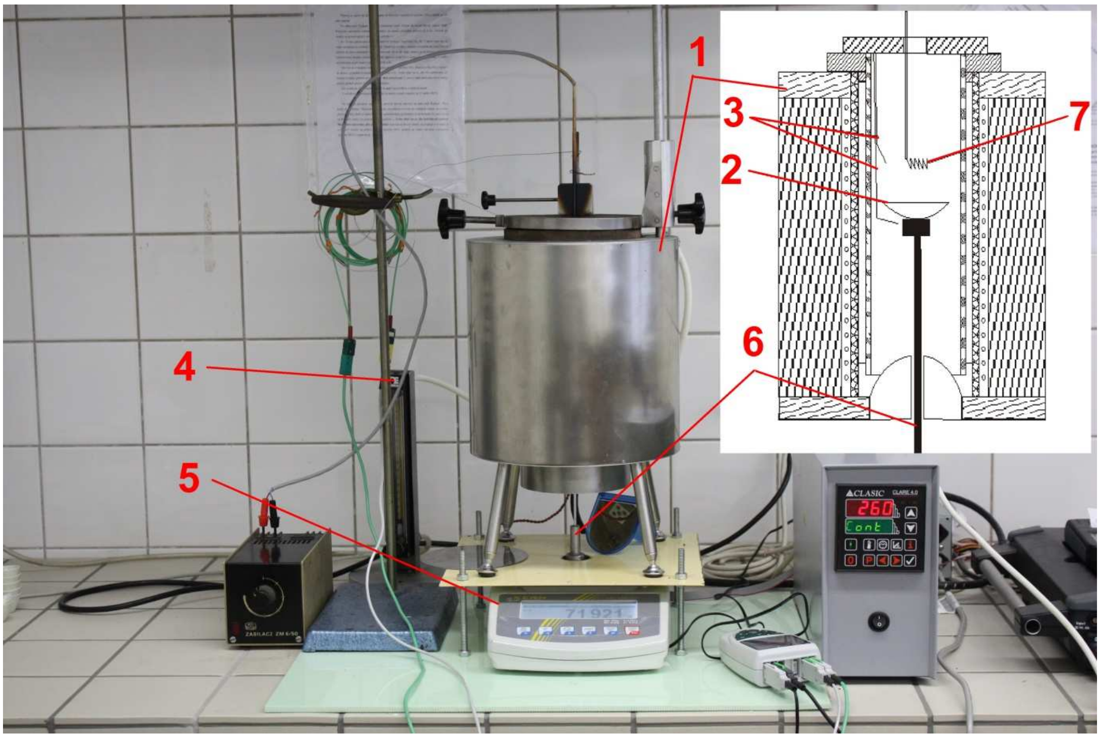

Fig. 1 *Testing equipment*

The temperature for determining the critical rate for the formation of degradation products of different samples was determined from the thermogram [6] under the condition of dynamic heating 5 $°C.min^{-1}$, when the highest rate of weight loss was observed. For each sample, four measurements were made at a given temperature and speed of airflow in the oven 30, 20, 10, 0 $mm.s^{-1}$, (calculation according to standard [5]). From the record of temperature course, we determined whether the process was ignition or burning.

Results

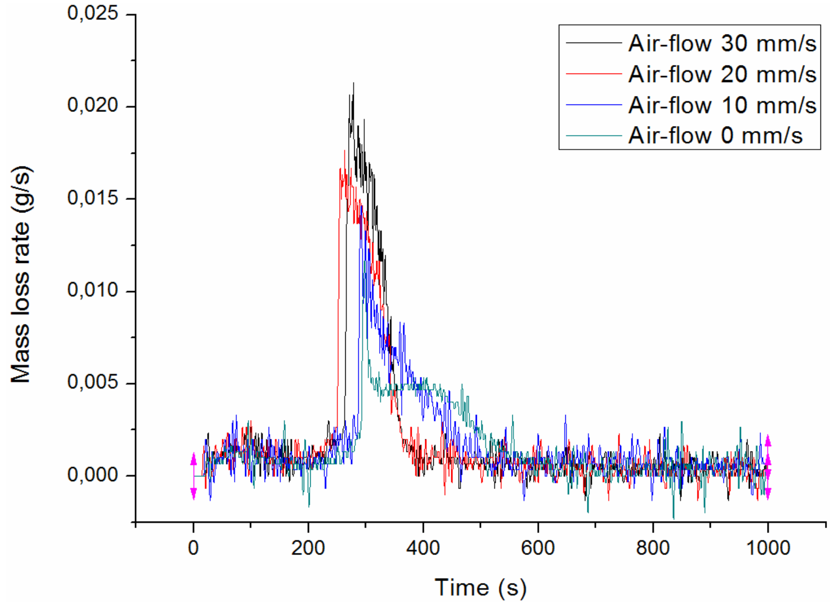

Fig. 2 *Dependence of mass loss rate from time for spruce wood at a temperature 320 °C at different speeds of airflow*

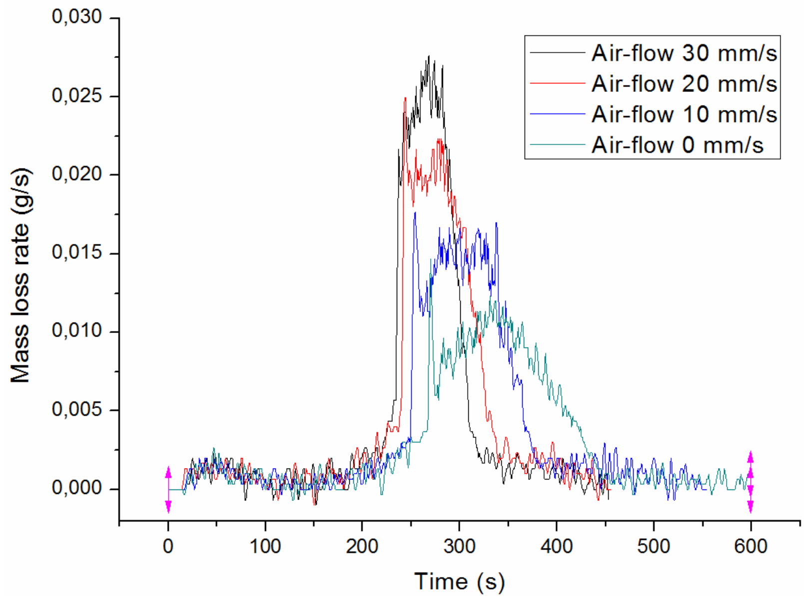

Fig. 3 *Dependence of mass loss rate from time for pure cellulose at a temperature 320 °C at different speeds of airflow*

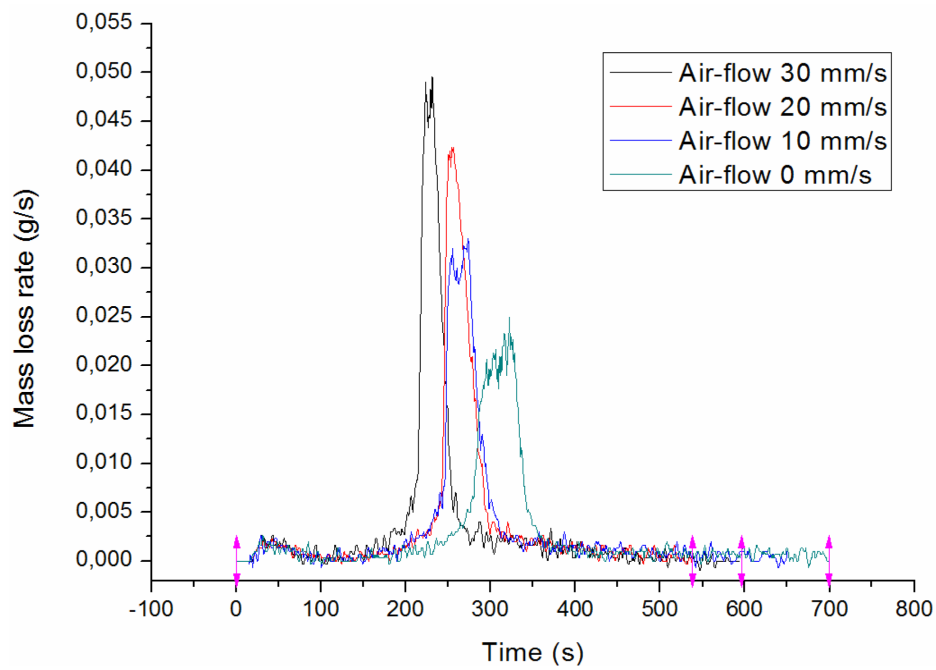

Fig. 4 *Dependence of mass loss rate from time for flax at a temperature 270 °C at different speeds of airflow*

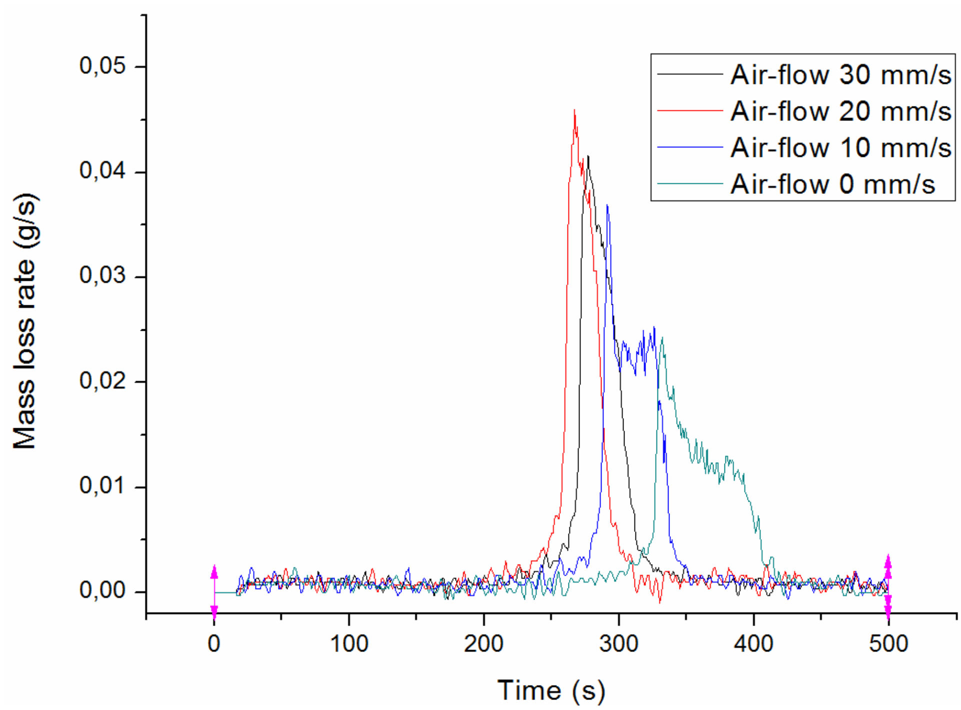

Fig. 5 *Dependence of mass loss rate from time for cellulose impregnated by 5 % water solution of* $KHCO_3$ *at a temperature 230 °C at different speeds of airflow*

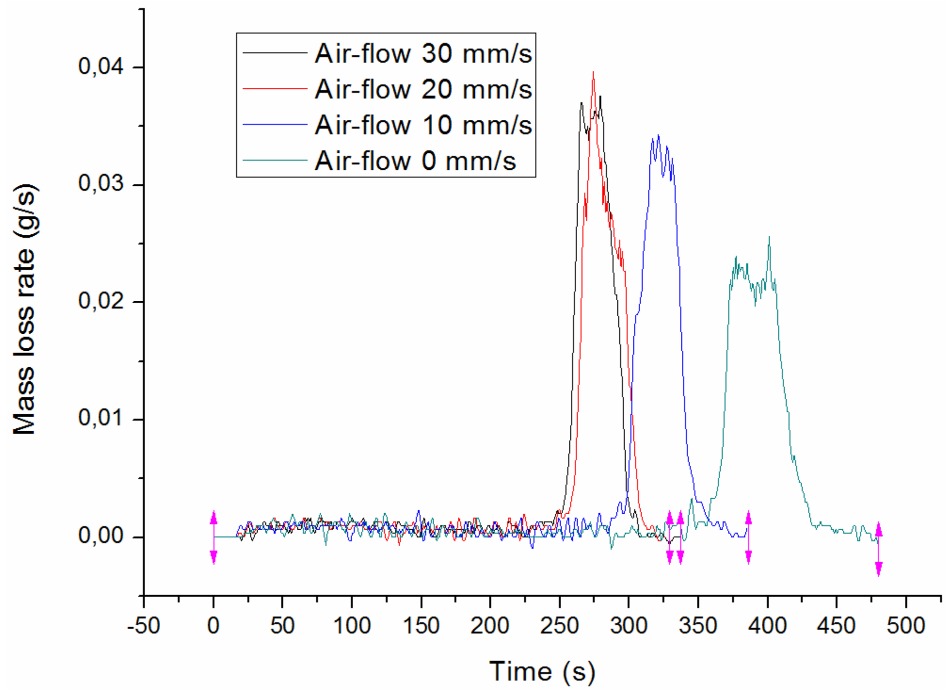

Fig. 6 *Dependence of mass loss rate from time for cellulose impregnated by 1 0% water solution of $KHCO_3$ at a temperature 220 °C at different speeds of airflow*

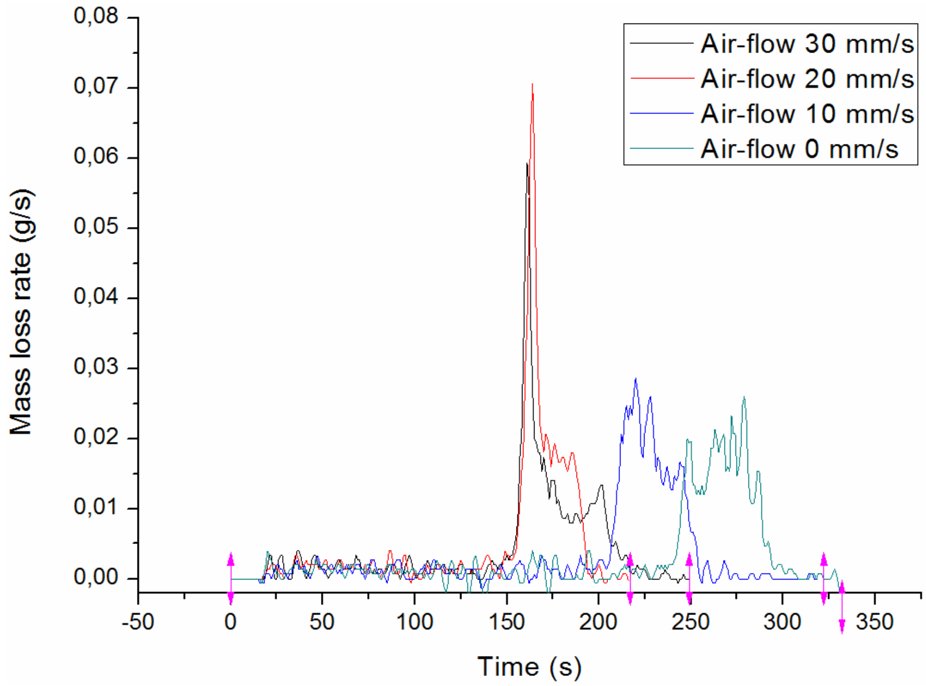

Fig. 7 *Dependence of mass loss rate from time for cellulose impregnated by 15% water solution of $KHCO_3$ at a temperature 220 °C at different speeds of airflow*

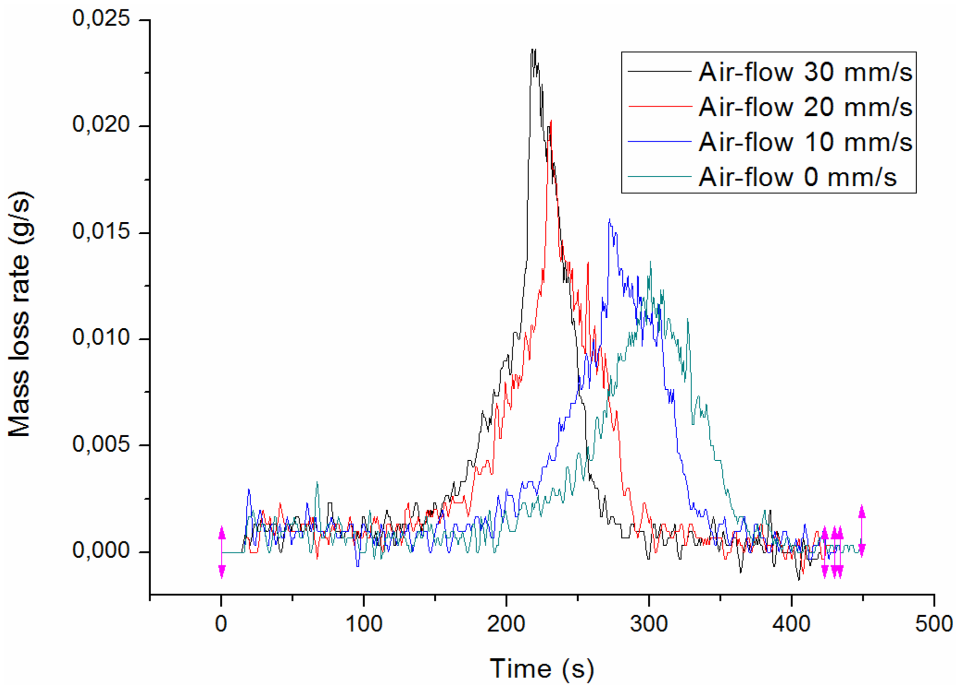

Fig. 8 *Dependence of mass loss rate from time for cellulose impregnated by 5% water solution of $(NH_4)_2HPO_4$ at a temperature 260 °C at different speeds of airflow*

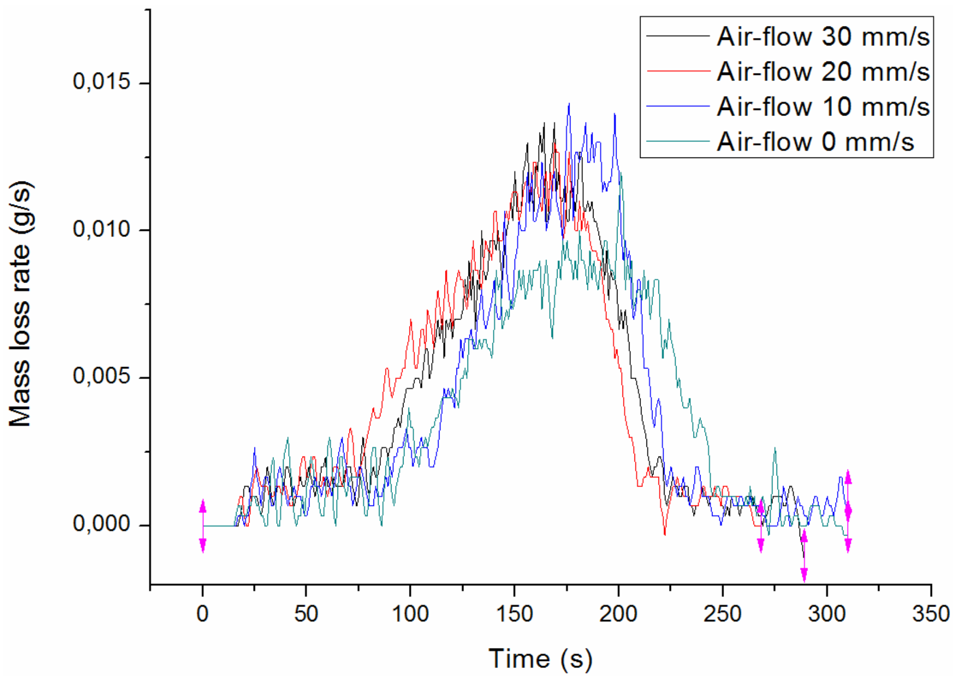

Fig. 9 *Dependence of mass loss rate from time for cellulose impregnated by 10% water solution of $(NH_4)_2HPO_4$ at a temperature 300 °C at different speeds of airflow*

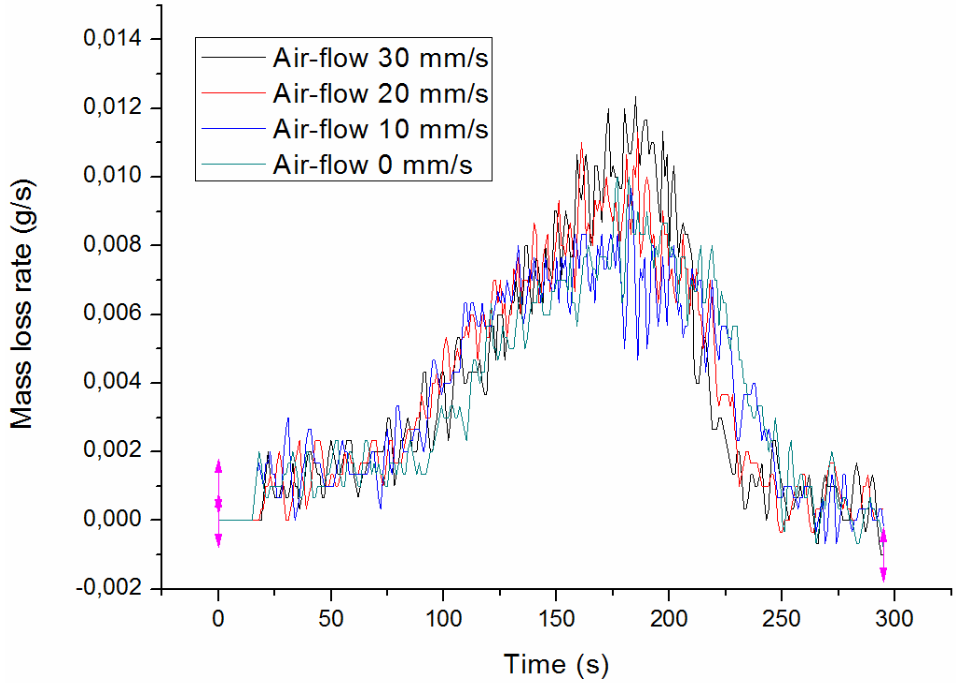

Fig. 10 *Dependence of mass loss rate from time for cellulose impregnated by 15 % water solution of $(NH_4)_2HPO_4$ at a temperature 300 °C at different speeds of airflow*

Review and discussion

Bamford suggested the critical rate of flammable gases generation as a condition for ignition of wood degradation products. The value of this critical rate is $2.5.10^{-4}$ $g.cm^{-2}s^{-1}$ near the surface of the condensed phase. In Fig. 2, there is the mass loss rate for spruce wood at a temperature 320 °C. The mass loss rate in the moment of initiation of flame combustion was approximately 0.0035 $g.s^{-1}$. The used samples had the shape of cubes with side of 1.5 cm and weight approximately 2 grams. After the conversion of mass loss rate per unit, the area of consequential mass flux rate was $2.49.10^{-4}$ $g.cm^{-2}s^{-1}$ witch corresponds with Bamford criteria. The samples were burning at the speed of airflow 30, 20 and 10 $mm.s^{-1}$.

In Fig.3, courses of mass loss rate of pure cellulose at a temperature 320 °C can be seen. The ignition of degradation products in samples of pure cellulose occurred at a mass flux rate $2.63.10^{-5}$ $g.cm^{-2}s^{-1}$ from the sample, which is about 10 times less than for the sample of spruce wood. After the initiation, fire occurred for more than 5 seconds at the speeds of airflow 30, 20 and 10 $mm.s^{-1}$.

The courses of mass loss rate depending on the speed of airflow at temperature 270 °C for flax are shown in Fig. 4. The ignition of degradation products was at mass flux rate 7.44E-05 $g.cm^{-2}s^{-1}$ from the sample. After the initiation, the sample burnt more than 5 seconds at a speeds of airflow 30 and 20 $mm.s^{-1}$.

For the samples of cellulose impregnated by water solution of $KHCO_3$, a significant reduction of the temperature was observed, at which the maximum mass loss rate against the pure cellulose was observed on a thermogram, 5% solution temperature dropped to 230 °C, and 10% and 15% solution temperature dropped to 220 °C. As can be seen in Figs. 5, 6 and 7, the minimum mass loss rate needed for ignition increased when compared to pure cellulose, which was also reflected on the minimum mass flux rate; in case of 5% solution it is $4.46.10^{-5}$ $g.cm^{-2}s^{-1}$, for 10 % solution it is $5.08.10^{-5}$ $g.cm^{-2}s^{-1}$ and for 15% solution it is $7.72.10^{-5}$ $g.cm^{-2}s^{-1}$.

For the samples of cellulose impregnated by water solution of $(NH_4)_2HPO_4$, reduction of the temperature was also observed, when the thermogram showed the maximum mass loss rate, 5% solution temperature dropped to 260 °C, and 10% and 15% solution to the temperature of 240 °C. The minimum mass loss rate for ignition of 5% solution of $(NH_4)_2HPO_4$ (Fig. 8) compared to pure cellulose increased, as demonstrated by the increase in the minimum mass flux rate to $6.48.10^{-5}$ $g.cm^{-2}s^{-1}$. For the samples impregnated with 10% and 15% solution of $(NH_4)_2HPO_4$ at temperature 240 °C, mass loss did not achieve the rate needed to initiate the flame combustion.The necessary mass loss rate to ignition was not achieved even after increasing the temperature to 300 °C (Figs. 9,10). Mass flux rate at the maximum mass loss rate was calculated and it can be assumed that the initiation would occur at the rates greater than 7.25.10-5 $g.cm^{-2}s^{-1}$ for 10% solution of $(NH_4)_2HPO_4$ and 6.62.10-5 $g.cm^{-2}s^{-1}$ for 15% solution of $(NH_4)_2HPO_4$.

All measured values are more clearly presented in Table 1.

MEASURED VALUES OF MASS LOSS RATE OF TESTED SAMPLES
(MLR - MASS LOSS RATE) Table 1

Sample	**Tempe-rature (°C)**	**Speed of airflow ($mm.s^{-1}$)**	**Time to igni-tion (s)**	**Mass loss rate ($g.s^{-1}$)**	**Ignition method**	**Average value of MLR ($g.s^{-1}$)**	**Square density ($g.cm^{-2}$)**	**Mass flux rate ($g.cm^{-2}s^{-1}$)**
Spruce wood	320	30	264	0.004	Burning			
	320	20	251	0.003	Burning			
	320	10	287	0.004	Burning			
	320	0	293	0.003	Ignition	0.0035	0.142	0.000249
Pure Cellulose	320	30	236	0.006	Burning			
	320	20	242	0.007	Burning			
	320	10	250	0.004	Burning			
	320	0	268	0.004	Ignition	0.00525	0.01	2.63E-05
Flax	270	30	243	0.008	Burning			
	270	20	215	0.009	Burning			
	270	10	247	0.008	Ignition			
	270	0	281	0.007	Ignition	0.008	0.0186	7.44E-05

Sample	Tempe-rature (°C)	Speed of air-flow ($mm.s^{-1}$)	Time to igni-tion (s)	Mass loss rate ($g.s^{-1}$)	Ignition method	Average value of MLR ($g.s^{-1}$)	Square density ($g.cm^{-2}$)	Mass flux rate ($g.cm^{-2}s^{-1}$)
Cellulose + 5% $KHCO_3$	230	30	268	0.008	Burning			
	230	20	258	0.009	Burning			
	230	10	287	0.008	Ignition			
	230	0	327	0.008	Ignition	0.00825	0.0108	4.46E-05
Cellulose + 10% $KHCO_3$	220	30	258	0.009	Burning			
	220	20	262	0.008	Burning			
	220	10	301	0.01	Burning			
	220	0	368	0.008	Ignition	0.00875	0.0116	5.08E-05
Cellulose + 15% $KHCO_3$	220	30	157	0.012	Ignition			
	220	20	157	0.012	Ignition			
	220	10	217	0.012	Ignition			
	220	0	248	0.013	Ignition	0.01225	0.0126	7.72E-05
Cellulose + 5% $(NH_4)_2HPO_4$	260	30	215	0.013	Burning			
	260	20	227	0.012	Ignition			
	260	10	272	0.012	Ignition			
	260	0	298	0.011	Ignition	0.012	0.0108	6.48E-05
Cellulose + 10% $(NH_4)_2HPO_4$	300	30	-	Nothing	-			
	300	20	-	Nothing	-			
	300	10	-	Nothing	-			
	300	0	-	Nothing	-	0.0125	0.0116	<7.25E-05
Cellulose + 15% $(NH_4)_2HPO_4$	300	30	-	Nothing	-			
	300	20	-	Nothing	-			
	300	10	-	Nothing	-			
	300	0	-	Nothing	-	0.0105	0.0126	<6.62E-05

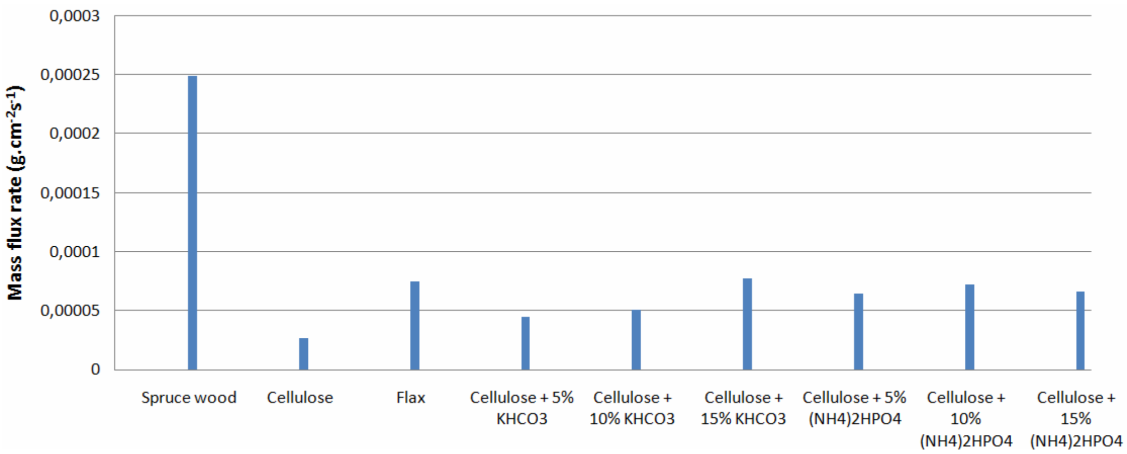

Fig. 11 *Minimum mass flux rate for ignition of tested materials*

Conclusion

The use of $KHCO_3$ and $(NH_4)_2HPO_4$ water solutions showed the significant decrease in temperatures, at which the maximum mass loss rate and increased critical mass flux rate for the initiation of flame combustion were observed on thermograms. In the case of using 10% and 15% solutions of $(NH_4)_2HPO_4$,, the necessary mass loss rate for initiation was not achieved.

Fig. 11 shows the comparison of the critical mass flux rate for the tested samples. The difference between the mass flux rate of spruce wood and other samples is due to the shape of the sample, while spruce wood was used in a cube by the side of 1.5 cm, while other samples were of a flat shape and provided therefore greater surface from which the pyrolysis products were released. Confirmation of Bamford criteria gives the possibility of using this measurement procedure to determine the critical mass loss rate also of other materials.

References:

[1] KANURY, A. M. *Flaming ignition of solid fuels*. SFPE Handbook of Fire Protection Engineering, Society of Fire Protection Engineers, Quincy, 1995, p. 2-190. ISBN 0-87765-354-2

[2] BAMFORD, C.H , CRANK, J., MALAN, D.H. The combustion of wood. Part I. In *Proceedings of the Cambridge Phil. Soc.*, 1946, 42, p. 166-182.

[3] NELSON, M. I., BRINDLEY, J., McINTOSH, A. Polymer Ignition, Elsevier Science Ltd, 1996. Dostupné na: http://www.sciencedirect.com/ [1.12.2008]

[4] BALOG, K. *Study of flaming and nonflaming combustion process of cellulosic materials.* Dissertation thesis. Bratislava: VŠCHT, 1986, 150 s.

[5] ISO 871:2006 Plastics – Determination of ignition temperature using a hot-air furnace.

[6] STN EN ISO 11358:1997 Plasty - Thermogravimetry (TG) polymers, common principles.

[7] KOTOYORI, T. Critical Ignition Temperatures of Wood Sawdusts. In *Proceedings of the First International Symposium on Fire Safety Science*, Gaithersburg (Myryland), 1985, 463.

[8] HIRATA, T., KAWAMOTO, S., NISHIMOTO, T. Thermogravimetry of wood treated with water-insoluble retardants and a proposal for development of wood materials. In *Fire and Materials*, 1991, 15, l, p. 27-36.

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THE IMPACT OF VESSEL WALL THICKNESS ON BURNING RATE OF ETHANOL

Miroslav NOVOTNÝ, Ivana TUREKOVÁ

Abstract

A significant influence to burning rate of flammable liquids has vessel wall thickness. Dependence of the burning rate of vessel wall thickness resulting from the thermal balance of a system :flammable liquid and vessel. If the thickness of the walls comes to changes, the heat transfer through the walls of the vessel is changing. The article deals with the velocity of the burning rate of burning time and vessel wall thickness containing ethanol.

Key words

flammable liquid, ethanol, burning rate, vessel wall thickness

Introduction

Burning rate as one of the most important parameters of burning of flammable liquids is using in mathematical dependencies to simulate fire of flammable liquids. Uniform methods to set burning rate of flammable liquids don´t exist in presence. To determine burning rate are using old study results or experimental results achieved by different methods. Burning rate of flammable liquids was getting by different ways and methods in last studies (table 1).

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BURNING METHODS FROM DIFFERENT AUTHORS Table 1

Vessel dimensions	Study citation	Specification
Vessel to cone calorimeter, cylindrical vessel 0,44 m and 1 m	[1]	Burning rate in the vessel without specifications and burning rate on the cone calorimeter
Diameter 8 mm, 10 mm, 12 mm	[2]	Injection into a burning sphere
Cylindrical vessel, diameter 10 mm - 304 mm	[3]	Vessel specifications, material : steal, copper, glass, dimensions and wall thickness

Mass burning rate is defined as burned liquid mass (g,kg) in time unit (min, h) from surface unit (cm2,m2) (8). The parametres of vessel have significant impact to burning rate. The parametres that affect burning rate from characteristics of vessel are shown in Picture 1.

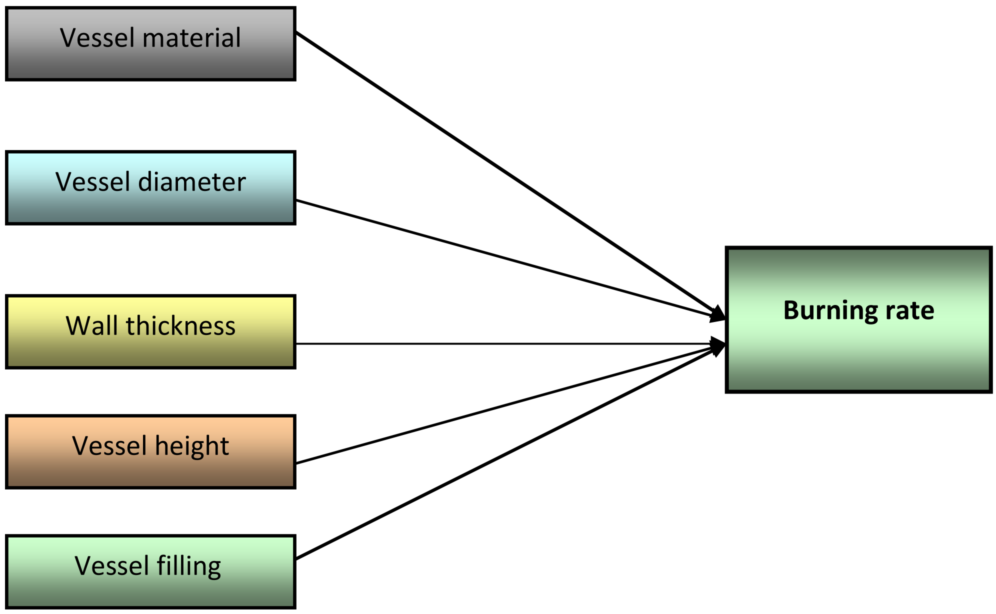

Fig. 1 *Vessel impact to burning rate*

Thermal balance

Heat transfer to liquid at burning of flammable liquids can be divided to heat transfer from vessel walls through flame radiation and through burning residues convention. Heat is transferred from the liquid through the vessel to the ambient. Heat balance between the total heat input and the total heat loss in the combustion system which includes both the liquid fuel and the vessel must be examined (3).

The total heat input into the combustion system $Q_{in,\,s}$ is generally expressed as (3):

$$Q_{in,s} = Q_{cond,l} + Q_{conv,l} + Q_{rad,l} + Q_{cond,v} + Q_{conv,v} + Q_{rad,v} \;, \tag{1}$$

where Q_{cond}, Q_{conv} and Q_{rad} are the conductive, convective, and radiative heats and the subscripts L and v correspond to the liquid fuel and the vessel, respectively.

The total heat loss, that is, the sum of the heat transfer from and heat accumulation in the combustion system $Q_{out,s}$ can be given by correlation(3):

$$Q_{out,s} = Q_g + Q_{rr,l} + Q_{rr,v} + Q_{sens,l} + Q_{sens,v} + Q_{refl,l} + Q_{refl,s} + Q_{v,air} + Q_{v,\sup t} \,, \tag{2}$$

where:

Q_g is the total gasification heat of the liquid,

Q_{rr} is the reradiation,

Q_{sens} is the heat required to increase the sensible heat of a substance,

Q_{refl} is the reflection of the incident radiation,

$Q_{v,\,air}$ is the convective heat from the vessel to the surrounding air and is supstituted by $Q_{v,\,water}$ when the vessel is cooled with water,

$Q_{v,\,supt}$ is the heat loss from the support of the vessel and the pipeline for measuring sensors which penetrates through the vessel.

The model of heat transfer is in Picture 2.

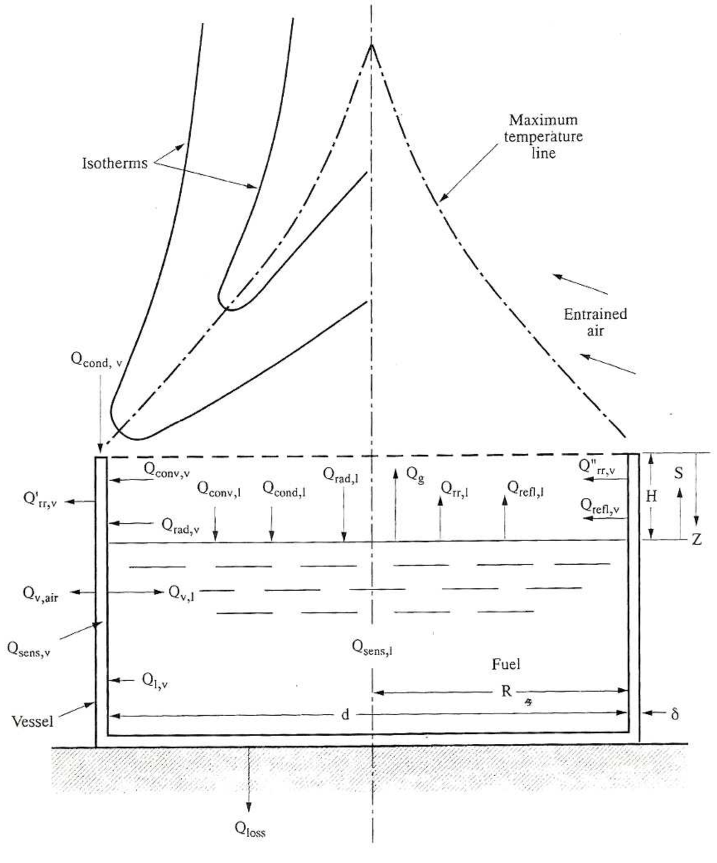

Fig. 2 *Heat transfer in the vessel and liquid [3]*

Heat balance in vessel

Heat input into the fuel

The heat input into the fuel is generally expressed as:

$$Q_{in,v} = Q_{rad,v} + Q_{conv,v} + Q_{cond,v} + Q_{l,v} \tag{3}$$

The radiative heat from the flame to the inside surface of the vessel $Q_{rad,\ v}$, is generally neglected because of its quite low values of surface which are exposed to radiation in comparison with surface of liquid. Radiative heat transfer is not neglected in large liquid decline in relatively large average of vessel over 10 cm. At large ullage heights (H› 0,2d), the convective heat $Q_{conv,\ v}$ becomes large, because the hot gas mixture o fair and combustion products entrained into the ullage of the vessel circulates in the ullage (4) and transfers heat convectively to the wall surface.

Assuming that the radiative heat is transmitted from the isothermal and homogenous flame through a nonabsorbing medium and its reflectivities at wall and fuel surfaces are both equal to zero, the ratio of radiative heats $r = \frac{Q_{rad,v}}{Q_{rad,l}}$ is expressed approximately as (3) :

$$r = \frac{(\phi\sqrt{\phi^2 + 4} - \phi^2)}{(2 + \phi^2 - \phi\sqrt{\phi^2 + 4})} \quad , \tag{4}$$

where

$$\phi = \frac{H}{R} \quad . \tag{5}$$

From eqn (4) , its seen that r increases with increasing fí and is equal approximately to 1 at H=0.35d. Therefore, the sum of convective heat $Q_{conv,v}$ and radiative heat $Q_{rad,v}$ is expected to be comparable to or larger than that to the fuel surface at large ullage heights. The conductive heat from the flame to the edge of the vessel $Q_{cond,\ v}$ is dominant in small scale pool fires (D≤2cm).

Heat loss in the vessel

The heat loss in the vessel $Q_{out,v}$ is expressed by(3):

$$Q_{out,v} = Q_{rr,v} + Q_{refl,v} + Q_{v,air} + Q_{v,l} + Q_{v,\sup t} + Q_{sens,v} \ , \tag{6}$$

where $Q_{rr,\ v}$ is the sum of reradiations $Q'_{rr,\ v}$ at the outside and $Q''_{rr,\ v}$ at the inside of the vessel wall. The reradiation $Q_{rr,\ v}$ is not negligible when the boiling point of the fuel is high, the ullage height is large, and(or) the thermal conductivity of the vessel is poor, because the temperature of the wall rises to a high level. $Q_{refl,v}$ will also not be negligible at the low fuel level especially when the vessel wall surface is coarse. $Q_{sens,v}$ is negligible compared with $Q_{sens,l}$, because the bulk volume and the specific heat of the vessel material are generally very small compared with those of the liquid fuel.

The convective heat from the vessel wall to the air $Q_{v, air}$ is very small compared with that to the fuel $Q_{v,l}$ but becomes dominant at large ullage heights and in the vessel of very poor thermal conductivity and very thin walls. (23)When the height of the vessel is small, the convective heat at the bottom of the vessel $Q_{v,l}$ or $Q_{l,v}$ or $Q_{v,air}$ or $Q_{v,water}$ may become considerable, depending on the fuel, the ullage height, the material, thickness and height of the vessel, and the burning time.

Experimental part

General purpose of the experiment was to monitoring graphic dependency of burning rate in time in conatiners with different wall thicknesses.

The dimensions of the vessel are shown in Table 2, as well as vessels material.

THE DIMENSIONS OF THE VESSELS Table 2

Vessel	Inner diameter of vessel [mm]	Wall thicknesses [mm]	Vessels material	Height [mm]
thick	60	8	Structural steel	45
Moderate thick	60	4	Structural steel	45
thin	60	2	Structural steel	45

Experiment was made in two steps, we followed burning rate parameter by change of wall thicknesses:

1. Filled with ethanol at 50 % (H □ 0,2 d) (Picture 3.)
2. Filled with ethanol at 100 %) H = 0) (Picture 4).

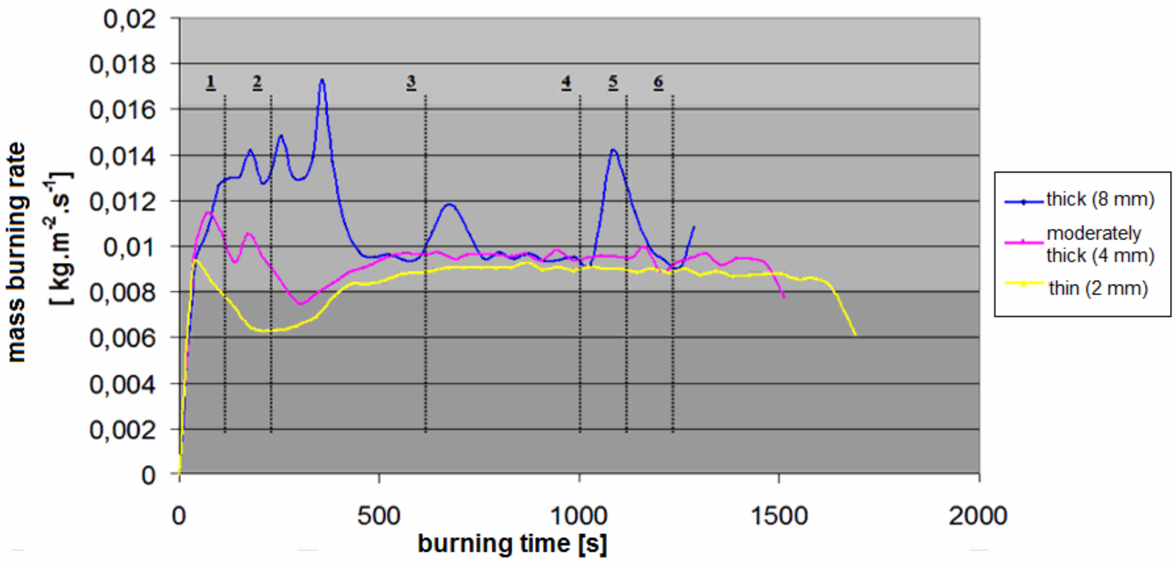

Fig. 3 *Ethanol mass burning rate in dependency of burning time*

Maximum of mass burning rate was for vessel, which had thicker walls (8 mm) and the longest time of burning was for thin – walled (2 mm). By comparing the result time of ethanol burning in vessels with different wall thickness was found, that the burning time in thin – walled vessel, compared with thick – walled is extended by about 750 seconds, wchich corresponds ≅ 22 %.

The curves in Picture 3. Can be divided into 3 parts. In the heat balance of the curve in Picture 3. Describes the following process:

1. Transfer of energy from the flame to vessel walls and flammable liquid, when the vessel with thick wall reaches higher mass burning rate, than vessels with thin walls.
2. Stabilization of the mass burning rate as a result of vessel walls and liqiud partially overheating.
3. Subsequent changes in the final part of curve in consequence lack of oxygen and low levels of flammable liquids.

Vessel with wall thickness of 8 mm is more complicated course of the curve, while the remaining two curves have almost the same course of clearance of temperatures. It is caused by thick walls, which absorb a larger share of heat from the flame. This reduces the proportion of energy defection from the vessel walls into the environment ($Q_{rr,v}$, $Q_{v,air}$).

Thick – walled vessel creates good insulating conditions for the energy produced by burning. The thin – walled vessel, heat penetrates more easily into the surrounding of the vessel and $Q_{rr,v}$ $Q_{v,air}$ share powering in the relationship (6) is increasing.

Increased of mass burning rate also means increase the amount of flame, which is described by mathematical relationships in studies (5,6,7). During the burning was captured flame in photograps shown in Picture 4. Images were made in the positions shown in Picture 3.

Position	**Thick (8 mm)**	**Moderate thick (4 mm)**	**Thin (2 mm)**
1			
2			

Position	Thick (8 mm)	Moderate thick (4 mm)	Thin (2 mm)
3			
4			
5			
6			

Fig. 4 *Height of the flame during burning*

Dependence of burning rate to flame hight was confirmed in the second part of burning process description.

Differences at the beginning of burning rate curve are caused by transfer system vessel-liquid. It results of images comparation and burning rate curve with thick wall (first part of Picture 3).In this part of curve, the burning rate reaches significantly higher values as in the other cases, however this fact is not noticeable in images, it is in line with heat transfer through the vessel wall. In first part, the highest values achieves the vessel, which has thick walls while the flame is the same as in case of thin and moderately thick vessel, because the wall of the vessel consumes bulk volume of energy to its heating.

In the second part of the experiment (Picture 5) ethanol reaches edge of the vessel (100 % filling) (experiment made in the same conditions).Maximal burning rate is similar to previous experiment. Ethanol was burning longest in the vessel with thin walls and it was burning shortest in the vessel with thick walls. The burning in thin-walled vessel was prolonged approximately about 750 seconds (10 %).

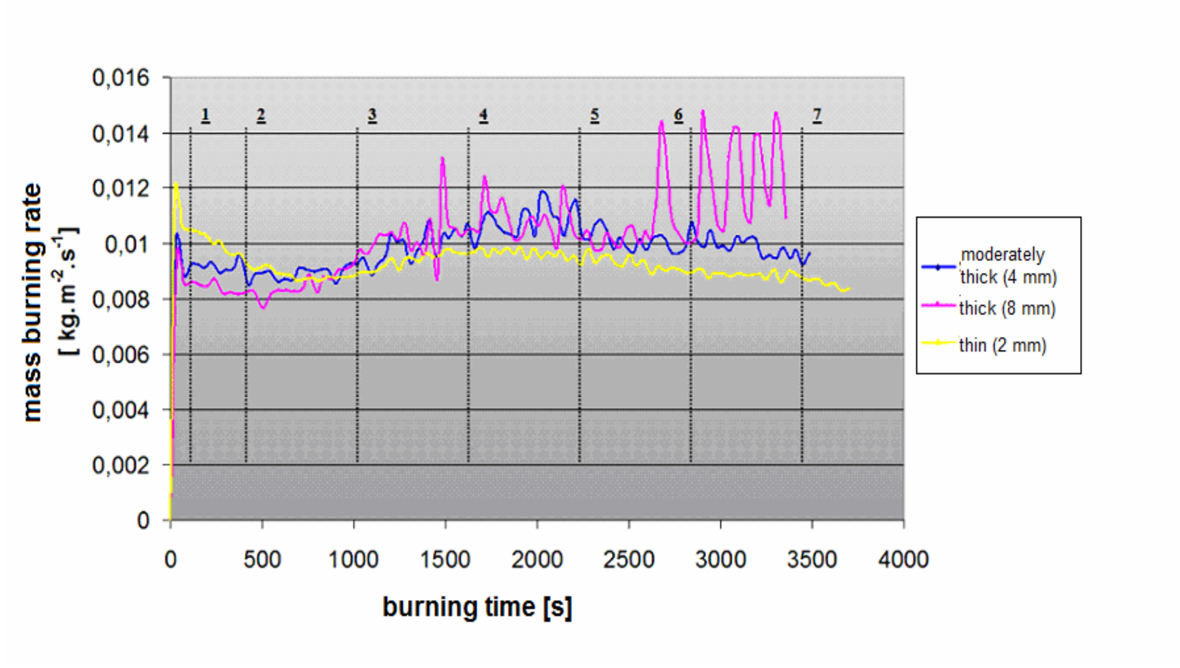

Fig. 5 *Ethanol mass burning rate in dependence on burning time*

In curves comparison in Picture 4 we can see that the largest growth of mass burning rate in begining part achieved curve of thin-walled vessel. It differs of Picture 3 in experiment 1. This fact is caused by burning near vessel aperture. Consequence of this is both of ideal access of flame to oxygen and vessel wall overheating is progressive. Especially overheating of thin-walled vessel occurs faster and also therefore the growth of the curve is faster in first part of graph. Subsequently the burning rate jiggles (in case of every vessel). This is caused by desrease of the liquid level and consecutive deficiency of the oxygen.

The behavior of the flame during the burning of the liquid is in the Picture 6.

Position	**Thick (8 mm)**	**Moderate thick(4 mm)**	**Thin (2 mm)**
1			

Position	Thick (8 mm)	Moderate thick(4 mm)	Thin (2 mm)
2			
3			
4			
5			
6			

Position	Thick (8 mm)	Moderate thick(4 mm)	Thin (2 mm)
7			

Fig. 6 *Height of the flame during burning*

Both of the height of the flame and the burning rate reach more stable values at the 100 % vessel filling as at the 50 % vessel ethanol filling.

Temperature distribution in liquid

Changes of burning rate are in the line with change of thickness of vessel walls and with the temperature distribution in liquid. For better understanding of the problem, temperature measurement was realized in the vessel by thermocouples. The thermocouples were distributed in 1/3 of vessel height. The first thermocouples was placed close to the wall of the vessel, and second one in the middle of the vessel. Above the thermocouples was 25 g of liquid, which correspond with thermocouples distribution in the middle of liquid, because the liquid level was in 2/3 height of the vessel.

The result of the experiment is seen in picture 7. The vessel with thin wall had faster increase of temperature at the beginning of burning, in contrast to thick wall, which absorb energy, and increase of temperature seems to be linear. After a while, the vessel with thick wall gets higher values, which is caused by releasing of accumulated energy in the walls of the vessel.

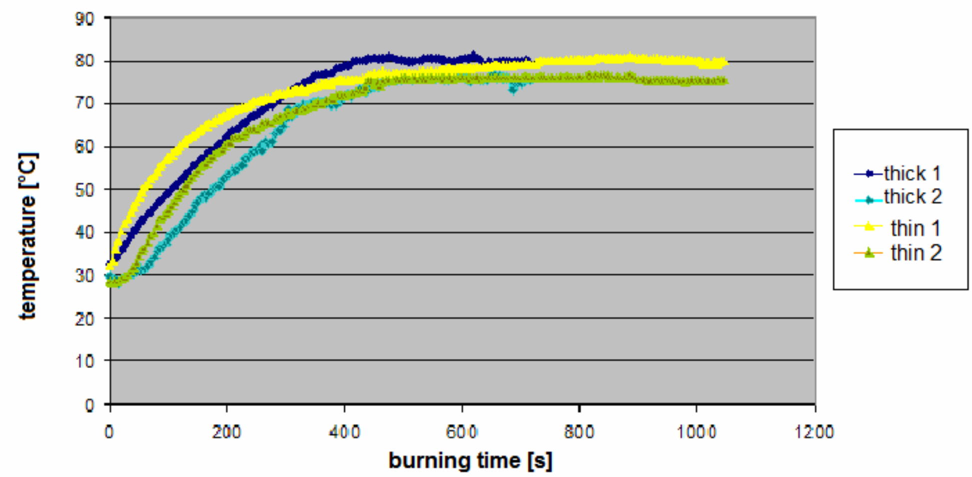

Fig. 7 *Temperature process on the wall (curve 1) and in the middle (curve 2) of the vessel in dependence on burning time*

Discussion

Influence of thickness of vessel walls has significant influence to burning rate. The increase of burning time increased about 22 %. Closer differences were achieved in experiment no. 2, because of better access of ethanol toward air, and so the part of transfer energy is decreasing. Differences between thin and thick walls of the vessel are caused by heat transfer from vessel to surround.

Connection between flame height and burning rate was published by many authors. Experiments described in this study show flame behavior during burning and they are compared with burning rate. The curve of burning rate was divided to 3 parts. In the first part, the biggest differences were caught; however, the height of flame doesn't change.

While in the second and third part of the figure, the dependence is manifested. It is caused by heat transfer and by energy balance in the vessel. In the first part, the energy is released to liquid and to walls of the vessel. In the second and third part, the energy is utilized for liquid gasification, and participates in height of flame.

Conclusion

According to frequent utilization of burning rate, a parameter of flammable liquid burning is not much measured. Nowadays, the burning rate comes to the background. Differences and variances from mathematical simulations are often solved with correlation of different coefficients. In spite of their usage, significant inaccuracies are brought into real behaviour of liquids. Therefore, significant role plays experimental data verification, which are utilized in mathematical modelling. This fact is in it more remarkable, that experimental results, which we measured, confirm, that change of wall thickness increases burning time about 10.22 %, whereby literature and mathematical formulas don't allow this parameter.

References:

[1] APTE, V. B. Effect of scale and fuel type on the charakteristics of pool fires for fire fighting training. In *Fire Safety Journal*, 1998, 31, pp. 283-296.

[2] Shintre Parag, Vasudevan Raghavan. Experimental invegistigation of burning rates of pure ethanol and ethanol blend fuel. In *Combustion and Flame*, 2008, 156 , pp. 997-1005.

[3] Atsushi Nakakuki. Heat Transfer Mechanisms in Liquid Pool Fires. In *Fire Safety Journal* 1995, 23, Elsevier Science Limited Printed in Northen Ireland, pp.339-363.

[4] WANG, Z,-X. A three layer model for oil tank fires. In Second In S*ymp. On Fire Safety Science*, 1988, p. 209.

[5] ZABETAKIS, M. G., BURGESS, D. S. Research on the hazards associated with the production and handling of liquid hydrogen, report of investigations 5707. United States Department of the interior Fred A. Seaton, Secretary.

[6] KASHEF, A., BÉNICHOU, N., TORVI, D., RABOUND, W. HADJISOPHOCLEOUS, G., REID, I. FIERA system Encloused Pool Fire Development Model: Theory Report, NRC-CNRC, 2002, IRC-RR-121.

[7] HAMINS Anthony, JIANN C. Yang, TAKASHI Kashiwagi. A *Global Model for Predicting the Burning Rates of Liquid Pool Fires*. NIST, 1999, NISTIR 6381.

[8] DĚMIDOV, P. G. *Hoření a vlastnosti hořlavých látek.* Praha: ČSSPO, 1966.

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ROLE OF PROCESS MODELS IN SAFETY MANAGEMENT

Miroslav RUSKO, Dana PROCHÁZKOVÁ

Abstract

Management is a type of human activity that establishes and ensures the system functions. The process models and project models are currently used for management support. Main aim of the process model is to describe the possible development tendencies as a consequence of certain phenomenon and to define functions and role of functions. The process models enable to compile procedures and scenarios for the situations that have similar features. They are suitable for planning, response and renovation. In this paper, we present the risk management model used at present in professional practice, two simple models from daily practice and the evaluation of process models for crisis management.

Key words

management, risk, safety, model

Introduction

Life, health, security and a chance of development are important for each human. In integral sense, the safety is a set of measures and activities aimed at conservation, protection and sustainable development of all protected interests. Basic protected interests are the human lives, health and security, property and welfare, environment, technologies and the infrastructures facilitating the human life [1]. In concord with proclamation of the EU, the UN and other world organisations and with professional knowledge, it is necessary to ensure the safe community, safe region, safe state, safe Europe and safe world in order to conserve sustainable development of human society.

With regard to the present findings, the safety management of territory directed to sustainable development concentrates on:

- preceding the disasters if possible,

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- removing the causes of origination of severe disaster impacts or at least reduction of their frequency of occurrence,
- mitigation of unacceptable disaster impacts by preventive measures and activities, preparedness, optimal defeating the disaster impacts and induced critical situations (i.e. shortening the emergency situation duration to acceptable level),
- ensuring the territory renovation after disasters and starting the further development.

Strategic proactive management and its tools are used to hit this target there.

Selected Tools Supporting the Management

The management is a type of human activity that establishes and ensures the given system functions. It is a conscious way of applying the theoretical and practical knowledge of top managers directed to identification and diagnosis of the problems and targets in a given system, matters of defeating the problems, determination of procedures for required targets reaching and on implementation of procedures connected with supervisory mechanisms directed to the aim in order that required targets might be optimally reached. The tasks are to diagnose each problem, to decide rationally, to realise decision-making in given real conditions.

It is evident that the management is successful only if it is based on professional knowledge and experience. To obtain required knowledge and experience, we must permanently collect, process and verify data, perform qualified assessment that can only be done by qualified and experienced specialists. These demands can be met only on the state level. Therefore, in developed countries, there are different organisational structures, dependent on the state administration organisation that monitor safety, disasters etc. and prepare grounds for decision making and strategic development of land.

The management consists of making individual decision. It consists of the following steps:

- assembling and processing the information with respect to the fact that processing must be adequate to particular problem (i.e. that data processing methods for needs of safety management must respect that big disasters with devastative impacts occur rarely, and therefore, the procedures respecting the great numbers law, i.e. algorithms based on extreme or marginal estimations must be used,
- recognition of solution variants,
- searching for optimal problem solution,
- own decision making.

To make the decision making objective and qualified, it is necessary:

- to have a sufficient number of information, its objective processing and cognition of suitable reactions,
- permanent reaction to an access to new findings,
- to understand the solved problems in connection to their vicinity and in their internal structure,
- to combine the suitable knowledge, experience and new information in order to obtain practical way of problem solution,
- credible data assessment.

In decision making, it is necessary to consider:

- the judgement of present conditions and present decision making from the viewpoint of a future development,
- the qualitative factors and strategies of different participants,
- the fact that the future is multidimensional and indefinite,
- the fact that each system must be investigated both globally and systemically,
- the fact that information and strategies are not neutral but tendentious,
- that more approaches complement each other,
- the fact that there are prejudices against the strategies and humans which should be prohibited.

Decision making must be objective and qualified. From the viewpoint of the knowledge that might be decisive in systemic concept, decision making can be classified as:

- standard; all is known and standard procedures of solution are also known,
- well structured; there is a clear and quantitatively described structure of problem in systemic concept and the optimizing methods may be used,
- weekly structured; i.e. there are not only uncertainties but also unclearness in case of several elements of structure of judged system. To put under control, the methods of system analysis that join exact mathematical methods with normalised quantitative considerations (i.e. heuristic methods) must be used. Decision making heuristic methods are the methods of decision making analysis that are usually divided into:
  - decision making tree (process model),
  - decision making matrix.

  Assessment of process models is often performed by the Delphi method [2] and the assessment of decision making matrixes is performed by the way described in appropriate handbooks , e.g. [3];

- non-structured; i.e. there are uncertainties regarding many elements, links and flows of the judged system. Their solution is possible by the expert methods. Expert methods simulate intellectual procedures of specialists. They are based on the scenario of process in which a decision maker is directed to solve partial problems of decision making in certain logic procedure of considerations and activities connected with generation and assessment of different variants of solution of a given problem. Expert systems can be classified as diagnose and generative (designing) ones [4, 5]. To support decision making, case studies are processed [6] that use qualitative data in a way enabling to obtain the idea of frequent solution of problem in certain context determined by given conditions in the evaluated system and its vicinity.

When selecting a method of decision making, it is necessary to respect the nature of the solved problem, determine aims of solution, criteria for solution and possibilities of collecting the necessary input information. In a domain of land safety management, it is necessary to realise that the majority of problems is connected with uncertainties and unclearness induced by fact that the human system has been continuously developing in permanently changing outer medium, and that to fulfil the safety management targets, it is necessary to choose a good strategy for ensuring the human system security and sustainable development.

Strategy is a set of rules for decision making under the conditions of uncertainties and unclearness. The development of strategic management accompanied by formation of effective tools started in the second half of the 20th century, when methods of operating analysis based on the creation and assessment of variants of possible evolutionary tendencies of system were processed. In the 70s, the process approach was worked out which was in the 80s linked with the systemic approach that represented net interface and complex view on a given reality.

To produce variants of processes, the methods based either on the estimation or on the mathematic modelling are used today. When selecting a method for decision making, it is necessary to respect the nature of the solved problem, determine aims of solution, solution criteria and possibilities of collection of necessary input information. The first group of methods comprises the methods of analogy, brainstorming, brain writing, panel discussion, Delphi method, Gordon methods (technique of creative thinking), application of fuzzy sets, and application of fractals [7]. The methods based on mathematical modelling are based on the time series processing. Excessive exactitude in the construction of exact models often leads to overestimation of theoretical viewpoints and to non-respecting the real needs and possibilities of future users. Pragmatic approach, based on the analysis of real situation and on building a model suitable just for it, depends on the methodology of model compilation – objectivity, non-prejudiced and comprehensiveness of data, capabilities and competence of professionals.

There is always an effort to divide the problem into a hierarchy of sub problems of different orders, i.e. structure the problem. Problem structuring has two dimensions, namely the problem decomposition and the level of abstraction of problem representation.

For management support, the process models and the project models are elaborated at present [8]. Main aim of the process model is to depict possible development tendencies as a consequence of certain phenomena, pertinently to demark functions and role of functions. The application of process model is suitable for repeated activities that can be structured and consecutively described. The typical case is the production enterprise with a serial production. The application of project approach is conversely suitable for unique projects, e.g. big buildings, software development etc. Individual projects allocate in life cycle own and external sources according to momentary need. The project approach has always higher uncertainty and is worse described by tree model [8].

Process Models

Fundamental for process management is the elaboration of process models. Modelling is a specific sort of cognition of reality that is around us. It is an efficient activity that we have been using in case of complex process / activity / object etc., when we want to investigate only certain matters, i.e. the existing reality is simplified or sometimes only reduced or magnified. During the modelling, we elaborate the model of identified reality (mathematical, thought, oral, graphical, physical (imitation)) for defined purpose, that (following from condition of isomorphic or homomorphism representation) may give great evidence capability that is only valid in the extent of reality for each model. Mathematical and physical models come from analogies among physical quantities. The model compiled according to principles for physical model has the same physical nature as the object. The model compiled according to principles for mathematical model has a different nature, but its function is perceived by the set of equations identical with the set of equations describing the items of original.

Mathematical models we can classified according to the different viewpoints. According to the character of parameters and deciding variables [9], the models are divided into:

1. Deterministic models, i.e. models in which all parameters are fixed deterministic values and in which there are only deterministic quantities and relations, i.e. nor uncertainties neither unclearness are allowed.
2. Stochastic models, i.e. such models in which at least one parameter that is a random quantity occurred and there is no unclearness (i.e. deviations from reality connected with blunder error at collection or at interpretation of data, measurement or with lack of data or with non-linearity of process or with intentional or non-intentional neglecting sure actions or events). It means that at least one decisive variable in model is a random quantity. Uncertainties connected with this random quantity (or with these random quantities) may be assessed by the methods of mathematic statistics. Probability distribution of random variables in the model is known (in practice this distribution is deduced either from logic – theoretical considerations or by methods by mathematical statistics or by expert methods).
3. Models with unclearness are sometimes called strategic, i.e. the ones when there is at least one quantity that is random, but its distribution (unlike stochastic models) is not known and cannot be determined by logic – theoretical considerations or by the methods of mathematical statistics (usually owing to low number of events) or by expert methods. We usually say that we only know bottom and top limits of these quantities in these models.

Modelling is one of the methods used for solving the tasks of practice if inputs and outputs are known. Terminologically, clean-out models are e.g. the models:

- fuzzy multi-criteria,
- conceptual or qualitative,
- quantitative,
- dynamic and simulative,
- ecological effectiveness.

Chosen typology of continuous discrete decision models leads to classification into two basic groups, namely multi-criteria discrete models and multi-purpose continuous optimising models. The other possible classification is according to so called degree or “softness” or “hardness”, i.e. according to completeness and accuracy of input information. There are models of certain softness type (SOFT) and certain hardness type (HARD).

Process models belong to the category of qualitative models on the basis of process analysis and graphical representation. In the 90s of last century, many different technologies have been developed. The most popular methods were the OMT (Rumbaugh), the OOAD (Booch) and the OOSE (Jacobson). Each of these methods had its own value and advantages. The OMT emphasizes the analysis, the OOAD proposal and the OOSE behaviour analysis. The methodologies have been converged; however, they have been using their own symbols. Using the different symbols caused the problems on market, since one symbol was interpreted differently by various people. This war of methods was terminated by UML (Unified Modelling Language) that represents the unification of Booche, Rumbaugh and object symbols of many others. UML is a fundament/standard in the domain of object oriented analyses and of proposals based on experience of professionals [10].

Process model supported by qualitative tool enables to describe actual conditions, to propose new processes or to optimise existing processes, to reveal unnecessary or inefficient processes, to simulate and to evaluate possible impacts of changes before their implementation. From the viewpoint of formalised process analysis, process models represent sophisticated tools in which pure graphic representation may be misguided and it may mean unacceptable simplification of judged system.

Process Models Supporting the Safety Management

As an example, we will show the risk management model that has been used at present in professional practice, two simple models from daily practice and the evaluation of process models for crisis management.

Risk Management Model

The risk management model leads the project medium to proactive continuous risk management. The risk management process according to this model comprises five steps – identification, analysis, countermeasure planning, monitoring and own management. Each risk goes through these steps at least once.

In the first step, the source of risk, character of possible failure of object, operational and commercial connections are determined. In the second step, the probability and impacts (for calculation and mutual comparison of risk) are determined. In the third step, countermeasures leading to risk reduction, risk mitigation and transfer of risk to somebody else are defined. In the forth step, information on risk and change of its elements in time is obtained. In the fifth step, planned actions as reactions to appurtenant changes are performed.

Outputs from risk management process are the following:

1. ***Risk assessment document –*** it includes all information on appurtenant risk.
2. ***Top risks list –*** it contains list of selected risks, the solution of which has the highest demands on sources and time.
3. ***Retired risk list*** - it serves as historical reference to future decision making.

Process Models Derived for Practice

The following figures (Fig. 1 and Fig. 2) show the examples from practice. The first one describes the processes necessary to ensure the security and sustainable development of land in the case of traffic accident of tanker. The second one describes the processes that can cause the destruction of boiler.

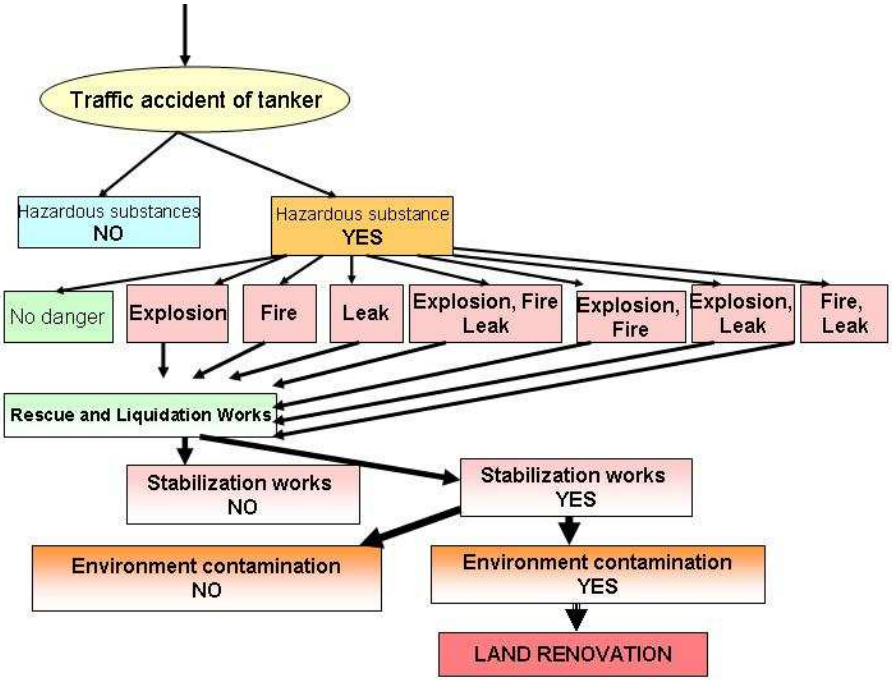

Fig. 1 *The process model describing the tanker traffic accident*

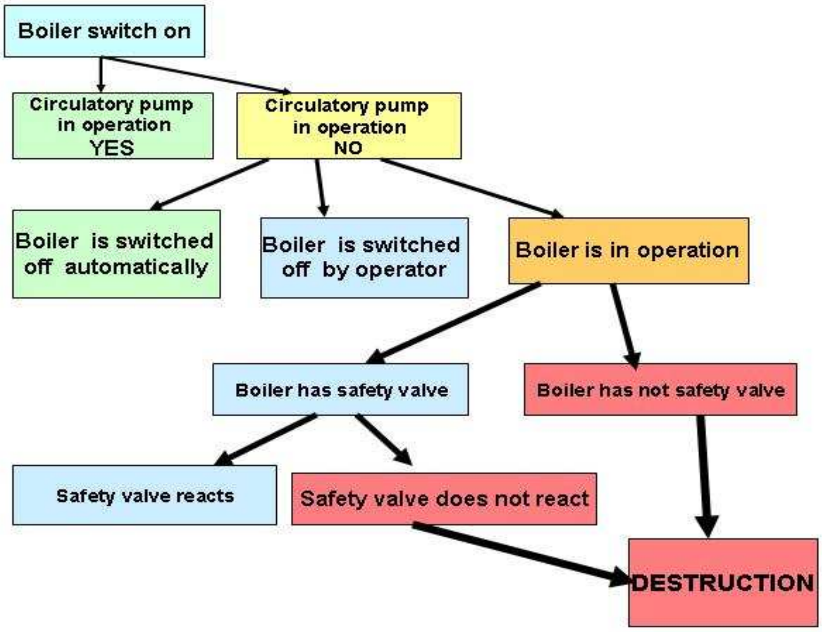

Fig. 2 *The process model describing the boiler destruction*

Process Models Supporting the Crisis Management

On the crisis management portal of public administration [11]**,** there is the use of process models for crisis management. Possibilities of standardisation, simulation, processing and evaluation of process models for individual domains of crisis management are described there. the uses of individual models for crisis management in practice, the sequences of works at life cycle of extra ordinary event or crisis situation with regard to individual specifications of domains in which they originate are shown. Interpretation of the EU and NATO standards, compatibility with legislative and other favourable properties for domain of teaching, preparation and training of individual components participating in crisis management are described. One can find there a description of procedures and conditions for connection of process models for crisis management with used and originating tools for crisis management support, including the links to the IT.

Conclusion

Each process is a sequence of phenomena or activities in space and time, in which we can distinguish inputs and outputs. Inside of each process, there are usually parallel but distinct sub processes. Each of sub processes is bound up to certain element in space or to certain group of elements in process under account. The process model is a representation of certain process directed to a certain target. As targets are not the same in practice, there are several process models for one process.

The process models enable to compile procedures and scenarios for certain situations that have certain similar features. They are suitable for planning, response and renovation. They are constructed according to real needs. Results of process model application are the norms, standards, security, emergency, accident, crisis, continuity and other plans, disaster scenarios, response scenarios, renovation scenarios etc.

In management domain, namely in the planning, it is possible to use the process models reflecting the reality type for certain, strictly limited type of activities. With regard to the above mentioned theory, each process model must be tested whether a given reality corresponds to model assumptions. If yes, it is possible to use this model and vice versa. With regard to the multiplicity and variety of reality, it is not sufficient to use only deterministic and stochastic models, but in the case of higher demands on accuracy, it is necessary to apply the models with unclearness in which unclearness is eliminated by expert methods or by case study methodology [6].

The domain of security, emergency, accident and crisis planning are the domains in which it is necessary to consider the origination of unforeseeable phenomena (human error at decision making, lack of necessary sources of all kinds, occurrence of meteorological conditions, unusual combination of phenomena etc.), it is the domain in which it is necessary to use the process models based on the models with unclearness because:

- deterministic models that are conservative, i.e. that are very expensive,
- stochastic models do not perceive possible situations because they are too simplified.

Process models based on deterministic approach have been used at sitting, designing, building and processing the technologies and objects because they ensure the highest level of safety with regard to the present knowledge and experience.

Process models based on stochastic approach have been most often used in inspection activities and routine management of safety of certain processes or objects.

References:

[1] PROCHÁZKOVÁ, D. *Strategie řízení bezpečnosti a udržitelného rozvoje území*. PA ČR, Praha 2007, 203 p. ISBN 978-80-7251-243-0

[2] COPPERSMITH, K. J., YOUNGS, R. R. *Probabilistic Seismic - Hazard Analysis Using Expert Opinion; An Example from the Pacific Northwest*. In: Krinitzsky E. L., Slemmons D. B., eds - Neotectonics in Earthquake Evaluation. Am. Geol. Soc., Boulder 1990, pp. 29-46.

[3] PROCHÁZKOVÁ, D. et al. *Metodika pro odhad nákladů na obnovu majetku v územích postižených živelnou nebo jinou pohromou*. Metodická příručka pro veřejnou správu. Praha: CITYPLAN, spol. s r.o., 2006, 52 p. ISBN 80-239-7680-X

[4] VEPŘEK, J. *Systémové řešení neostrých problémů*. Praha: Academia, 1990.

[5] EISENHARDT, K. M. Building Theories from Case Study Research. In *The Academy of Management Review*, 1989, Vol. 14, No. 4, pp. 532-550.

[6] PROCHÁZKOVÁ, D. Případová studie a metodika pro její sestavení. In *Manažérstvo životného prostredia 2006*. (eds M. Rusko, K. Balog) - Zborník z konferencie so zahraničnou účasťou konanej 24.-25.2.2006 v Trnave. Žilina: Strix et VeV. ISBN 80-89281-02-08, pp. 507-534. http://mazp2006.emap.sk

[7] PROCHÁZKOVÁ, D. et al. *Pomocný multikriteriální systém pro rozhodování ve prospěch udržitelného rozvoje krajiny a sídel*. Kompendium pro veřejnou správu. Praha: CITYPLAN, spol. s r.o., 2007, 96 p. ISBN 978-80-254-0885-8

[8] PROCHÁZKOVÁ, D. *Principy správného řízení věcí veřejných s ohledem na bezpečí*. 2008, 112, 9, příloha 1-20. ISSN: 1213-7057

[9] KLŇAVA, J. *Modelování 10*. Operační výzkum 1. Praha: ČVUT, 2000.

[10] JACOBSON, I., BOOCH, G., RUMBAUGH, J. *The Unified Software Development Process.*

[11] The Ministry of Interior Web Portal.

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INTEGRATED PREVENTION AND POLLUTION CONTROL AS AN IMPORTANT TOOL OF ENVIRONMENTAL POLICY IN SLOVAK REPUBLIC

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Abstract

The concept of "integrated environmental protection" takes into consideration all sectors of environment impacts (air, water, waste) like a complex, instead of a separated view on each sector. The reason of this concept is that the substances and emissions outflow from one environmental sector can cause transport to another environmental sector.

New attitude in integrated process represents a change which can be applied within the segment system of assessment and permitting installations to the integrated permitting. It is a new aspect with which we do not have any practical experience with and poses demands on both sides involved in this process. Integrated permit does not mean increased responsibilities, but allows operators to be actively connected to the permitting and transposing their own ideas in communication between the competent authority and operator, what the existing practice does not allow.

Key words

IPPC, integrated permit, competent authority, installation, operator

Introduction

Integrated prevention and industrial pollution protection is a set of measures aimed at pollution prevention, reduction of emissions to air, water and soil, reduction of waste

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generation, and at waste recovery and disposal, in order to achieve a high level protection of the environment taken as a whole, whereas focusing on industrial sphere.

Integrated pollution and prevention control presents a shift from keeping each environmental sector (air, water, waste) to industrial activities. The field of IPPC activity is consequently divided according to the industrial activities.

The purpose of Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control is to achieve integrated prevention and control of pollution arising from the activities listed in Annex I. It lays down measures designed to prevent or, where not practicable, to reduce emissions in the air, water and land from the abovementioned activities, including measures concerning waste, in order to achieve a high level of protection of the environment taken as a whole, without prejudice to Directive 85/337/EEC and other relevant Community provisions.

Environment is a necessary condition of our existence and life. It is the only environment for life which we have. It is logically necessary to protect and develop this environment. The real guarantee of preserving and improving the present situation of environment are laws and their efficient enforcement.

A very important tool for upholding the environmental laws to the practice are the competent authorities which may give sanctions. The main executive body in Slovakia is the Slovak Inspectorate of Environment, which has been established by the Slovak Ministry of Environment.

The Slovak Inspectorate of Environment (SIE) is an experienced controlling authority providing the state supervision and giving sanctions to keep the environment in good conditions and make the state control in integrated prevention and pollution control section [1].

For activities which SIE initiated immediately after the IPPC law come into force, it was necessary to establish the new department and build it personally, materially and also technically. At the same time, five local departments of integrated prevention and pollution control in Inspectorates in Bratislava, Nitra, Banska Bystrica, Žilina and in Košice were established [2].

Headquarters coordinate the SIE work in the national and international range. It works like a second degree – appeal authority to first degree decisions of local Inspectorates.

Legislative scope

Within the approximation process in the conditions of Slovakia, the Council Directive 96/61/EC of 24 September 1996 on integrated prevention and pollution control (IPPC Directive) was implemented by approving the Act No. 245/2003 of the Coll. on integrated prevention and pollution control (IPPC) and Regulation No. 391/2003 of the Coll., which regulate IPPC via implementation of the Act No. 245/2003. Gradually, later amendments of this Act, such as 205/2004, 220/2004, 572/2004 and 587/2004, were implemented.

IPPC Directive was recently codified – European Parliament and Council Directive 2008/1/EC of 15 January 2008 on integrated prevention and pollution control.

Regarding the continuous amendments of individual Directives on important industrial emissions, the European Commission admitted the Directive proposal on Industrial emissions on 21 December 2007, processing the seven existing Directives related to industrial emissions into a simple, clear and coherent legislative tool, including the following documents:

- IPPC Directive,
- Large Combustion Plant Directive,
- Waste Incineration Directive,
- Solvents Emissions Directive,
- Three Directives on Titanium Dioxide (disposal, monitoring, pollution reduction programs) [10].

Directive on industrial emissions should facilitate the governmental bodies to specify the conditions of integrated permission. When the Directive comes into force, the BREF documents will be obligatory.

Integrated permitting process

Integrated permitting is the process open to general public. Except for negotiating participants and competent authorities, also civil community of physical people, interest group of juridical people and people connected with integrated permitting process can be involved [2].

A demanding and lengthy process beginning with sending operator a notification and continuing with running negotiating application preceded the publication of the integrated permission. The integrated process itself begins when operator submits an application, then ensues its processing and verifies the information in installation. After oral hearing and each condition of permission is agreed with operator then an integrated permission is issued [5]. To issue the integrated permission lasts 90 days from oral hearing and maximum 6 months from the process beginning – from clear and correctly filled in application.

The system of integrated permission brings different advantages for competent authorities on one hand, and for operators on the other hand. The system contribution can described as follows:

- *From the operator point of view:* considerable simplification of process because the operators need only one application for most decisions in the environment protection sphere. The example of the application is compiled in an understandable and clear way. In case the installation is new, integrated process is connected also with building permission. These aspects make process easier and speed it up.
- *From the competent authorities point of view:* the advantage of this process is assessing the activities in permitting installation with one competent authority instead of existing permitting by different authorities with often complicated mutual interconnection. For this reason, it is possible to set installation conditions with focus on all environmental impacts mainly in air protection, water protection and waste management area (Fig. 1). This system simplifies the inspection of permits conditions, carried out by one competent authority.
- *For both sides:* different approvals issued up to the present are now concentrated in one well arranged document – integrated permit [11].

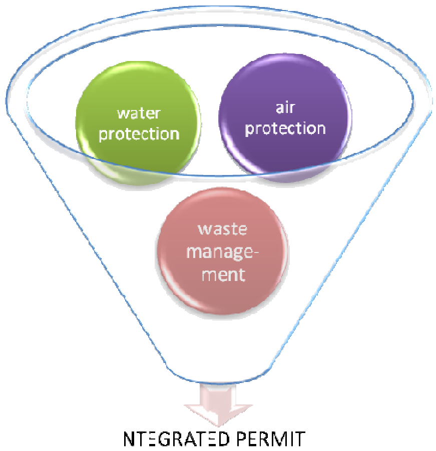

Fig. 1 *Integrated process and its simplification*

What does IPPC permit allow?

- IPPC permit allows the whole control of the installation and confirms that if the conditions in the permit are fulfilled, the installation will not cause the environment pollution.
- With the IPPC permit, the operator is obligated to use hierarchy of the waste management. The IPPC permit obligates the operator to use energy efficiently.
- IPPC permit obligates the operator to take measures for prevention of failures and reduce its consequences.
- After finishing the installation activities, IPPC permit obligates the operator to take some measures for location remediation and for bringing the environment in a satisfactory condition. With the IPPC permit, the existent installations should be able to meet the required conditions in the specified time.
- IPPC permit obligates the operator to help during the inspection supervision.
- IPPC permit obligates the operator to supervise himself, to report violated regulations and to allow the public access to the obtained data [12].

The deadline for issuing all integrated permits was 30/10/2007 regarding the Act No. 245/2003 on integrated prevention and pollution control (IPPC), and therefore the activities of Inspectorates involved mainly the permissions of installation listed in Annex 1 of Act 245/2003.

Integrated permits were issued in accordance with the schedule developed on following IPPC installations databases. The deadline for issuing all integrated permits for all IPPC installations in Slovakia was fulfilled to 100 %.

In comparison with previous years, year 2008 was much more demanding considering the huge amount of already issued integrated permits. The operators often applied for substantial change (Fig. 2) in installations of functions or for building decisions (like approbation decision).

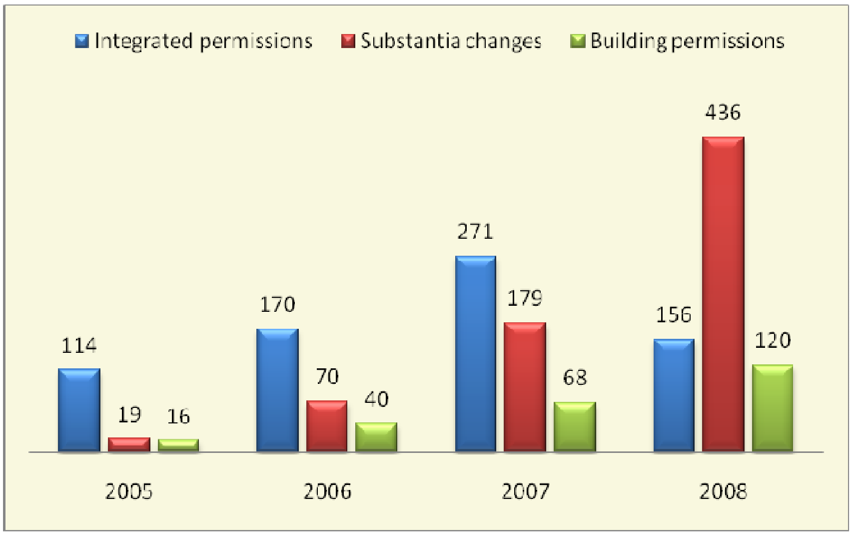

Fig. 2 *Integrated permissions, substantial changes and building permissions issued in each Inspectorates in period 2005-2008 [3, 4]*

Inspectors act not only as a permission competent authority, but also as an inspection authority. In years 2007/2008, inspectors made much more on-site visits then in the years 2005/2006 as can be seen in Figure 3. The reason was that not many integrated permits were issued in years 2005/2006.

Act 532/2005 came into force on 1 January 2006 and it changed and amended the Act 245/2003 on IPPC – SIE, extending the competencies of the permitting body in the field if the air and water protection, waste management and in building permission process [5].

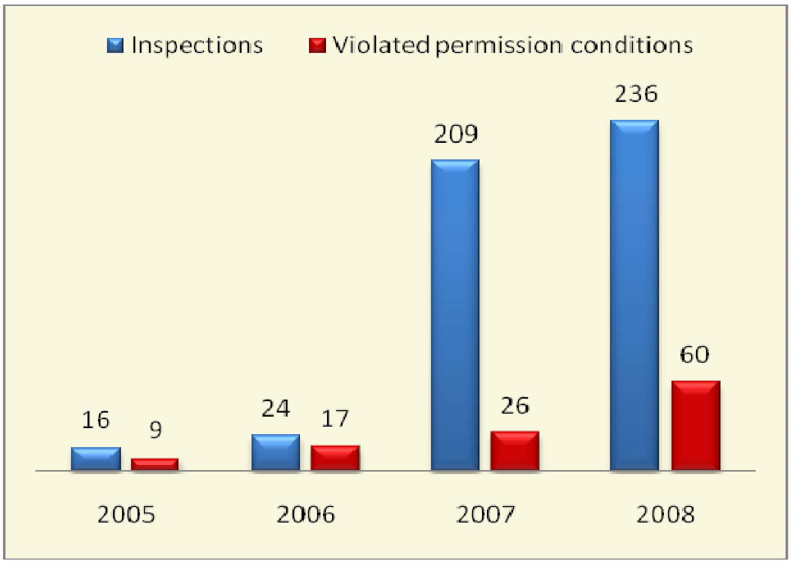

Fig. 3 *Inspections made on each Inspectorates in period 2005-2008 [5,6,7,8]*

BAT and BREFs

The main target of integrated prevention is to protect environment as a whole from industrial and agricultural pollution by regulating installations. It is possible to achieve higher degree of environmental protection by using BAT [9].

IPPC Directive for this purpose introduces a new concept known as **BAT** - Best Available Technique. BATs are defined as the most effective and developed degree of development using technologies and the way of their operation. They are made to be set up in an applicable economic branch. The conditions must be economically and technically acceptable with respect to the expenses and contributions. An installation operator can accept the conditions only when they are reasonable and at the same time most effective in the protection of environment as a whole.

The outcome of the formal information exchange has a form of BAT Reference Documents – **BREFs**. They are gradually being published for all activities under IPPC. BREFs summarized and recommended (but not as obligatory) Best Available Technique in a given industrial branch. BREFs are prepared by **TWG**s (Technical working groups) and are used as background papers for integrated permit applications. TWGs consist of the experts from EU countries, EFTA countries (European Free Trade Association) and associated states, representing industrial and non-governmental environmental organizations. These technical working groups prepare BREFs on the base of the obtained information. The information exchhange is monitored by the Information Exchange Forum (**IEF**) which meets twice or three times a year and provides official comments to BREFs proposals.

The BREFs target is to provide information about:

- given industrial branch,
- used technologies and processes,
- materials flows,
- emissions limits in EU member states,
- emissions monitored by relevant authorities of EU member states, by installation operator, by European Commission and finally by general public.

The core of each BREF is a row of elements which lead to identification of what can be considered a BAT. It is done on the basis of previous information and specific emissions limits set for an industrial branch. At the end of each BREF, there is information about developing the techniques in a given industrial branch. BREF documents should not contain political views and attitudes.

How to use BREF in the Permit?

When evaluating BAT for the applicant, it is important that the applicant and the authority make reference to the BAT Reference Documents used, and discuss the choice of document, investigating possible substitution for dangerous substances, and then revising technological processes. It shall be described which dangerous substances are used in the production, and what should be done in terms of substitution to reach BAT. It shall be described which processes are used in the production, and what should be done to reach BAT. A subdivision of this paragraph into single processes can be useful for clarification. All new productions shall apply BAT according to the definition in the IPPC Directive. For existing companies, it should be described:

- whether the process uses BAT and if not - why not,
- which terms in the permit that will ensure that a plan towards BAT will be mandatory for the installation,
- the time limits and why it is necessary to give the installation time to apply BAT [13].

Conclusion

Integrated permitting is process in which conditions for defined industrial activities in installations are being set. New installations are permitted to meet the target – integrated environmental protection and protection of all environmental sectors, to keep the pollution degree in environmental quality standards.

The main target of integrated prevention is to protect environment like a whole before industrial and agricultural pollution by regulating installations. In spite of integrated permitting is still relatively new problematic in markedly lesser extend come to breaking of duties which followed from integrated permits. The operators, which are under the IPPC Directive, are satisfied, that they don't need to ensure so many permits from different competent authorities as in the past. All conditions of installation operation are contained in one integrated permit.

Integrated permit does not mean increased responsibilities; on the contrary, it allows operators to be actively involved in the process of permitting and to foster their own concepts in mutual communication of competent authority and operator, which former practice did not allow.

References:

[1] Slovak Inspectorate of Environment.[online]. Available on-URL: >http://www.sizp.sk/< [in Slovak]

[2] NITSCHNEIDEROVÁ, H. 2005: The role of SIE like a permitting authority. In *Enviromagazín*. Banská Bystrica: MŽP SR a SAŽP, 2005, p. 6-7. ISSN 1335-1877 [in Slovak]

[3] Slovak Inspectorate of Environment: An Annual report 2006. [online]. Available on-URL: >http://www.sizp.sk/< [in Slovak]

[4] Slovak Inspectorate of Environment: An Annual report 2007. [online]. Available on-URL: >http://www.sizp.sk/< [in Slovak]

[5] Evaluation of fulfilling the main planed IPPC tasks for 2007. - Slovak Inspectorate of Environment, Bratislava [in Slovak]

[6] Evaluation of fulfilling the main planed IPPC tasks for 2006. - Slovak Inspectorate of Environment, Bratislava [in Slovak]

[7] Evaluation of fulfilling the main planed IPPC tasks for 2005. - Slovak Inspectorate of Environment, Bratislava [in Slovak]

[8] Evaluation of fulfilling the main planed IPPC tasks for 2008. – Slovak Inspectorate of Environment, Bratislava [in Slovak]

[9] SUCHANEK, Z. 2004: EMS and IPPC. In RUSKO, M., BALOG, K. [Eds.]: *Management of Environment ´2003. Proceedings of the International Conference*. Trnava: December 11 - 12, 2003, First Edition, Trnava: Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology, 2004, ISBN 80-227-2005-4 [in Czech]

[10] The IPPC Directive. [online]. - Available on-URL: >http://ec.europa.eu/environment/air/pollutants/stationary/ippc/index.htm<

[11] NITSCHNEIDEROVÁ, H. 2007: SIE (Slovak Inspectorate of Environment) successfully deal with European Union tasks in integrated permitting. In *Enviromagazín*, 2007, XII, N^{o}. 6, pp. 4-5. Banská Bystrica, MŽP SR a SAŽP. [in Slovak]

[12] PETROVSKA, S., ACESKA, N., PETROVSKA, M. Role of IPPC Permit in the Process of Reduction of Pollution Caused by Waste Water in Two Pilot Plants in the Municipality of Prilep [online]. - Available on-URL: >http://www.balwois.com/balwois/administration/full_paper/ffp-1438.pdf<

[13] Application of BAT/Clean technologies in industry. [online]. - Available on-URL: >http://www.esmak.ru/infolibrary/FAQ/IPPC/bat.html#6<

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COMPARSION OF SOLUTIONS OF SECOND ORDER LINEAR DIFFERENTIAL EQUATIONS WITH CONSTANT COEFFICIENTS

Marcel ABAS

Abstract

In this contribution we compare solutions of second order linear differential equations with constant coefficients with respect to the form of right-hand side of the equation and to the form of initial or boundary conditions. We will see that some types of such differential equations one can resolve by the method of variation of constants and it is not possible solve them by Laplace transform. On the other hand, some of them are solvable by Laplace transform and are unsolvable by the method of variation of constants. The reason for the comparison is to show that the students of automation have to know both ways of solving linear differential equations with constant coefficients.

Key words

linear differential equation, Laplace transform, variation of constants

Introduction

Consider the following problem: solve linear differential equation of second order

$$y''(t)+a_1y'(t)+a_2y(t)=g(t),\quad a_1,a_2\in\Re \tag{1}$$

with either initial conditions $y(t_0)=a, y'(t_0)=b$ or with boundary conditions of the form $y(t_0)=a, y(t_1)=b$ or $y(t_0)=a, y'(t_1)=b$ or $y'(t_0)=a, y'(t_1)=b$. The right-hand side of (1) - the function $g(t)$ - can by continuous as well as discontinuous on $(0;\infty)$. It is well

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known, that one can solve the differential equation by the method of variation of constants only if the function $g(t)$ is continuous (and it is impossible to use the method whenever $g(t)$ is discontinuous). On the other hand, one can solve the equation with the help of Laplace transform only when the initial conditions are given (and it is not possible to use the method when boundary conditions are given). In the next part, we show the examples of solving the differential equation in various cases.

Problem solution

Problem 1: Solve the differential equation $y'' + 4\mathrm{y} = \mathrm{t}^2 + 1,$ with boundary conditions $y(0) = 1,\ y'\left(\frac{\pi}{2}\right) = 0.$

Solution: The equation is an inhomogeneous linear differential equation of second order with constant coefficients. Because $0 \neq \frac{\pi}{2}$, we cannot solve the equation with the help of Laplace transform. Firstly, we solve the homogeneous differential equation $y'' + 4\mathrm{y} = 0$ to obtain the general solution (complementary function) of the homogeneous differential equation. The characteristic equation is $\lambda^2 + 4 = 0,$ so $\lambda_1 = 2i, \lambda_2 = -2i.$ It follows that the two linearly independent solutions of the homogeneous differential equation are $y_1 = \cos 2t$ and $\mathrm{y}_2 = \sin 2t$ and so complementary function is of the form $y_c = c_1 y_1 + c_2 y_2 = c_1 \cos 2t + c_2 \sin 2t.$

The right-hand side of the original equation has a special form $g(t) = t^2 + 1$, so we can use the method of undetermined coefficients. Because the function $g(t)$ is a polynomial of degree two and zero is not a root of the characteristic equation, the particular solution of the inhomogeneous equation will be of the form $y_p = at^2 + bt + c$ with undetermined coefficients $a, b, c.$ Substituting $y_p = at^2 + bt + c$ and $y_p'' = 2a$ into the original equation we obtain $a = \frac{1}{4}, b = 0, c = \frac{1}{8}.$ The general solution of the inhomogeneous equation is the sum of the complementary function and the particular solution. So

$$y_g = y_c + y_p = c_1 \cos 2t + c_2 \sin 2t + \frac{1}{4}t^2 + \frac{1}{8},$$

where c_1 and c_2 are arbitrary real numbers. To obtain the coefficients c_1 and c_2 (for given boundary conditions) we have to derivate the function y_g:

$$y_g' = -2c_1 \sin 2t + 2c_2 \cos 2t + \frac{1}{2}t.$$

Substituting $y(0)=1$ and $y'\left(\frac{\pi}{2}\right)=0$ onto $y_g(t)$ and $y'_g(t)$, we get $c_1=\frac{7}{8}$, $c_2=\frac{\pi}{8}$ and the solution of the equation with boundary conditions on $\left\langle 0;\frac{\pi}{2}\right\rangle$ is the function $y(t)=\frac{7}{8}\cos 2t+\frac{\pi}{8}\sin 2t+\frac{1}{4}t^2+\frac{1}{8}$.

Problem 2: Solve the differential equation $y''-3y'+2y=g(t)$, where the function $g(t)$ is given by: $g(t)\begin{cases}0, \text{ for } t\in(-\infty;0)\bigcup(1;\infty)\\ 1, \text{ for } t\in\langle 0;1\rangle\end{cases}$, with the initial conditions $y(0)=0, y'(0)=1$.

Solution: Because the function is not continuous on $(0;\infty)$, we cannot use the method of variations of constants. Instead, we have to solve the equation with Laplace transform. For the originals y'', y', y and $g(t)$ we obtain the following images: $\mathcal{L}[y(t)]=Y(p)$, $\mathcal{L}[y'(t)]=p\mathcal{L}[y(t)]-y(0)=pY(p)$, $\mathcal{L}[y'']=p^2\mathcal{L}[y(t)]-py(0)-y'(0)=p^2Y(p)-1$ and $\mathcal{L}[g(t)]=\int_0^\infty g(t)e^{-pt}dt=\int_0^1 1\cdot e^{-pt}dt+\int^\infty 0\cdot e^{-pt}dt=\int_0^1 e^{-pt}dt=-\frac{1}{p}\left[e^{-pt}\right]_0^1=\frac{1}{p}\left(1-e^{-p}\right)$.

Substituting onto the differential equation we get $\left(p^2Y(p)-1\right)-3pY(p)+2Y(p)=\frac{1}{p}\left(1-e^{-p}\right)$,

from which we obtain the image of the solution $Y(p)=\frac{p+1}{p(p-1)(p-2)}-\frac{e^{-p}}{p(p-1)(p-2)}$.

After partial fraction decomposition, we will have $Y(p)=\frac{1}{2}\cdot\frac{1}{p}-2\cdot\frac{1}{p-1}+\frac{3}{2}\cdot\frac{1}{p-2}-\frac{1}{2}\cdot\frac{e^{-p}}{p}+\frac{e^{-p}}{p-1}-\frac{1}{2}\cdot\frac{e^{-p}}{p-2}$. The solution of the differential equation $y(t)$ is the original of $Y(p)$. So, for $y(t)$ we have $y(t)=\mathcal{L}^{-1}[Y(p)]=\frac{1}{2}-2e^t+\frac{3}{2}e^{2t}-\frac{1}{2}\eta(t-1)+e^{t-1}\eta(t-1)-\frac{1}{2}e^{2(t-1)}\eta(t-1)$ or equivalently

$$y(t)=\begin{cases}\frac{1}{2}-2e^t+\frac{3}{2}e^{2t}, \text{ for } \mathrm{t}\in(-\infty;1)\\ \left(\frac{1}{e}-2\right)e^t+\left(\frac{3}{2}-\frac{1}{2e^2}\right)e^{2t}, \text{ for } t\in\langle 1;\infty)\end{cases}.$$

Problem 3: Solve the differential equation $y''-3\mathrm{y}'+2\mathrm{y}=\mathrm{t}^2+1$, with initial conditions $y(0)=0$, $y'(0)=0$.

Solution: The equation is an inhomogeneous linear differential equation of second order with constant coefficients. Because the right-hand side of the equation is continuous and, additionally, it is of a special type, we can solve the equation with the Laplace transform as well as by the method of undetermined coefficients.

a) Method of undetermined coefficients: We solve the homogeneous differential equation $y'' - 3y' + 2y = 0$. The characteristic equation is $\lambda^2 - 3\lambda + 2 = 0$ with the roots $\lambda_1 = 1$ and $\lambda_2 = 2$. The two linearly independent solutions of the homogeneous differential equation are $y_1 = e^t$ and $y_2 = e^{2t}$. The complementary function is $y_c = c_1 y_1 + c_2 y_2 = c_1 e^t + c_2 e^{2t}$.

The right-hand side of the original equation has a special form $g(t) = t^2 + 1$, so we can use the method of undetermined coefficients. As in the problem 1, the right-hand side of the differential equation is a polynomial of degree two and zero is not a root of the characteristic equation. So, the particular solution of the inhomogeneous equation will be again of the form $y_p = at^2 + bt + c$ with undetermined coefficients a, b, c. Substituting $y_p = at^2 + bt + c$, $y_p' = 2at + b$ and $y_p'' = 2a$ into the original equation we obtain $a = \frac{1}{2}, b = \frac{3}{2}, c = \frac{9}{4}$. The general solution is the inhomogeneous equation $y_g = y_c + y_p = c_1 e^t + c_2{}^{2t} + \frac{1}{2}t^2 + \frac{3}{2}t + \frac{9}{4}$, c_1 and c_2 in $\Re$. Substituting the initial conditions $y(0) = 0$, $y'(0) = 0$ into $y_g(t)$ and $y_g'(t) = c_1 e^t + 2c_2 e^{2t} + t + \frac{3}{2}$ we obtain the solution of the differential equation with initial conditions $y(t) = -3e^t + \frac{3}{4}e^{2t} + \frac{1}{2}t^2 + \frac{3}{2}t + \frac{9}{4}$.

b) Laplace transform: For the originals y'', y', y and $t^2 + 1$ we obtain the images: $\mathcal{L}[y(t)] = Y(p)$, $\mathcal{L}[y'(t)] = p\mathcal{L}[y(t)] - y(0) = pY(p)$, $\mathcal{L}[y''] = p^2\mathcal{L}[y(t)] - py(0) - y'(0) = p^2 Y(p)$ and $\mathcal{L}[t^2 + 1] = \frac{2}{p^3} + \frac{1}{p}$. Substituting onto the differential equation we get $p^2 Y(p) - 3pY(p) + 2Y(p) = \frac{2}{p^3} + \frac{1}{p}$. So, the image of the solution $Y(p) = \frac{p^2 + 2}{p^3(p-1)(p-2)}$. After partial fraction decomposition we get the image in the form $Y(p) = \frac{9}{4} \cdot \frac{1}{p} + \frac{3}{2} \cdot \frac{1}{p^2} + \frac{1}{p^3} - 3 \cdot \frac{1}{p-1} + \frac{3}{4} \cdot \frac{1}{p-2}$. The solution of the differential equation $y(t)$ is the original of $Y(p)$. So, for $y(t)$ we have $y(t) = \mathcal{L}^{-1}[Y(p)] = \frac{9}{4} + \frac{3}{2} \cdot \frac{t^1}{1!} + \frac{t^2}{2!} - 3e^t + \frac{3}{4}e^{2t} = -3e^t + \frac{3}{4}e^{2t} + \frac{1}{2}t^2 + \frac{3}{2}t + \frac{9}{4}$.

Results and discussions

In the previous section we have seen that the methods of solution of second order linear differential equation depend on the form of the right-hand side and on the types of conditions setting on solutions. We showed solutions in some particular cases.

Conclusion

Dynamical systems (which are one of main objects in the area of operations research**)**, can be described by differential equations of various orders. Frequently, such a differential equation is an $n-$ th order homogeneous linear differential equation with constant coefficients. Looking for a reaction of the system on input function, students of automation often have to solve such (inhomogeneous) equations. In regard to the form of the right-hand side (input function) and on the type of starting conditions they have to know both ways of solving linear differential equations with constant coefficients – the method of variation of constants and Laplace transform. In this contribution, we showed how such equation can look like and how to solve it.

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References:

[1] KLUVÁNEK, I., MIŠÍK, L., ŠVEC, M. *Matematika pre štúdium technických vied, II. diel.* Bratislava: SVTL, 1965.

[2] MORAVSKÝ, L., MORAVČÍK, J., ŠULKA, R. *Matematická analýza (2).* Bratislava: Alfa, 1992.

[3] ROVDER, J. *Vybrané state z matematiky.* Bratislava: Slovenská vysoká škola technická, 1986.

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THE FINANCIAL SECTOR AND SUSTAINABLE DEVELOPMENT

Miroslav RUSKO, Anton KORAUŠ

Abstract

Growing load and deterioration of the environment can be interpreted as a result of some external effects interventions. While the positive externalities influence the positive productional and utilizational functions of other subjects, the negative externalities influence the negative ones. Both types of external effects can act as parcial or global externalities. Linking the environmental issues to economy and finance is an important sphere. Co-implementation of both marketing and environmental audits is an important element of this sphere too.

Key words

environment, economics, management, audit

Introduction

When considering the planet Earth, the current human activities are of a global nature. Significant problems include worsening of the environmental conditions. Humanity nowadays has the most modern tools of its whole history at its disposal to influence the environment (both in the positive and negative sense). Unlimited economic growth especially in the states with developed economies, the so-called countries of the rich North, and an exponential growth of human population bring along distortion of certain systems all throughout the planet. The present human civilisation affects the air, climate, soil, water, circulation of substances, live organisms as well as the civilisation itself. Environmental problems caused by human activity are getting more and more globalized.

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Concept of a sustainable development

A recent notion of humanity development identified only with the economic growth has now been corrected so that it would lead also to fulfilment of social goals, in particular to reduction of poverty, enhancement of the quality of life, and improved opportunities for better education and health. This change of orientation requires a comprehensive approach to the development of mutual relations management between natural and human, as well as branch and structural aspects of development on all levels [6]. As a result of this changed orientation, a concept of sustainable development was created, which is further developed and internationally applied. Since 1960s the knowledge that an unlimited or uncontrolled growth, whether of human population, consumption or pollution etc., is not sustainable under the circumstances of real, existing and limited resources is becoming more wide-spread [5].

It is therefore necessary to replace the model of industrial civilisation by a more sustainable and just concept. Sustainable development concept is nowadays considered a possible solution to adverse consequences of global trends in the society development and their negative impact on the environment. The emphasis is put on the need to base this concept on healthy ecosystems, strong economy and well-functioning social issues [4].

In its draft Sustainable Development (SD) Principles, the EU has declared that SD is the key factor of all EC policies stipulated by the Treaty. This document determines the crucial objectives such as environmental protection, social equity and cohesion, economic prosperity and meeting the international responsibilities. In fulfilling these objectives, the EU is guided by the following political principles: promotion and protection of fundamental human rights, solidarity within and between generations, open and democratic society, involvement of citizens, involvement of social and business partners, policy coherence and governance, policy integration, use of best available knowledge, precautionary principle, “polluter pays” principle [1].

Nowadays, there are still many areas in Slovakia contaminated by the past and current industrial activities, which cause serious negative impact not only on the human health and life, but lead to the constantly worsening quality and conditions of the environment. The most important principles in case of negative impact of anthropogenic activities on the environment is giving preference to preventive measures rather than to corrective ones, and application of the “polluter pays” principle [2].

Prevention or remedying of environmental damage should be implemented via “polluter pays” principle in accordance with the sustainable development principles [3].

Quality Management System

The adoption of Quality Management System (QMS) has to be a strategic decision of an organisation. The proposal and introduction of the Quality Management System in an organisation is influenced by various needs, specific objectives, delivered products, used processes, as well as the size and structure of the organisation. The aim of the standard is not to introduce a unitary structure of quality management systems or a single documentation. The requirements put on a quality management system specified in this international standard meet the requirements put on products. The international standard may be used by internal and external parties, including certification bodies, in order to assess the ability of an organisation to comply with requirements of a customer, as well as the regulations and requirements of the organisation.

An important milestone in the development of quality management systems was the issuance of ISO standards of 9000 series in 1987 by the International Organisation for Standardisation, the Technical Committee TC/176 Quality Management and Quality Assurance. ISO standards of 9000 series were the beginning of the path towards the top quality and were an effective tool of enhancing work within a company via the quality management system. The first extensive revision of these standards was carried out in 1994, and then the norms were again substantially reviewed in 2000.

STN EN ISO 9001 (01 0320) is identical with the norm *EN ISO 9001: 2000 Quality Management System. Requirements.* This standard replaces STN EN ISO 9001 of December 1996 (01 0321), STN EN ISO 9002 of March 1997 (01 0322) and STN EN ISO 9003 of January 1997 (01 0323) in their full scope. The text of the international norm ISO 9001: 2000 was prepared by the Technical Committee ISO/TC 176 "Quality Management and Quality Assurance", Subcommittee 1 "Concepts and terminology", in cooperation with the CEN Management Centre.

The standard applies in particular to the organisations which would like to mark their products as CE, and therefore they have to comply with the new approach to the European directives, and to other parties involved in the process. Publication of EN ISO 9001: 2000 concerns Council Decision 93/465/EEC of 22 July 1993 concerning the modules for the various phases of the conformity assessment procedures and the rules for the affixing and use of the CE conformity marking, which are intended to be used in the technical harmonisation directives.

Standard STN EN ISO 9001 is harmonised with ISO 14001 so that compatibility of the two standards is beneficial for the user public.

Environmental Management System

The environmental policy focuses, besides the application of legislative approach, also on the implementation of voluntary tools which support economic growth of the company, its competitiveness, profitability, including new vacancies, and helps reduce negative impacts of human activity on the environment.

The principles and key requirements of the environmental management are common within the application of:

- Standard STN EN ISO 14001 – Environmental Management System,
- Eco-management and Audit Scheme - EMAS.

The documents are based on a common principle – to initiate an active attitude of companies towards the improvement of their relation to the environmental protection, and differ in the fact that one document requires certain system components, while the other only recommends them. Both technical regulations include a management system.

Normative documents for the establishment of the Environment Management System are the set of ISO standards of 14000 series, within which the decisive is the standard *STN EN ISO 14001: 2004 Environmental Management System. Specification with instructions for use.* STN ISO 14004 standard specifies the way to fulfil STN EN ISO 14001: 2004 standards.

EMAS (Eco-Management and Audit Scheme) is based on an environmental management system pursuant to ISO 14001 standard. On the other hand, however, it enhances the environmental management to a higher level, because a company wishing to register within the scheme has to inform about its environmental conduct in an open, clear and truthful manner.

EC Regulation 1836/1993 (EMAS I) allowing voluntary participation by industrial companies in the industrial sector in a Community eco-management and audit scheme adopted on 29 June 1993 by the EC Council of Ministers came into force on 13 July 1993 and became effective for individual EU Member States as of 13 April 1995.

EU Regulation 761/2001 of 19 March 2001 allowing voluntary participation of organisations in a Community eco-management and audit scheme (EMAS II) later amended EC Regulation 1836/1993 (EMAS I).

Sustainable development and financial institutions

The interconnection of economics with environmental issues is of great significance. Banks, insurance companies and other financial institutions financially saturate production projects in compliance with environmental requirements. This highlights the significance of auditing marketing and environmental aspects in close connection.

When carried in frame of marketing audit, the environmental audit helps to judge whether the project of potential loan applicant meets the criteria of environmental protection in compliance with legal regulations and standards. Environmental audit can reveal insufficient compliance with environmental duties imposed on companies within their individual operative units of production. Subsequently it can help to prevent or even eliminate emergency states and eventually increase the probability that the loan applicant will be able to pay off the loan.

The goal of environmental audit is to judge complexly the existent state of business operation and the impact of used technologies on individual components of environment (air, water, soil, environmental protection, noise, vibrations, public health, etc.).

In the past, the main goal of industrial companies was the production as such, often disregarding the environmental limits. The increase in production gradually increased also the pollution of environment and food chains. The products became less expensive but their production was environment-unfriendly.

The current trend is based on harmonisation of production with environmental requirements by means of introducing modern environment-friendly technologies decreasing the pollution. This process has a beneficial effect on producing healthy food and improving public health.

Economics and protection of environment need to be in balance. Environmentally friendly production can be economical. This statement does not always have to hold true in reverse order. The prevalence of economic interest can lead to permanent and irreversible environmental changes.

Linking of environmental issues to economics and finance

The performance of environmental audit within the frame of marketing audit can reveal particular insufficiencies/inadequacies in the project of loan applicant. These inadequacies can increase the risk that the loan will not be paid off. The latter risk can be eliminated by financial institutions by introducing a clause of improvement measures whereby the loan can be provided upon elimination of environmental inadequacies. Many loan applicants object by claiming the funds provided by financial institutions insufficient. Nevertheless, the loan can be designed to include also the funds bound directly to environmental investment and thus the potential investors are directly forced to purchase environmentally friendly technologies and take part in environmental improvement.

Unless the loan applicant meets all environmental priorities, the project represents an increased risk of emergency states, incurred business interruptions, subsequent financial insolvency and inability to pay off the loan. In such cases, the risk born by the financial institution is projected into a loading applied to the interest rate.

If the applicant eliminates the defined environmental inadequacies as e.g. by purchasing environment-friendly technologies decreasing pollution of air and water and limiting the production of waste, the financial institution can decrease the interest rate amidst instalments because the applicant has begun meeting his environmental duties and the risk born by financial institution has decreased.

Conclusion

The interconnection of economics with environmental issues is of great significance. Environmental audit can reveal insufficient compliance with environmental duties imposed on companies within their individual operative units of production. Subsequently it can help to prevent or even eliminate emergency states and eventually increase the probability that the loan applicant will be able to pay off the loan.

References:

[1] Action Plan for Sustainable Development in Slovakia 2005 – 2010, adopted by Government Resolution no. 574 of 13 July 2005 [document file number 12744/2005]

[2] Directive of the European Parliament and of the Council no. 2004/35/CE on environmental liability with regard to the prevention and remedying of environmental damage

[3] Rules and procedures for the implementation of the EEA financial mechanism 2004 2009 adopted by the EEA Financial Mechanism Committee on 16 June 2004 pursuant to Article 8 of Protocol 38a to the EEA Enlargement Agreement, as amended on 7 July 2005. [3.2.3 Application of the „polluter pays“ principle']

[4] RUSKO, M. *Environmental management in practice-oriented manager*. Žilina: Strix, 2004. 190 p. ISBN 80-969257-1-7

[5] RUSKO, M. *Safety and environmental management.* Bratislava: VeV et Strix, 3rd edition, 2008. 389 p. ISBN 978-80-89281-37-4

[6] World Resources 2005 – The Wealth of the Poor: Managing ecosystems to fight poverty. 2005. UNDP. Available on Internet at: http://www.wri.org

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SINGULARLY PERTURBED LINEAR NEUMANN PROBLEM WITH THE CHARACTERISTIC ROOTS ON THE IMAGINARY AXIS

Ľudmila VACULÍKOVÁ, Vladimír LIŠKA

Abstract

We investigate the problem of existence and asymptotic behavior of solutions for the singularly perturbed linear Neumann problem

$$\varepsilon y'' + ky = f(t), \quad k > 0, \qquad 0 < \varepsilon << 1, \quad t \in \langle a, b \rangle$$
$$y'(a) = 0, \qquad y'(b) = 0.$$

Our approach relies on the analysis of integral equation equivalent to the problem above.

Key words

singularly perturbed ODE, Neumann problem, boundary condition, characteristic roots

Introduction

In this paper, we will study the singularly perturbed linear problem

$$\varepsilon y'' + ky = f(t), \quad k > 0, \qquad 0 < \varepsilon << 1, \quad f \in C^3(\langle a, b \rangle) \tag{1.1}$$

with Neumann boundary condition

$$y'(a) = 0, \qquad y'(b) = 0 \, . \tag{1.2}$$

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We can view this equation as a mathematical model of the dynamical systems with high-speed feedback. The situation considered here is complicated by the fact that a characteristic equation of this differential equation has roots on the imaginary axis i.e. the system be not hyperbolic. For hyperbolic ones the dynamics close critical manifold is well-known (see e.g. [1], [3-10]), but for the non-hyperbolic systems the problem of existence and asymptotic behaviour is open in general and leads to the substantial technical difficulties in nonlinear case [2]. The considerations below may be instructive for these ones.

We prove, that there exist infinitely many sequences $\{\varepsilon_n\}_{n=0}^{\infty}$, $\varepsilon_n \to 0^+$ such that $y_{\varepsilon_n}(t)$ converges uniformly to $u(t)$ on $\langle a,b\rangle$ where y_ε is a solution of problem (1.1), (1.2) and u is a solution of reduced problem (when we put $\varepsilon = 0$ in (1.1)) $ku = f(t)$ i.e. $u(t) = \dfrac{f(t)}{k}$.

We will consider for the parameter ε the set J_n only,

$$J_n = \left\langle k\left(\frac{b-a}{(n+1)\pi - \lambda}\right)^2, \, k\left(\frac{b-a}{n\pi + \lambda}\right)^2 \right\rangle \quad n = 0,1,2,\ldots,$$

where $\lambda > 0$ be arbitrarily small but fixed constant which guarantees the existence and uniqueness of the solutions of (1.1), (1.2).

Example. Consider the linear problem

$$\varepsilon y'' + ky = e^t, \quad k > 0, \qquad 0 < \varepsilon << 1, \quad t \in \langle a,b\rangle$$

$$y'(a) = 0, \qquad y'(b) = 0.$$

and its solution

$$y_\varepsilon(t) = \frac{-e^a \cos\left[\sqrt{\frac{k}{\varepsilon}}(b-t)\right] + e^b \cos\left[\sqrt{\frac{k}{\varepsilon}}(t-a)\right]}{\sqrt{\frac{k}{\varepsilon}}(k+\varepsilon)\sin\left[\sqrt{\frac{k}{\varepsilon}}(b-a)\right]} + \frac{e^t}{k+\varepsilon}.$$

Hence, for every sequence $\{\varepsilon_n\}_{n=0}^{\infty}, \varepsilon_n \in J_n$ the solution of considered problem

$$y_{\varepsilon_n}(t) = \frac{e^t}{k+\varepsilon_n} + O\left(\sqrt{\varepsilon_n}\right)$$

converges uniformly for $n \to \infty$ to the solution $u(t) = \dfrac{e^t}{k}$ of the reduced problem on $\langle a,b\rangle$.

The main result of this article is the following one.

Main result

Theorem. *For all* $f \in C^3(\langle a,b\rangle)$ *and for every sequence* $\{\varepsilon_n\}_{n=0}^{\infty}, \varepsilon_n \in J_n$ *there exists a unique solution* y_ε *of problem (1.1) , (1.2) satisfying*

$$y_{\varepsilon_n} \to u \ \textit{uniformly} \quad \textit{on} \quad \langle a,b\rangle \qquad \textit{for} \ n \to \infty$$

More precisely,

$$y_{\varepsilon_n}(t)=u(t)+O\left(\sqrt{\varepsilon_n}\right) \quad on \ \langle a,b\rangle .$$

Proof. Firstly, we show that

$$y_\varepsilon(t)=\frac{\cos\left[\sqrt{\frac{k}{\varepsilon}}(t-a)\right]\int_a^b\cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s)\right]\frac{f(s)}{\varepsilon}ds}{\sqrt{\frac{k}{\varepsilon}}\sin\left[\sqrt{\frac{k}{\varepsilon}}(b-a)\right]}+\int_a^t\frac{\sin\left[\sqrt{\frac{k}{\varepsilon}}(t-s)\right]\frac{f(s)}{\varepsilon}}{\sqrt{\frac{k}{\varepsilon}}}ds \tag{2.1}$$

is a solution of (1.1) , (1.2). Differentiating (2.1) twice, taking into consideration that

$$\frac{d}{dt}\int_a^t H(t,s)f(s)ds=\int_a^t\frac{\partial H(t,s)}{\partial t}f(s)ds \ + \ H(t,t)f(t)$$

we obtain

$$y_\varepsilon'(t)=-\frac{\sqrt{\frac{k}{\varepsilon}}\sin\left[\sqrt{\frac{k}{\varepsilon}}(t-a)\right]\int_a^b\cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s)\right]\frac{f(s)}{\varepsilon}ds}{\sqrt{\frac{k}{\varepsilon}}\sin\left[\sqrt{\frac{k}{\varepsilon}}(b-a)\right]}+\int_a^t\frac{\sqrt{\frac{k}{\varepsilon}}\cos\left[\sqrt{\frac{k}{\varepsilon}}(t-s)\right]\frac{f(s)}{\varepsilon}}{\sqrt{\frac{k}{\varepsilon}}}ds \tag{2.2}$$

$$y_\varepsilon''(t)=-\frac{\left(\sqrt{\frac{k}{\varepsilon}}\right)^2\cos\left[\sqrt{\frac{k}{\varepsilon}}(t-a)\right]\int_a^b\cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s)\right]\frac{f(s)}{\varepsilon}ds}{\sqrt{\frac{k}{\varepsilon}}\sin\left[\sqrt{\frac{k}{\varepsilon}}(b-a)\right]}-$$

$$-\int_a^t\frac{\left(\sqrt{\frac{k}{\varepsilon}}\right)^2\sin\left[\sqrt{\frac{k}{\varepsilon}}(t-s)\right]\frac{f(s)}{\varepsilon}}{\sqrt{\frac{k}{\varepsilon}}}ds+\frac{f(t)}{\varepsilon} \quad . \tag{2.3}$$

From (2.3) and (2.1) after a little algebraic arrangement, we get

$$y_\varepsilon''=\frac{k}{\varepsilon}(-y_\varepsilon)+\frac{f(t)}{\varepsilon}$$

i.e. y_ε is a solution of differential equation (1.1), and from (2.2) it is easy to verify that this solution satisfies (1.2).

Let $t_0\in\langle a,b\rangle$ be arbitrary, but fixed. Denote by I_1 and I_2 the integrals

$$I_1 = \int_a^b \cos\left[\sqrt{\frac{k}{\varepsilon}}\,(b-s)\right]\frac{f(s)}{\varepsilon}\,ds$$

$$I_2 = \int_a^{t_0} \sin\left[\sqrt{\frac{k}{\varepsilon}}\,(t_0-s)\right]\frac{f(s)}{\varepsilon}\,ds$$

Then

$$y_\varepsilon(t_0) = \frac{\cos\left[\sqrt{\frac{k}{\varepsilon}}\,(t_0-a)\right]I_1}{\sqrt{\frac{k}{\varepsilon}}\,\sin\left[\sqrt{\frac{k}{\varepsilon}}\,(b-a)\right]} + \frac{I_2}{\sqrt{\frac{k}{\varepsilon}}}\ .$$

Integrating I_1 and I_2 by parts, we obtain

$$I_1 = \left|\begin{matrix} h' = \cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s)\right] & g = \frac{f(s)}{\varepsilon} \\ h = -\sqrt{\frac{\varepsilon}{k}}\sin\left[\sqrt{\frac{k}{\varepsilon}}(b-s)\right] & g' = \frac{f'(s)}{\varepsilon} \end{matrix}\right| =$$

$$= \sqrt{\frac{\varepsilon}{k}}\sin\left[\sqrt{\frac{k}{\varepsilon}}\,(b-a)\right]\frac{f(a)}{\varepsilon} + \int_a^b \sqrt{\frac{\varepsilon}{k}}\,\sin\left[\sqrt{\frac{k}{\varepsilon}}\,(b-s)\right]\frac{f'(s)}{\varepsilon}\,ds$$

$$I_2 = \left|\begin{matrix} h' = \sin\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s)\right] & g = \frac{f(s)}{\varepsilon} \\ h = \sqrt{\frac{\varepsilon}{k}}\cos\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s)\right] & g' = \frac{f'(s)}{\varepsilon} \end{matrix}\right| =$$

$$= \frac{\sqrt{\frac{\varepsilon}{k}}\;f(t_0)}{\varepsilon} - \sqrt{\frac{\varepsilon}{k}}\cos\left[\sqrt{\frac{k}{\varepsilon}}\,(t_0-a)\right]\frac{f(a)}{\varepsilon} - \int_a^{t_0}\sqrt{\frac{\varepsilon}{k}}\,\cos\left[\sqrt{\frac{k}{\varepsilon}}\,(t_0-s)\right]\frac{f'(s)}{\varepsilon}\,ds\ .$$

Also

$$y_\varepsilon(t_0) = \frac{f(t_0)}{k} + \frac{\cos\left[\sqrt{\frac{k}{\varepsilon}}\,(t_0-a)\right]}{\sin\left[\sqrt{\frac{k}{\varepsilon}}\,(b-a)\right]}\int_a^b \sin\left[\sqrt{\frac{k}{\varepsilon}}\,(b-s)\right]\frac{f'(s)}{k}\,ds - \int_a^{t_0}\cos\left[\sqrt{\frac{k}{\varepsilon}}\,(t_0-s)\right]\frac{f'(s)}{k}\,ds.$$

Now we estimate $y_\varepsilon(t_0) - \dfrac{f(t_0)}{k}$. We obtain

$$\left| y_\varepsilon(t_0) - \frac{f(t_0)}{k} \right| \le \frac{1}{k\sin\lambda} \left| \int_a^b \sin\left[\sqrt{\frac{k}{\varepsilon}}(b-s) \right] f'(s)ds \right| + \frac{1}{k} \left| \int_a^{t_0} \cos\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s) \right] f'(s)ds \right| . \qquad (2.4)$$

The integrals in (2.4) converge to zero for $\varepsilon = \varepsilon_n, \varepsilon_n \in J_n, n \to \infty$.

Indeed, with respect to assumption on f, we may integrate by parts in (2.4). Thus,

$$\int_a^b \sin\left[\sqrt{\frac{k}{\varepsilon}}(b-s) \right] f'(s)ds = \left[\sqrt{\frac{\varepsilon}{k}} \cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s) \right] f'(s) \right]_a^b - \int_a^b \sqrt{\frac{\varepsilon}{k}} \cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s) \right] f''(s)ds \le$$

$$\le \sqrt{\frac{\varepsilon}{k}} \left(|f'(a)| + |f'(b)| + \left| \int_a^b \cos\left[\sqrt{\frac{k}{\varepsilon}}(b-s) \right] f''(s)ds \right| \right) \le$$

$$\le \sqrt{\frac{\varepsilon}{k}} \left\{ |f'(a)| + |f'(b)| + \sqrt{\frac{\varepsilon}{k}} \left(|f''(a)| + \mu_2(b-a) \right) \right\} \qquad (2.5)$$

and

$$\int_a^{t_0} \cos\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s) \right] f'(s)ds = \left[-\sqrt{\frac{\varepsilon}{k}} \sin\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s) \right] f'(s) \right]_a^{t_0} + \int_a^{t_0} \sqrt{\frac{\varepsilon}{k}} \sin\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s) \right] f''(s)ds \le$$

$$\le \sqrt{\frac{\varepsilon}{k}} \left(|f'(a)| + \left| \int_a^{t_0} \sin\left[\sqrt{\frac{k}{\varepsilon}}(t_0-s) \right] f''(s)ds \right| \right) \le$$

$$\le \sqrt{\frac{\varepsilon}{k}} \left\{ |f'(a)| + \sqrt{\frac{\varepsilon}{k}} \left(\mu_1 + |f''(a)| + \mu_2(b-a) \right) \right\}, \qquad (2.6)$$

where $\mu_1 = \sup_{t\in\langle a,b\rangle} |f''(t)|$ *and* $\mu_2 = \sup_{t\in\langle a,b\rangle} |f'''(t)|$.

Substituting (2.5) and (2.6) into (2.4), we obtain an a priori estimate of solutions of (1.1), (1.2) for all $t_0 \in \langle a,b \rangle$ of the form

$$\left| y_\varepsilon(t_0) - \frac{f(t_0)}{k} \right| \le \frac{1}{k\sin\lambda} \sqrt{\frac{\varepsilon}{k}} \left\{ |f'(a)| + |f'(b)| + \sqrt{\frac{\varepsilon}{k}} \left(|f''(a)| + \mu_2(b-a) \right) \right\} +$$

$$+ \frac{1}{k} \sqrt{\frac{\varepsilon}{k}} \left\{ |f'(a)| + \sqrt{\frac{\varepsilon}{k}} \left(\mu_1 + |f''(a)| + \mu_2(b-a) \right) \right\} \qquad (2.7)$$

Because the right side of the inequality (2.7) is independent on t_0 the convergence is uniformly on $\langle a,b \rangle$. Theorem holds.

Remark. As remark we conclude that in the case $|f'(a)| = |f'(b)| = 0$, the convergence rate is $O(\varepsilon_n), \varepsilon_n \in J_n$, as follows from (2.7).

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Conclusion

In our contribution, we determined a convergence rate of the solutions of a certain class of the singularly perturbed differential equations subject to Neumann boundary conditions to the solution of a reduced problem as a small parameter ε at highest derivative tends to zero.

References:

[1] Christopher K.R.T. JONES. *Geometric Singular Perturbation Theory,* C.I.M.E. Lectures, Montecatini Terme, June 1994, Lecture Notes in Mathematics 1609, Springer-Verlag, Heidelberg, 1995.

[2] VRÁBEĽ, R. Singularly perturbed semilinear Neumann problem with non-normally hyperbolic critical manifold. In *E.J.Qualitative Theory of Diff. Equations*, 2010, No. 9, pp. 1-11.

[3] VRÁBEĽ, R. Upper and lower solutions for singularly perturbed semilinear Neumann's problem. In *Mathematica Bohemica*, 122, 1997, No.2, pp.175-180.

[4] VRÁBEĽ, R. Three point boundary value problem for singularly perturbed semilinear differential equations. In *E.J.Qualitative Theory of Diff. Equations*, 2009, No.70, pp. 1-4.

[5] VRÁBEĽ, R. On the solutions of differential equation $\varepsilon^2\left(a^2(t)y'\right)' + p(t)f(y) = 0$ with arbitrarily large zero number. In *Journal of Computational Analysis and Applications*, 2004, Vol. 6, No. 2, pp. 139-146.

[6] VRÁBEĽ, R. Singularly pertubed anharmonic quartic potential oscillator problem. In *Zeitschrift für angewandte Mathematik und Physik ZAMP*, 2004, Vol. 55, pp. 720-724.

[7] VRÁBEĽ, R. Semilinear singular perturbation. In *Nonlinear Analysis,* TMA, 1995, Vol. 25, No. 1, pp. 17-26.

[8] VRÁBEĽ, R. Quasilinear and quadratic singularly perturbed periodic boundary value problem. In *Archivum Mathematicum*, 2000, Vol. 36, No.1, pp. 1-7.

[9] VRÁBEĽ, R. Quasilinear and quadratic singularly perturbed Neumann`s problem. In *Mathematica Bohemica*, 1998, Vol. 123, No. 4, pp. 405-410.

[10] VRÁBEĽ, R. Upper and lower solutions for singularly perturbed semilinear neumann`s problem. In *Mathematica Bohemica*, 1997, Vol. 122, No 2, pp. 175-180.

[11] VRÁBEĽ, R. Asymptotic behavior of T-periodic solutions of singularly perturbed second-order differential equations. In *Mathematica Bohemica*, 1996, Vol. 121, No. 1, pp. 73-76.

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