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Technical Possibilities of Noise Reduction in Material Cutting by Abrasive Water-jet

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Preliminary note

The technical procedure of noise reduction in material cutting by abrasive water-jet is described in this paper. The paper is aimed at the implementation of technical possibilities of noise reduction in the cutting of material by abrasive water-jet technology. Both the theoretical and experimental investigations were performed to verify and specify the new findings in the reduction of acoustic sound pressure at abrasive water-jet machining of engineering materials. By means of identification, the influence of pressure and traverse speed on acoustic sound pressure level L_{Aeq} was identified. Furthermore, a possible way of acoustic pressure level reduction at the technological node of material cutting by abrasive water-jet by means of technically relatively simple adjustment, is described.

Tehničke mogućnosti smanjenja buke kod rezanja materijala abrazijom vodenog mlaza

Prethodno priopćenje

U radu je dan prikaz tehničkog postupka smanjenja buke u rezanju materijala abrazijom vodenog mlaza. Cilj rada je usmjeren na provedbu tehničkih mogućnosti smanjenja buke kod rezanja materijala tehnologijom abrazije vodenim mlazom. Zajednička teorijska i eksperimentalna istraživanja provedena su kako bi se njima potvrdile i odredile nove spoznaje u smanjenju vrijednosti buke kod obrade abrazivom vodenog mlaza inženjerskih materijala. Sredstvima identifikacije je bio identificiran utjecaj tlaka i radijalne brzine zvuka na tlak zvuka razine L_{Aeq}. Nadalje, opisan je način i mogućnost smanjenja razine tlaka zvuka na tehnološkom mjestu rezanja materijala abrazivnim mlazom vode, pomoću tehnički relativno jednostavne prilagodbe.

1. Introduction

Cutting technology by abrasive water jet (AWJ) is ranked among the most important sources of noise, which is also confirmed by noise analyses of risks evaluation of the cutting technology through abrasive water jet by a Failure Models and Effect Assessment Method [1]. From analyses, the results are that in the production system of AWJ cutting technology parts and structural nodes with excessive noisin occur endangering workers mainly operators, by noise exposure. According to [2] in material cutting by AWJ with own head tank, noise reached t values L_{Aeq} approximately of 90 dB and in an open space a noise level can reach up to 110 dB and more. According to [3-5] and [5] the process of cutting by abrasive water jet contributes to the production process through a lot of emergent dangers significantly contributing with their reactions to the risks creation of AWJ technology. Besides the noise from AWJ technology also, a background noise affects the final level of acoustic pressure. The background noise is a noise or other influence registered by a measuring instrument also if a noise source which

Symbols/Oznake

AWJ - technology by abrasive water jet
- tehnologija rezanja vodenim mlazom

L_{Aeq} - the noise reached values approximately, dB
- približna ekvivalentna razina buke

L_{zdroj} - assessed noise source, dB
- procijenjena buka izvora

L_{poz} - background noise, dB
- buka u pozadini

L_s - together create total level, dB
- zajednička razina buke

v - regulated factor of feed speed, mm/min
- regulirani koeficijent brzine

m_a - abrasive type mass flow, g/min
- maseni protok abraziva

x - lift, mm
- visina dizanja

d_o/d_f - proportion of water nozzle diameter and focusing tube diameter,
- faktor odnosa promjera vodene sapnice i promjera cijevi raspršivača

$L_{AEX, 8h}$ - value of normalized level of noise, dB
- normalizirana vrijednost razine buke tijekom osmosatnog trajanja

f - frequency of the noise, Hz
- frekvencija buke

K_{T1} - correction factor of noise, dB
- korekcijski faktor buke

$L_{t, EX, 8h}$ - the value of high-frequency sound of noise, dB
- visokofrekvencijska vrijednost zvuka buke

should be assessed based on measurement does not affect it. When measuring the noise level of assessed source, the noise of assessed source L_{zdroj} and noise of background L_{poz} together create total level L_s [6]. In this case the difference between the total level of noise and background noise level was higher than 18 dB, i.e. the background influenced negligibly the level of assessed source.

2. Previous and related works

At formation of source instrument is the jet bounded by sides of focusing tube. At the outlet of the abrasive waterjet on the environment boundary line, AWJ flows at hypersonic speed 900 m/s, where it transfers energy to molecules situated in external elastic environment. In this way it wobbles parts and in consequence of energy conversion creates acoustic field afterwards spreading into the environment. Based on own experimental third octave analyses of levels of acoustic pressure in material cutting by abrasive waterjet, parts with high frequencies which have a negative influence on the central nervous system of operation staff were mostly found. Many works have dealt with the problem – [7-8], but the result was the statement that there are precautions to reduce noise whereby there were mainly proposed expensive solutions how to reduce this negative phenomenon. To limit the noise effectively, there is a need to correctly and precisely qualify as well as quantify the sources of acoustic pressure level not only in the production system of the AWJ cutting technology, but also in the technological node itself where the process of material cutting takes place. In the cutting process (Figure 1)

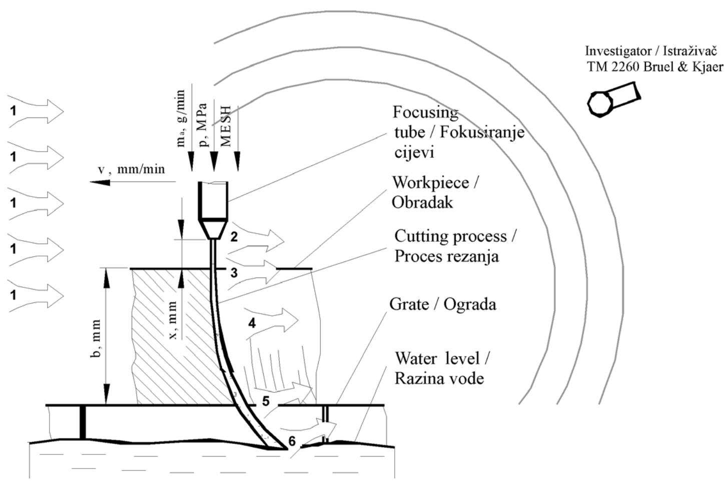


Figure 1. Noise emissions sources at technological node in AWJ. 1-background noise, 2- focusing tube outlet, 3, 4-cutting process, 5-residual flow outlet from workpiece, 6-residual flow contact with water surface in catcher tank

Slika 1. Izvori emisije buke na tehnološkom mjestu kod AWJ. 1-pozadinski šum, 2 - usmjeravanje izlaznog cijevnog otvora, 3, 4-proces rezanja, 5 - preostali izlazni mlaz iz radnog komada, 6-preostali kontkatni mlaz s vodenom površinom u prihvatnom spremniku two main elements are involved – high speed abrasive waterjet as the tool and the cut material. According to analyses [9-10] of the main sources of acoustic pressure level in AWJ technological node, besides mechanical vibrations sources, are the following (Figure 1):

- Outlet of focusing tube,
- Contact of AWJ with separated material surface,
- Cutting process,
- Outlet of residual flow from workpiece,
- Contact of residual abrasive waterjet flow with the water surface in catcher tank. Here also the following source belongs – contact of abrasive waterjet with water column, where the residual kinetic energy is absorbed (Figure 1).

3. Analysis of potential noise sources

Following analyses made in the works [3-5], Cause and effect (C-E) diagram (Figure 2) was used for diagnostics of the causes influencing noise of the operation with abrasive waterjet technology as well as technological node itself, where the process of material cutting takes place. From the (C-E) diagram, there results that a lot of factors influence the final level of acoustic pressure, among which are the following - cutting factors, workpiece, hydraulic factors, background noise, mixing factors, factors of abrasive type and factors of motional system. However, particular components of the factors influence the noise level in AWJ in a different way. Among the factor components of cutting are feed speed, lift, number of pass-overs, where the values of acoustic pressure level are different in their variability. Here also are appertain the factors as AWJ diameter, direction of cutting and incidence angle adherent to potential sources of the acoustic pressure level. The focusing tube diameter, its wear, length and its material belong to the mixing factors. Figure 2 indicating the diameter and wear of focusing tube are assumptions of an additive effect and its length and material are the assumption of the digressive one on the acoustic pressure level in AWJ material cutting. According to analysis the workpiece factor consists of following components: chemical structure, thickness and hardness. With increasing thickness of the material the noise decreases in the process [2]. Another group of factors influencing the acoustic pressure level are also abrasive factors influencing hardness of the abrasive type, mass flow, MESH and humidity.

From C-E diagram for this factor, inter alia, it results that by decreasing the mass flow the noise level will probably be reduced. Pressure, water jet diameter and contact of high speed abrasive water jet with water level belong to significant hydraulic factors influencing the noise of the technology. Along with increasing pressure at AWJ outflow from focusing tube the numeric values increase. From the work [1] it results that by increasing the pressure, the total acoustic pressure level increases, mainly its high-frequency components. Background noise factor comprises subgroups pumping device, control unit, operation, manipulations with cooling material and cutting device also influencing the final acoustic pressure level as well. Moreover, factors influencing AWJ noise and contributing to the final acoustic pressure level also are factors of technological head carrier compound of subgroups accuracy, operational conditions, material placing, vibrations, stiffness and hardness. C-E diagram shows the effects of particular compounds of this factor.

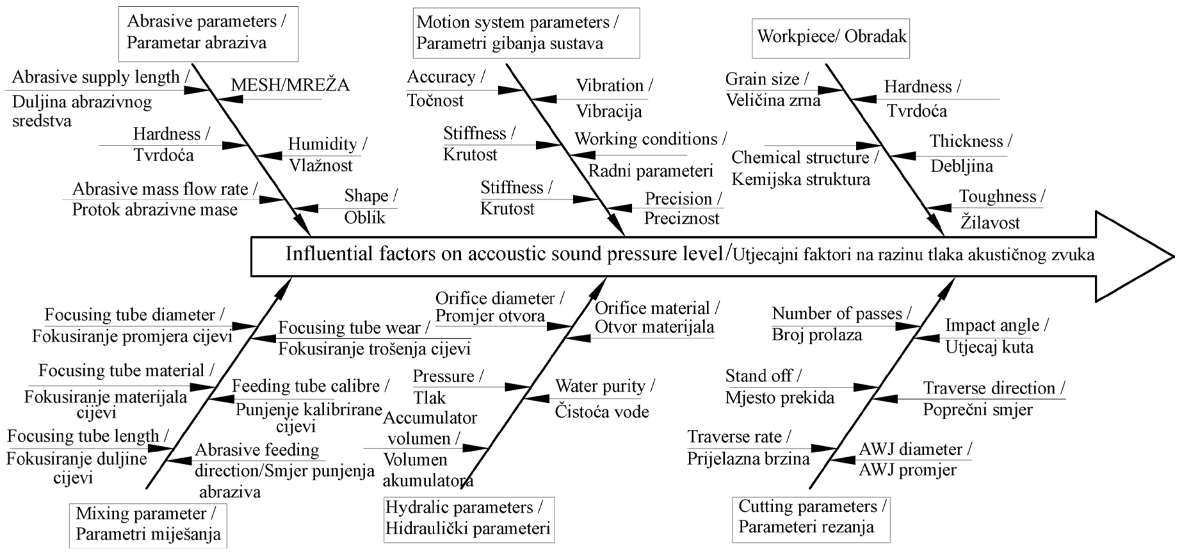


Figure 2. Causes and effect diagnostics

Slika 2. Uzorci i učinak dijagnostike

4. Presentation of experimental measurements results

When evaluating the acoustic load the method of planned experiments was followed, by which experiments for all combinations of levels of chosen factors were realised, which enabled a description of describe the structure of dependencies of the set of chosen evaluated factors influencing noise of the production system with AWJ (Figure 3b). For measuring of acoustic pressure the exact modular noise analyser Investigator ™ 2260 of Brűel & Kjaer firm with a programme for noise analysis was used, with linear measurement range adjustable in the interval of 80 dB, which can be subtracted in full scale from 70 dB to 130 dB after 10 steps. The measurements were controlled manually in the time period 60 s from the start of AWJ engagement, (Figure 3a). Experiment measurement consisted of noise measurement of background and environment, measurement of background noise with turned on pressure device–Streamline SLII pumping device and technological process measurement according to experimental schemes. The influence of particular factors on final value L_{Aeq} is shown in Pareto graphs (Figure 4a, b). From the graph (Figure 4a), the results that the biggest influence on the acoustic pressure level L_{Aeq} in aluminium cutting of 10 mm thickness has a regulated factor of feed speed *v*, (mm/min). Among other factors partaking significantly in noise level are the interaction of abrasive type mass flow m_a (g/min) and feed speed *v*, whereby their significance is increasing together with the increasing speed, as it indicates the interaction of feed speed *v* (mm/min) and lift *x* (mm).

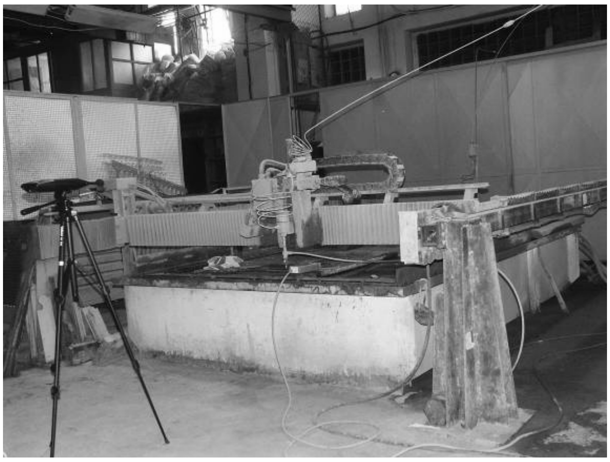


Figure 3a. Noise measurement
Slika 3a. Mjerenje buke

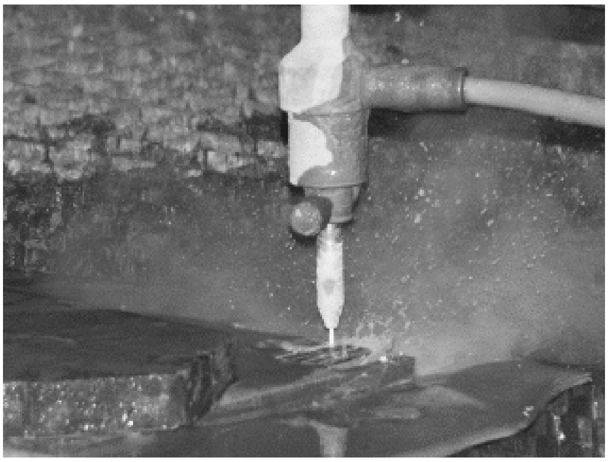
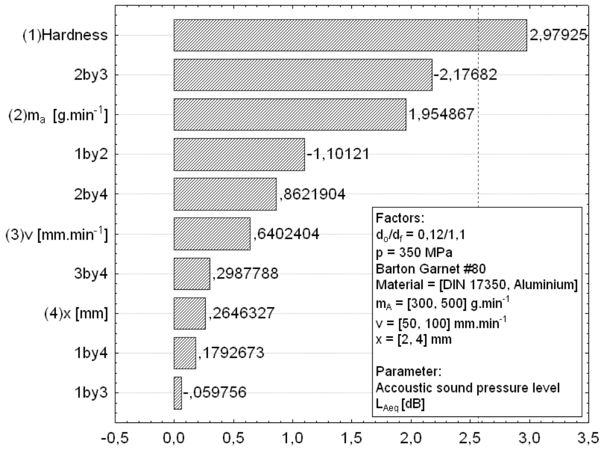
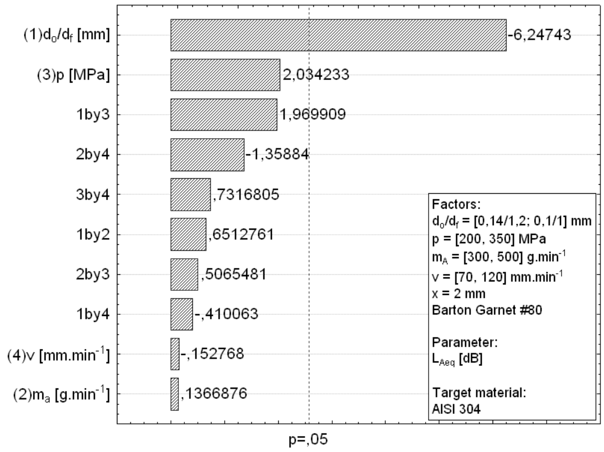


Figure 3b. Cutting of tool steel 19 038
Slika 3b. Rezanje alatnog čelika 19 038



a)



b)

Figure 4. Significance of factors influencing the acoustic sound pressure level
Slika 4. Značajnost faktora koji utječu na razinu buke

Following the experimental analyses interpreted in the graph (Figure 4b), where anti-corrosive steel AISI 304 was used as target material, it can be seen that the biggest influence on L_{Aeq} is the change of proportion of water nozzle diameter and focusing tube diameter d_o/d_f. It shall be taken into consideration especially the internal diameter of focusing tube in which the source instrument AWJ outlets as well as water nozzle by means of which high-pressure permeative is transformed (treated water by reverse osmosis) into a high speed one. Higher L_{Aeq} values were measured in performing previous experiments in anti-corrosive steel AISI 304 sample cuttings of 20 mm thickness. It cannot be definitely said that material thickness has an influence on the acoustic pressure level because the plate from which experimental samples were cut was deformed. While putting the material on the working table and fixing it, an air passage was created. The width of the air passage was approximately 20 mm (Figure 5).

feed speed of technological head, the lower the value is of expended energy on surface unit. Additionally the material at higher feeds absorbs a bigger part of kinetic energy of the flow. The flow coming out of down caval base of the workpiece is then a weaker source of the acoustic pressure. In these places the intensity of noise sources has decreased, which caused, at the end, lower values of the acoustic pressure.

5. Possibilities of noise reduction of sources in AWJ technological nude

In following Figures 6a, 6b, 6c the ways of material cutting are described. Final level of acoustic pressure can be influenced and also reduced in two ways, i.e. a technological way and a technical one. Technologically we can decrease noise at the source by a suitable adjustment of significant process factors, which in term

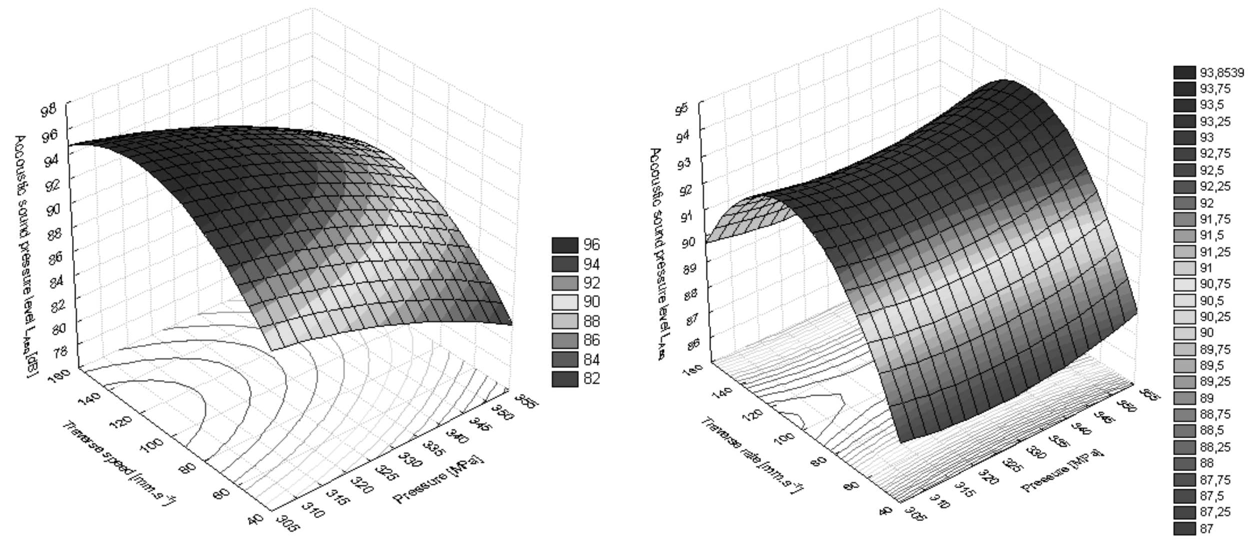


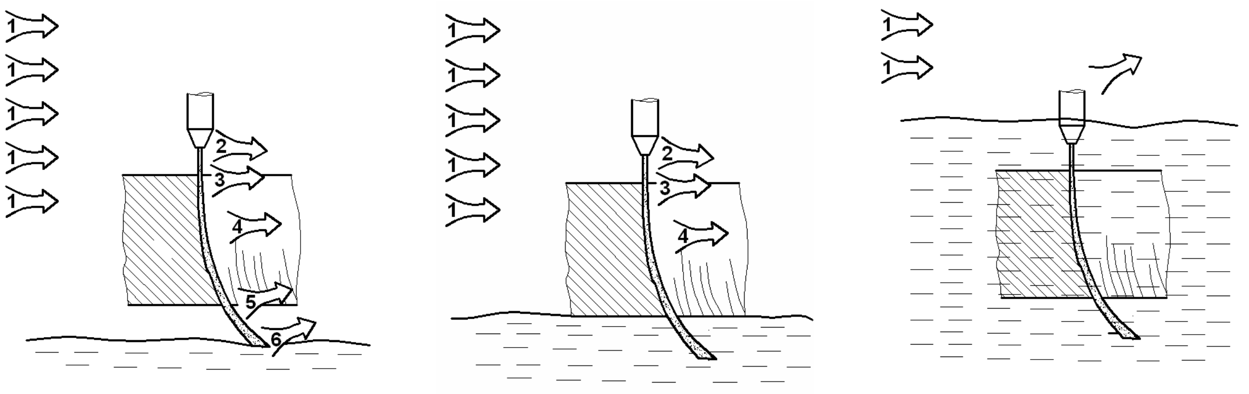
Figure 5. Experimental dependency of acoustic pressure L_{Aeq} (dB) and feed speed v (mm/min) in the cutting of anti-corrosive steel AISI 304 (b = 15 and 20 mm)

Slika 5. Eksperimentalna ovisnost razine buke L_{Aeq} (dB) i povratne brzine v (mm/min) kod rezanja antikorozivnog čelika AISI 304 (b = 15 i 20 mm)

In this manner other sources of the acoustic pressure level (Figure 5) were confirmed – one in the flow outlet from down caval base of the workpiece and other as the source of contact of residual energy of the flow with water level in the tank. When cutting with feed speeds v = 50 and 65 mm/min are noise values higher than 4 dB, gradually these values increased up to a maximum value of 94 dB at feed speed v = 95 mm/min. At higher feed speeds than 95 mm/min, a decline of L_{Aeq} values was recorded. It can be supposed that the higher the

of productivity, is not suitable. The technical measure is the most suitable and for noise reduction, adjusting of a height of material placing in regard to a water level in the catcher tank can be used. By using this technical measure three ways shown in the Figure 6 can be applied:

- the material placing above water level (Figure 6a),
- the material placing under water level (Figure 6b),
- the material placing on water level with little



submerged down edge (Figure 6c).

a) b) c)

Figure 6. Reduction of the sources of acoustic sound pressure level in order to eliminate the noise at AWJ technological node. a) the classic way of material cutting, b) material cutting under water, c) the cutting by submerged down part of material, where: 1 – background noise, 2 – flow outlet from focusing tube, 3 – AWJ contact with surface of cut material, 4 – cutting process, 5 – outflow of residual flow from the workpiece and 6 – contact of residual flow with water level in the catcher tank

Slika 6. Redukcija razine izvora zvuka buke kako bi se uklonio šum na AWJ tehnološkom mjestu: a) klasični način rezanja materijala, b) rezanje materijala pod vodom, c) rezanje djelomično potopljenog dijela materijala, gdje je: 1 - pozadinski šum, 2 – izlazni tok iz usmjerene cijevi, 3 - AWJ kontakt s reznom površinom materijala, 4 - proces rezanja, 5 – vanjski tok preostalog mlaza iz radnog komada (obradka) i 6 – kontaktni preostali mlaz s razinom vode u prihvatnom spremniku

6. Evaluation

Applying the first way of cut material placing we can reduce the source noise only by an adjustment of technological factors, whereby in the material cutting the noise sources arise which are described in the introductory part of the article (Figures 1, 2). The second way reduces noise, whereby as a source only the background noise will stay; nevertheless the quality of the cutting process due to abrasive cumulating on the surface of material which disables visual control of the cutting process is affected adversely. Another disadvantage is that on the surface of cut material an abrasive layer is being created obstructing water jet penetration into the material. At the same time the requirements on individual factors are increased, as e.g. mass flow of the abrasive type, pressure or feed speed decelerating etc. (Figure 6b).

By applying the third way the noise of the mouth of residual flow from the workpiece can be removed and the contact of residual AWJ with water surface in the catcher tank as a source of the acoustic pressure level, whereas residual kinetic energy is being absorbed in the water tank and do not create a noise (Figure 6c). By this application we will reach the most advantageous results at decreasing the final level of the acoustic pressure by technical measure.

It is possible to decrease the final level of noise at 10 dB. Working activity using technology mentioned is included in the IV. working group; this is the activity where noisy tools are used or the one which is performed in a noisy environment, which does not meet the conditions of the devices in the group I., II. or III. The action value of normalized level of A noise is $L_{AEX,\,8h}$ = 80 dB [11]. The determined difference of the sum level of noise and the level of background noise is 20 ÷ 25 dB, thus more than 18 dB; it means that background influences negligibly the noise level of assessed source. On the basis of the third octave analyses the tone element of the noise (f = 160 ÷ 250, 200 ÷ 315 and 315 ÷ 500 Hz) was determined. In this case, a correction can be applied at the evaluative level (1):

$$K_{T1} = +5 \text{ dB}. \quad (1)$$

Measured average equivalent noise level L_{Aeq} ranged around the average value of 90,5 dB depending on process factors of separation. Within a consideration of the L_{Aeq} = 90 dB consequently it will be (2):

$$L_{Aeq,\,T} = 90 + 5 = 95 \text{ dB}. \quad (2)$$

If an operator works the material during 4 hours out of 8 hours shift and he will stay in the mentioned noise source, he will be exposed to the following noise level (3):

$$L_{EX,\,8h} = 95 + 10 \log 4/8 = 92 \text{ dB} > AHNHZ = 80 \text{ dB}. \quad (3)$$

The stated value exceeds the action value of the normalized level of A noise; it means it does not meet the requirements on working environment. Nevertheless, by a proposed technical measure (Figure 3c) the noise level up to 10 dB can be reduced. It would mean a level of the total noise 82 dB, which is still higher than the action value of normalized level of A noise, though it approximates to it a lot. At the same time comparing the level reduced to 82 dB with the limit value of exposition $L_{\mathrm{AEX,\ 8h,\ L}}$ = 87 dB and upper action value of exposition $L_{\mathrm{AEX,\ 8h,\ a}}$ = 85 dB, this value is lower. Another unsolved question is a high-frequency sound influencing the operators at AWJ cutting. For the frequencies 8, 10 and 12,5 kHz the action value of high-frequency sound is $L_{\mathrm{t,\ EX,\ 8h}}$ = 70 dB for the IV. working group [11]. From experimental measurement the result was that the value is exceeded over more than 13 dB.

7. Conclusions

The technology of material cutting by high speed abrasive water jet presents one of the fastest developing technological processes of material cutting. At present, this technology offers very accurate, computer controlled form cutting of materials by cold way without mechanical deformation with minimal impact. These attributes place this technology on the position of continuous use in the future presenting the great perspective to spread in many industries, mainly where the materials of top manufacture qualities are used. Besides numerous advantages of the technology there is a negative phenomenon in the AWJ production system – noise significantly influencing workers, mainly the operators. The objective of this report was a simple identification of the influence of factors (independent variable) of AWJ on the acoustic pressure level L_{Aeq} (dependent variable), where the acoustic load in an operation with AWJ technology was evaluated in the particular process of material cutting. On the basis of the experiments results following conclusions were made:

The biggest influence on the acoustic pressure level is the factor of diameters ratio of water nozzle and focusing tube.

Another process factors – feed speed, mass flow of the abrasive have minimal or no influence on the acoustic pressure level.

When fixing of uneven sheet metals on the working table, values of the acoustic pressure are higher than at right placing of the material on the grate of working table.

Furthermore, a possible way was described of an acoustic pressure level reduction in the technological node in material cutting by abrasive water jet, by means of technically relatively simple adjustments. The most advantageous technical solution in this case represents the possibility of water level increasing or the use of capillary elevation by which two sources of acoustic pressure level are eliminated, by which it was confirmed that exactly the contact of residual flow with water level in the tank belongs between the most significant sources, mainly in a cutting of thin-gauge and soft materials. By this way the acoustic pressure level can be reduced by 10 dB at zero expenses on this technical solution realization. However, if a risk for workers' hearing, in consequence of the noise, cannot be eliminated by other measures, the employer provides his employees proper and adequate personal working means for the protection of hearing so that limit values overload will not happen.

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