Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 1, rok 2006, ročník LII, řada strojní
článek č. 1504

Sergej HLOCH*, Michal HATALA, Robert ČEP*****

INFLUENCE AND EVALUATION OF SELECTED FACTORS TO ACCOUSTIC SOUND PRESSURE AT ABRASIVE WATERJET CUTTING TECHNOLOGY

VPLYV A HODNOTENIE VYBRANÝCH FAKTOROV NA HLADINU AKUSTICKÉHO TLAKU V TECHNOLÓGII DELENIA VYSOKORÝCHLOSTNÝM HYDROABRAZÍVNYM PRÚDOM

Abstract

The paper deals with experiments, research and evaluation of the influence of pressure and traverse rate to acoustic sound pressure level at abrasive waterjet machining. Significance of selected abrasive waterjet factors – independent variables (traverse rate, pressure) that influence the acoustic sound pressure level were evaluated by analysis of variance. Further, the manufacturing system with abrasive waterjet machining and the cutting process was evaluated. The regression equation obtained from analyses of variance gives the level of acoustic sound pressure significance as a function of the treatment factors. Different factor significance has been found, that were generated under defined conditions by abrasive waterjet. Results show the abrasive waterjet machining factors significance and their effect to noise environment. It has been found that significant in that case is traverse rate in the experiment.

Abstrakt

Článok sa zaoberá vplyvom a hodnotením vybraných faktorov, tlaku a rýchlosti posuvu vysokorýchlostného hydroabrazívneho prúdu na hladinu akustického tlaku. Výzmanosť hodnotených faktorov bola hodnotená pomocou analýzy variácií. Pomocou regresnej diagnostiky bol zostavený nelineárny model, kde je hladina akustického tlaku a funkcia vyšetrovaných významných faktorov. V tomto experimente sa zistilo, že najväčší vplyv má rýchlosť posuvu. Avšak so postupným zvyšovaním rýchlosti posuvu namerané hodnoty hladiny akustického tlaku boli nižšie. Z hľadiska bezpečnosti práce boli prekročené limitné hodnoty hladiny akustického tlaku.

1 INTRODUCTION

Competition and scientific progress requires introduction of technologies that perform challenging claims of modern production in automation field, from economy, environmental and energy efficiency point of view. Abrasive waterjet cutting represents all of these claims. The abrasive waterjet cutting technique is considered to be a flexible tool in the processing of a wide range of materials without time loss by tool changing and with minimal risk to occupational health and environment [1], [7]. Nowadays represents cold, precise, computer controlled shape cutting without any strain. Abrasive waterjet machining (AWJM) is for to-date high requirements on quality and productivity applied in full-automized workplaces with automatic CNC control. Flexible and smart automatized technique application does not exclude the human being from the manufacturing process; just move his working activities from strenuous jobs and jobs in malign environment to the areas of control, maintenance and operation management.

* Hloch Sergej, Ing., PhD. Department of Technology Systems Operation, Faculty of Manufacturing Technologies with the seat in Prešov, Technical University of Košice, Bayerova 1, Prešov, tel. (+421 51 77 23 504), e-mail: hloch.sergej@fvt.sk.

** Hatala Michal, Ing., PhD. Department of Manufacturing Technologies, Faculty of Manufacturing Technologies with the seat in Prešov, Technical University of Košice, Bayerova 1, Prešov, tel. (+421 51 77 23 504), e-mail: hatala.michal@fvt.sk.

*** Čep Robert, Ing., PhD. Department of Machining and Assembly, Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, 17. listopadu 15, 708 33, tel. +420 59 732 3193, email: robert.cep@vsb.cz.

2 RELATED AND PREVIOUS WORKS

The AWJ velocity reaches up to 900 m.s^{-1} and disposes of very high kinetic energy so it is the source of the majority of risks. At AWJ focusing tube outlet, where the elasticity interface is, jet interferes with the outer environment molecules. This induces the elements oscillation and results from the energy change that forms the acoustic field. This is manifested by noise, predominantly of high frequency, which has a negative impact on central nervous system of the CNC motion operator. AWJM technology is one of the significant noise sources in the workplace, what results from risk analysis [1] at AWJM by Failure Modes and Effects Assessment. The results of the Failure Modes and Effects Assessment show that the abrasive waterjet machining system poses the excess noise exposition, to which the workers and operators are exposed. To reduce this negative phenomenon and enhance operators' safety it is necessary to recognize the most potential noise sources in water jet machining system. The paper deals with experimental assignment of acoustic parameters that are compared with maximum allowed parameters. Noise environment of manufacturing system with AWJM and the cutting process was evaluated. Results show the abrasive waterjet machining factors significance and their effect to noise environment. Abrasive waterjet manufacturing system consists of systems, by which the initial tool is created. Technological cutting process by hydroabrazive erosion is performed by means of cutting tool – abrasive waterjet – properties of which are not reduced due to the operation unlike it is at the conventional cutting knife. The noise sources and hence potential threats for of occupational safety and health (fig. 1) are as follows: WJM system background noise, outlet of focusing tube, cutting process, outlet of residual flow from workpiece, and residual abrasive waterjet flow contact with water surface in catcher tank.

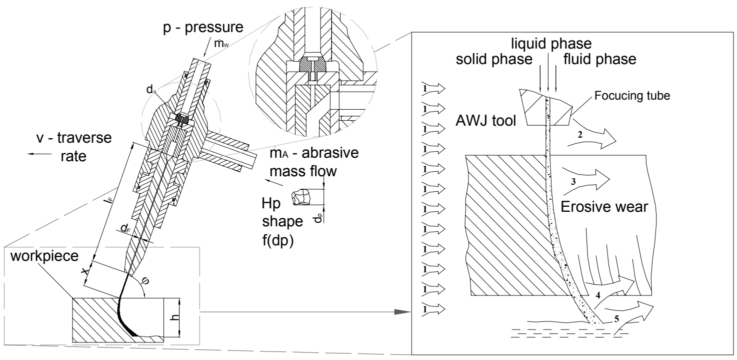

Fig. 1 Noise emissions sources at technological node in WJM

3 EXPERIMENTAL SET UP

A two dimensional abrasive waterjet machine Wating, was used in this work with following specification: work table x-axis 2000 mm, y-axis 3000 mm, z-axis discrete motion, with maximum traverse rate 250 mm.s^{-1}. The high-pressure intensifier pump was used the Ingersoll-Rand Streamline model with maximum pressure 380 MPa. As a cutting an Autoline cutting head from Ingersoll-Rand head has been used. The mechanical properties and chemical composition of the workpiece with austenitic composition is shown in table 2. The properties of each sample are: length 35 mm, width 8 mm, and height 10 mm. Abrasive machining conditions used in this study are listed in the table 1.

3.1 Measurement procedure

For acoustic sound pressure level measurement the modular sound analyzer Investigator^{TM} 2260 (Brüel & Kjær) has been applied, which allows sound analysis with adjustable – dynamic scale in 80 dB range. The noise sample can be detected in full range from 70 to 130 dB in 10-step interval. Measurements were manually controlled in the period 60 s from the AWJM hit the target material. Experimental measurement consisted of:

- ❑ Background and environment noise measurement,

- ❑ Measurement of the background noise with the pressure equipment switched on,
- ❑ Noise measurement at the technological process following the experimental schemes.

Tab. 1 Set up of experiments

Constant factors	**Values**	**Variable factors**	**Values**
Standoff	2 mm	Pressure p [MPa] 310,320,330,340,350	
Abrasive material Barton Garnet Mesh 80		Traverse rate v [mm.s^{-1}] 50, 65, 80, 95, 110, 125, 140	
Cutting head Autoline^{TM}		Traverse direction	± 180°
Impact angle φ	90°	**Target material:**	AISI 304
Abrasive mass flow rate [g.min^{-1}]	400	C 0,08; Mn 2,0; P 0,045; S 0,045; S 0,03; Si 1,0; Cr 18; Ni 8	
J/T abbreviation	0.14/1.2		
Material thickness h [mm]	20		
1.1.1.1.1.1.1.1 System characteristics of Streamline Pump			
Intensifier type	Double effect	Water pressure (max)	380 MPa
Intensifier power	50 kW	Intensification ratio	20:1
Oil pressure (max)	20 MPa	Accumulator volume	2 l

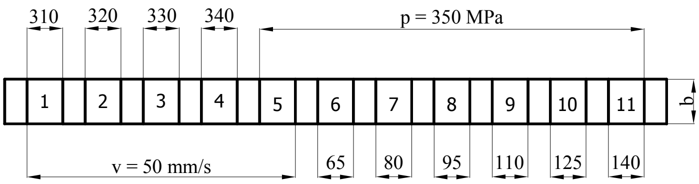

Fig. 2 Experimental methodology graphic illustration

Fig. 3 Noise measurement

4 STATISTICAL EVALUATION AND REGRESSION DIAGNOSTICS

The quantitative description of the conditions effects on acoustic sound pressure level was performed. Response surface methodology is an empirical modelling technique used to evaluate the relationship between a set of controllable experimental factors and observed results. The results were analyzed using the analysis of variance as appropriate to the experimental design used. The following equation (1) shows the correlation matrix of design variables.

$$\mathbf{b} = [\mathbf{X}^T.\mathbf{X}]^{-1}.\mathbf{X}^T.\mathbf{Y} = \begin{bmatrix} 1.53656071532049 \\ 0.04242624681290 \\ 0.13545691636382 \end{bmatrix} \quad (1)$$

The regression coefficients and equations obtained after analysis of variance gives the level of significance of variable parameters tested according Student's t-test. Obtained regression coefficients that show no statistical significance the critical value for $t_{1-\frac{\alpha}{2}}(f) = t_{0.975}$ (f = 8) = 2,306 have been rejected from the further evaluation. Testing of model adequacy has been done by Fisher-Snedecor; F-test, where testing criterion F = 4,2893 and critical value is $F_{1-\alpha(f1,f2)} = F_{0.95}(f_1=10,f_2=8) = 3,347$. Since $F > F_{1-\alpha}(f_1,f_2)$, H_0 hypothesis can be rejected, hence regression function describes variability of measured values, regression equation is designed adequately. Figure 4 shows those residual values do not show heteroskedasticity – during the measurement of dependent variable, acoustic sound pressure level variance of L_{Aeq} values has not been observed. Figure 5 shows the normal probability plot of residual values. Computed value of obtained reliability for Shapiro-Wilkson test of normality p = 0.57048 and value of W criteria W = 0,944153. According to inequality $W_\alpha \geq W$ since W_α (N=11) = 0.88700 the H_0 hypothesis for residual values normality can be accepted.

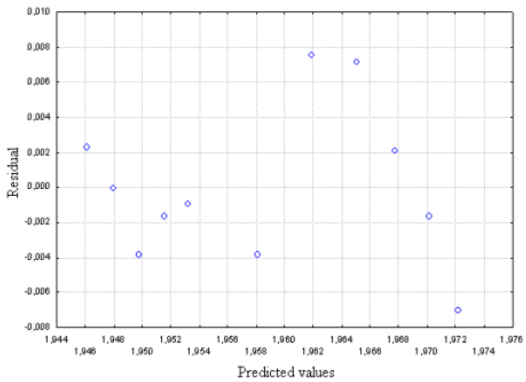

Fig. 4 Predicted vs. residual value

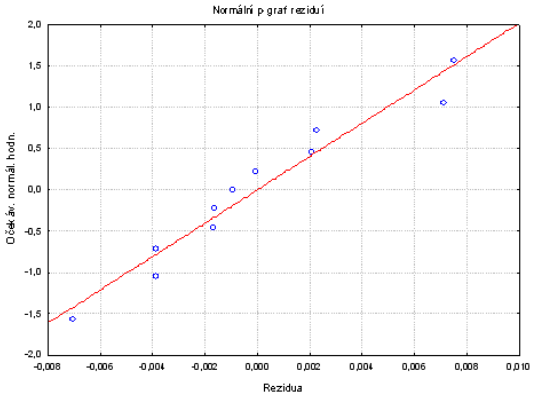

Fig. 5 Normal probability plot

The regression equation obtained from analysis of variance gives the level of acoustic sound pressure level as a function of independent variables: pressure, traverse speed at the cutting of 20 mm thick stainless steel. All terms regarding their significance are included in the following inverse logarithmic nonlinear polynomial equation:

$$L_{aeq} = 10^{1,53656(\pm 0,59879)} * v^{0,04243(\pm 0,02627)} \quad (2)$$

where L_{Aeq} is response, that is acoustic sound pressure level [dB]. The model has been checked by several criteria. The fit of the model has been expressed by the coefficient of determination R^2 = 0,8134 which was found to be for equation indicating that 81,34% for the model of the variability in the response can be explained by the models. The value also indicates that 18% of the total variation is not explained by the model. This shows that equation is suitable model for describing the response of the acoustic sound pressure level. The value of adjusted determination coefficient R_{adj} = 76,68% is high to advocate for a high significance of the model. A higher value of the correlation coefficient R = 90,193% justifies a good correlation among the independent variables.

This indicates good agreement between the experimental and predicted values of acoustic sound pressure level. Statistical significance of correlation coefficient $r_{L_{aeq}\cdot,x1,x2,x3,x4}$ = 90.193% has been tested by the Fisher's statistical test for analysis of variance. Statistical testing of the model has been tested by the Fisher's statistical test for analysis of variance. Generally, the calculated F-value equation (3) is greater than critical value $F_{1-\alpha}(f_1,f_2) = F_{0,95}(f_1=3,\ f_2=7) = 4.347$. The F value is the ratio of the mean square due to the real error.

$$F = \frac{r^2_{L_{aeq}\cdot,x1,x2,x3,x4}}{1-r^2_{L_{aeq}\cdot,x1,x2,x3,x4}} * \frac{N-q-1}{q} = 10{,}177 \tag{3}$$

Since $F > F_{1-\alpha}(f_1,f_2)$ H_0 hypothesis is rejected and correlation coefficient is statistically significant. These results can be further interpreted in the Pareto Chart, which graphically displays the magnitudes of the effects from the results obtained. The effects are sorted from largest to smallest.

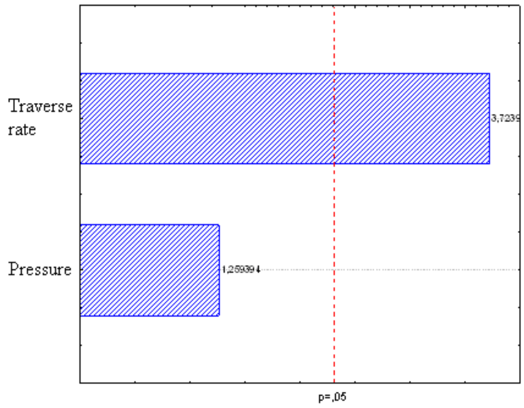

Fig. 6 Pareto chart shows that traverse rate was found to be the most sufficient factor that affects the acoustic sound pressure level at waterjet cutting in the experiment.

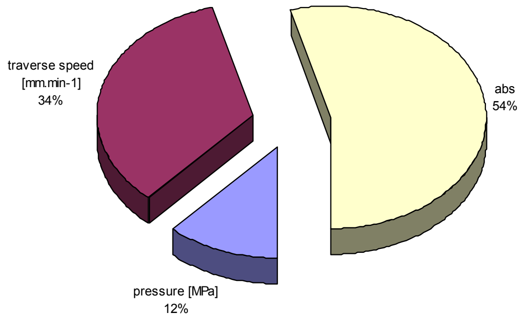

Fig. 7 Percentual expression of traverse rate and pressure significance

5 RESULTS AND DISCUSSION

From the statistical factor evaluation of the experiment is apparent, that acoustic sound pressure level is dominantly influenced by traverse speed as can be seen from Pareto chart (fig. 6) and from figure 9, which shows the percentual expression of treatment factors. The dominancy of the traverse rate is according to fig. 9 34%. The second treatment factor included in the experiment (the pressure) has no statistical significance as can be seen on figure 6 and figure 7.

The statistical significance of pressure is approximately 12%. The following figure 7 shows fitted surface of influence traverse speed and pressure to dependent variable acoustic sound pressure level. Three-dimensional surface plot showing predicted acoustic sound pressure level as a function of independent variables.

At the machining of 20 mm thick stainless steel there is a threshold traverse rate, at which the values of acoustic sound pressure level starts to decrease. The maximum values of acoustic sound pressure level were found out at the traverse rate 117 $mm.s^{-1}$. (fig. 8)

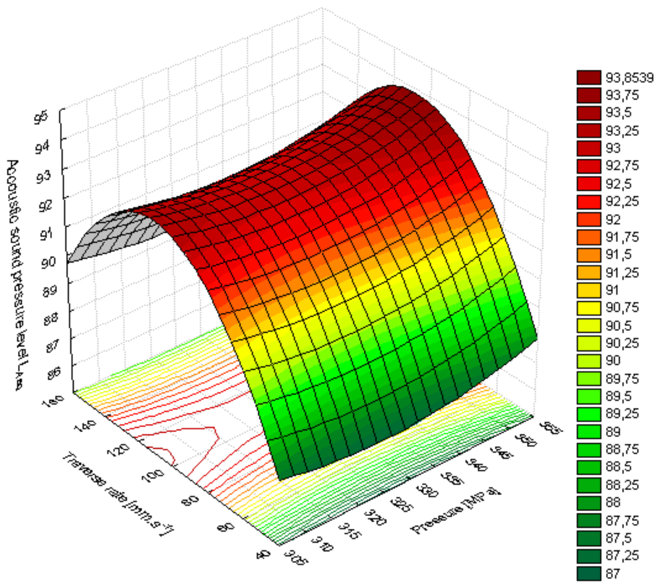

Fig. 8 3D surface plot for predicted acoustic sound pressure level

Increasing the traverse rate above the threshold traverse rate, the work piece absorbs kinetic energy of the stream, hence another sources of acoustic sound pressure level do not produce the noise. Decreasing the acoustic sound pressure level in direct proportion depends on the residual outflow from work piece, which hits the water surface in the catcher tank.

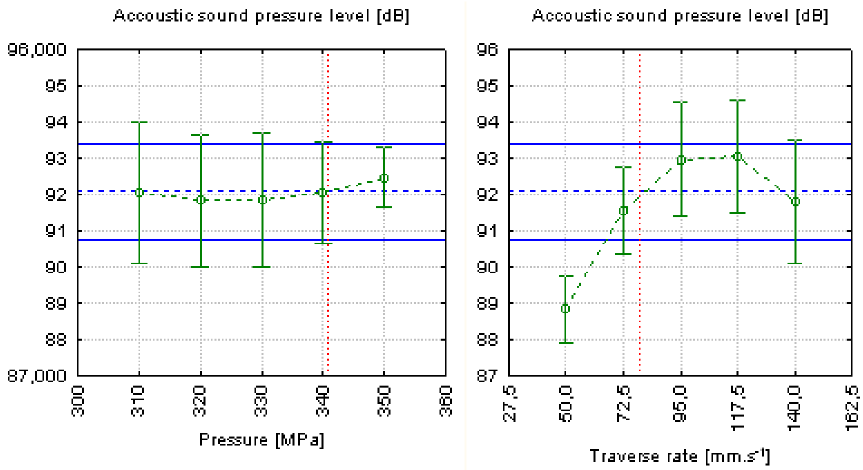

Fig. 9 Profiles for predicted values of acoustic sound pressure level

Following figure (fig. 9) shows the profiles behaviour for predicted values of acoustic sound pressure level that is influenced by examined factors - traverse rate and pressure. The predicted values of acoustic sound pressure level that is influenced by pressure are almost constant that is caused by low selection interval. It is assumed that with decreasing of pressure the values of acoustic sound pressure level will be lower.

6 CONCLUSION

At the experiments have been evaluated influence of pressure and traverse rate to acoustic sound pressure level at abrasive waterjet machining of 20 mm thick stainless austenitic steel AISI 304. Significance of the factors has been evaluated by factor experiment. It has been found that traverse rate dominating factor which influence the noisiness of environment on mutual evaluation of the pressure and traverse rate. At the experiment from the occupational safety and health point of view, the limits of acoustic sound pressure level were exceeded. For audio frequency noise the overrun was 7 dB, for high frequency noise up to 26 dB. The noise elimination at abrasive waterjet machining can be achieved by reduction of the sources of acoustic sound pressure level. New experiments additional experiments will be provided according design of experiments where full factorial design and Taguchi design will be used for evaluation and optimisation of noise environment at the abrasive waterjet cutting.

REFERENCES

[1.] Lebar, A., Junkar, M. Simulation of abrasive water jet cutting process. *Modelling Simul. Mater. Sci. Eng.* 12 (2004) 1159–1170.

[2.] Annoni, M., Monno M. A lower limit for the feed rate in AWJ precision machining. In. *BHR Group 2000 Jetting* Technology, p. 285-295, ISBN 1 86058 253 2.

[3.] Hashish, M. Machining of Hard Materials with Abrasive-Suspension Jets, *Proceedings of the 9th American Waterjet Conference*, (Dearbom, Michigan, August 23-26, 1997), pp. 267-280.

[4.] Blagodarny, V., Hloch, S., Ragan, E, Design of experiments of stainless steel abrasive waterjet macrogeometrical cutting quality. In: *Mechanical Engineering Technologies*. vol. 11, no. 4/72 (2004), p. 116-119, 1310-3946.

[5.] RADVANSKÁ, A. Hodnotenie rizík technológie delenia vysokorýchlostným hydroabrazívnym prúdom kombinovanou bodovou metódou. In: Nové trendy v prevádzke výrobnej techniky 2003. 80-8073-059-8 : Vol. 6, 2003.,

[6.] Híreš O. The study of cutting surfaces quality. In: *Funkčné povrchy 2004*: Trenčín, 27.-28. máj 2004. Trenčín: Trenčianska univerzita, 2004. ISBN 80-8075-021-1.

[7.] LEBAR, A. O razvoju obdelave z abrazivnim vodnim curkom. http://www.fs.uni-lj.si/lat/raziskaveawj/prezentacije/ AWJ_MIT2001 /W3P/img0.htm,

[8.] GOMBÁR M., Ing. Tvorba štatistického modelu drsnosti obrobeného povrchu s využitím Matlab. In *Výrobné inžinierstvo*. (s. 14-17) 2006.

[9.] Hloch S., Ragan E., Radvanská A.: Application of factorial design to study the effects of the selected abrasive waterjet factors on sound pressure level. In. Proc. *Of 4th DAAAM International Conference on Advanced Technologies for Developing Countries*, Osijek Croatia, ISBN 3-901509-49-6.

[10.] Valíček, J., Sodomka, L., Mádr, V., Lupták, M., Slivečka, L. Nondestructive testing with direct evaluation of changes in physical-mathematical properties of materials. *In. proc. Defektoskopie 2005*. Brno University of Technology. 2005 ISBN 80-214-3053-2, p. 245-250.

[11.] Valíček, J., Mádr, V., Drždík, M., Lupták, M., Slivečka, L. Method of the determination of superposition relation of changes in surface geometry to mechanical parameters of material due to corrosion. In. Acta Mechanica Slovaca. 3-A/2005. ISSN 1335-2393. p.171-176.

[12.] MONTGOMERY, D.C., *Design and Analysis of Experiments*, John Wiley & Sons, New York (1991) ISBN 0-471-52994-X.

[13.] TOUTENBURG H. *Statistical analysis of designed experiments*. Springer-Verlag New York, Inc. 2002, ISBN 0-387-98789-4.

Acknowledgement

The authors would like to acknowledge the support of Scientific Grant Agency of the Ministry of Education of Slovak Republic, Commission of mechanical engineering, metallurgy and material engineering, for their contribution to project 1/1095/04 - Optimization of abrasive waterjet cutting technology process, by mathematical and experimental planning.