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DIVIDING OF THE WATER JET – LARGE EXPERIMENTAL RESEARCH

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ABSTRACT:
high pressure waterjet cutting systems are used in the industry from 70-thy years. During these years several companies was working on the optimization of alone waterjet cutting performance.
KEYWORDS:
waterjet, stream coherence, water nozzle, abrasive focusing tube, linear model

1. INTRODUCTIONS

Several technical publications have analyzed common dependence between water jet coherence and its cutting ability. Majority of these publications clearly declare, that the waterjet is more coherent or sharper, afterwards it ensures smaller cutting gap, the better surface quality on the cutting edge, the smaller wet of cutting material, the minimal amount of abrasive on the cutting material and the higher cutting speed.

It has been realized studies on production of advanced stream coherence through gas injection, resolvents, melted plastics and other additives into water resource. Other studies indicate that advanced coherence can be achieved through delivery long chain polymers into the water used for cutting.

Current legislative in various countries require extensive cleaning of waste water contained additives before their releasing. Future regulations can evenly prohibit their using. Because companies used only clean water as cutting medium, it is not needed to buy other additives, neither expensive injection and mixing devices used with these additives. Existence of future environmental regulations related to releasing of waste water with additives is not by circumstance, with which must be engaged in producers used these cutting device.

Realized studies by R&D departments of several companies have proved that waterjet coherence is direct function of water flow property under high pressure into nozzle hole.

Geometric shape of cutting nozzles developed and delivered by current companies are specially designed on internal surface and hole border for forming and optimizing of water stream [3]. Quality of sapphire and diamond water nozzles is commonly competitive in nowadays waterjet cutting industry.

On the basis of mentioned short overview of current knowledge in the world in field of waterjet technology and on the basis of our practical skills at Wating company, we can formulate recommendation, that high-pressure pump pressure sets the amount of high-pressure water per one minute, hence waterjet coherence is set by right selection of water nozzle and toward this nozzle is set by adequate selection of abrasive focusing tube (or nozzle) – for hydro abrasive cutting with adequate feeding of abrasive amount per one minute.

2. DIVIDING OF THE WATERJET

High-pressure pump within the frame of waterjet technology is characterized with, that its performance is given by high-pressure water amount, which is able to produce per one minute and with that is characterized its performance, which thickness of material is able to cut at observance of specified cutting parameters by producer [2].

High-pressure pumps producers prescribe standard combination of water nozzle and abrasive focusing tube and that in rates according to the Tab. 1.

On the ground of scope requirements and assortment of cutting material at Wating company we have defined opportunity of water stream partition, whereby we came out from that, what is available. It means high-pressure pump SL II 50 hp, which provides 3,8 liter of high-pressure water at maximal performance. We have also come out from two cutting heads Active Autoline I for hydro abrasive cutting, which are placed on two cutting tables XY.

Table 1. Rate of water to abrasive nozzle with determination of water nozzle flow at pressure 300 MPa

Rate of water nozzle to abrasive nozzle and to high-pressure flow	Water nozzle and flow		Abrasive nozzle
	Internal diameter [mm]	High-pressure flow [l]	Internal diameter [mm]
0,17/0,54/0,5	0,17	0,79	0,54
0,20/0,76/1,05	0,20	1,05	0,76
0,25/0,76/1,65	0,25	1,65	0,76
0,30/1,1/2,37	0,30	2,37	(0,9 ; 1,02) ;1,1
0,35/1,1/3,25	0,35	3,25	(0,9 ; 1,02) ;1,1

Before we have cut according to ordinary usage so that, if it was cut on one table, on second table was taken away already cut material and it was prepared next material for cutting. All of this was happened in the lapped time and if first table stopped cutting, immediately in short time started to cut second table. By such way was mentioned cycle repeated. With that method we reached the maximal utilization of working time with minimal stoppage.

On the both tables we were used one cutting head, which cutting performance we were dimension as following:

1st table - cutting head 0,35/1,02/3,25 or 2nd table - cutting head 0,35/1,02/3,25
1st table - cutting head 0,35/1,02/3,25 or 2nd table - cutting head 0,30/1,02/2,37

According to grow of cutting requirements and increasing of competitiveness we have been starting to find the next opportunities of increasing efficiency and without increasing number of shifts. Therefore after six months practical examination, when we were cutting on the both tables on the same time, we have performed large experimental research of high-pressure water stream partition. We have realized 826 experimental cuts (or cutting edges) on 211 samples. We have chosen the combinations of flows and high-pressure water so that partition of water stream minimally affects cutting performance. We have also kept in mind the opportunity of abrasive material consumption decreasing at cutting, because abrasive consumption plays relatively interesting role in costs of cutting process. Totally we regarded maximum consumption 3,5 liters high-pressure water so, how is normal praxis. Because it is obvious that consumption of high-pressure water at both heads was so, how much is able pump push water per on e minute, i.e. 3,5 liter.

Table 2. Abrasive nozzles rates

Variant	1st table	2nd table
	Cutting head	Cutting head
1.	0,20/0,76/1,05	0,20/0,76/1,05
2.	0,20/0,76/1,05	0,25/0,76/1,65
3.	0,20/0,76/1,05	0,30/1,02/2,37
4.	0,25/0,76/1,65	0,25/0,76/1,65
or		
5.	0,20/1,02/1,05	0,20/1,02/1,05
6.	0,20/1,02/1,05	0,25/1,02/1,65
7.	0,20/1,02/1,05	0,30/0,76/2,37
8.	0,25/1,02/1,65	0,25/1,02/1,65

Table 3. Abrasive nozzles next variants

Variant	1st table	2nd table
	Cutting head	Cutting head
1.	0,20/0,76/1,05	0,20/1,02/1,05
2.	0,20/0,76/1,05	0,25/1,02/1,65
3.	0,25/0,76/1,05	0,25/1,02/1,65

Dividing of water stream can be performed at cutting by two heads and with using abrasive nozzles with inner diameter 0,76 and 1,02 mm and that is in rates (Table 2). Also can be combined rates of abrasive nozzles various dimensions in cutting heads on the first and second table by the rise next three variants (Table 3). Upon the ability of high-pressure flow combinations and combinations of the rates of abrasive focusing nozzle to water nozzle, we put the main accent to increasing the cutting performance, shorting cutting time, reduction of abrasive consumption and at the same time decreasing costs for abrasive, decreasing of pump operation load at the totally lower consumption of the water and the totally increasing of cutting process flexibility.

3. METHODOLOGY OF THE LARGE EXPERIMENTAL RESEARCH

From the mentioned abilities of flow combinations and combinations of abrasive focusing nozzle to water nozzle we've chosen the shape of test sample, which will be cut and from which will be evaluated the parameters important from praxis point of view. Experimental sample we've proposed according to figure 1. and on the figure 2. is shown direction of cutting.

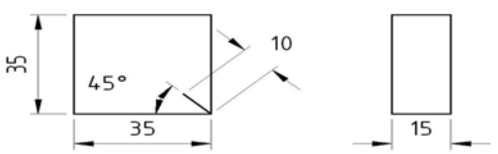

Figure 1. Experimental sample

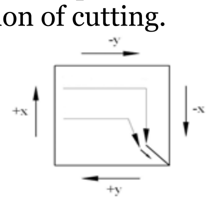

Figure 2. Cutting direction of experimental sample

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Table 4. Protocol of experimental samples cutting

WATING PREŠOV **Protocol of experimental sample cutting**

EXPERIMENTAL SAMPLE DATAS: Dimensions: 35x35x35x35 mm Cutting direction: +Y ; +X ; -Y ; -X (clockwise) Next: Penetration in sample + distance cutting gap 10 mm	Protocol serial number: P- 01 **PROTOCOL number:** 1 .1 **SAMPLE number:** 1-1/100/8-0.76/3

MATERIAL	Type of material	Stainless steel austenitic 17 240 W.Nr. 1.4301 Plate A304 * 15x1250x2500 mm
	Material volume	300x1250 mm
	Material thickness	15 mm

WORKS DESCRIPTION	Sample cut in shape of square. Every square edge cut by other speed, i.e. contains 4 different cutting speeds. Make penetration on sample. Sample must contain 10 mm long cutting gap, not collided with cutting edge.

CUTTING PARAMETERS			
Cut distance	35 mm for 1 edge and speed	Cutting time: [min. : sec. . st.] 02 : 04 . 09	Incidence angle of stream on the material: 90° upright to material
Cutting speed	50 ; 75 ; 100 ; 125 mm/min.		
Penetration time	03.24 sec . st.	HP water flow: 1,05 liter	Distance nozzle from material: 3 mm
Water pressure	300 MPa		
Abrasive volume	100 g	Abrasive material Mesh: # 80	Type abrasive: BENGAL BAY GARNET
Water/ abr. nozzle	0,25/1,02 mm (10/1.02)		

FINAL DATAS	
Company/Workshop: WATING Prešov, jsc. ; Operation: Budovateľská 38, 080 01 Prešov, Slovak republic	
Machine description: HP pump SL II 50 Hp; CNC X-Y table 3000x1500 mm; Cutting head AUTOLINE I	
Cutting performance: Radovan Pavlík	Sample cutting date: 17.12.2007
Protocol registration: Ing. Patrik Polák	Protocol approved by: Ing. Ján Kmec, CSc.

On the basis of personal experiences with water-jet technology we've been working from the year 1985, i.e. almost 23 years consecutively, alone methodology of experimental researching we divided into the two entities – protocols:

- First protocol introduces defined constant parameters and variable parameters measured at experimental tests (Tab. 4). On the figure 3 is cutting of samples.
- Second protocol shows measured parameters on cut samples, on the grounds which will be formulated conclusions and recommendations (Tab. 5). Figure 4 shows way of samples measuring.

Figure 3. Experimental sample cutting

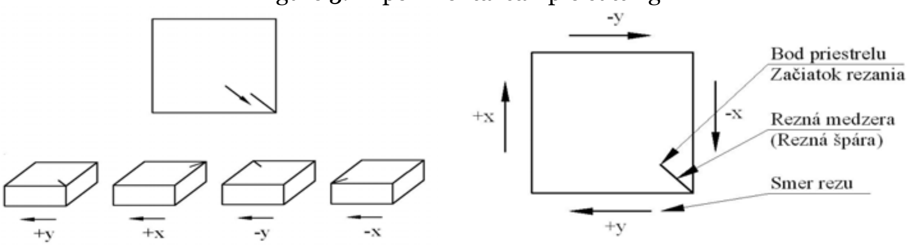

Figure 4. Experimental sample evaluation

Table 5. Protocol of experimental samples measuring

No.	Sample number	Speed	Measured distance [mm]	Edge angle [˚]	Entry/Exit of stream [mm]	Width Stream [mm]	Edge roughness [Ra]	Cut depth [mm]	Edge sharpness [a]
1.1	1-1/100/8-1.02/3	50							
	1-1/100/8-1.02/3	75							
	1-1/100/8-1.02/3	100							
	1-1/100/8-1.02/3	125							

4. TECHNOLOGICAL ASPECT – LINEAR MATHEMATIC MODEL

For using the big amount of information from experimentally measured results at individual samples it will be able to create inductive mathematic models with using of statistic methods. For creation such models are most frequently used mathematic processes, at which we will be come out from the Linear mathematic model.

Linear mathematic model can comprehend as model with the structure [1]:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + \ldots + a_m X_m \qquad (1)$$

where: Y is dependent variable, X_1, X_2, …, X_m are independent variables, a_1, a_2, …, a_m are parameters of the module.

Determination of model parameters (1) is also called regression. In the case, if m=1, we are speaking about liner regression (about linear regression model or regression line). If m>1, we are speaking about multi-linear regression [1]. Model parameters (1) are determinated from the matrix of observations (or measurements).

$$\begin{matrix} 1.measurement & x_{11} & x_{12} & \ldots & x_{1m} & y_1 \\ 2.measurement & x_{21} & x_{22} & \ldots & x_{2m} & y_2 \\ \ldots\ldots\ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots & \ldots\ldots & \ldots\ldots \\ n-th.measurement & x_{n1} & x_{n2} & \ldots & x_{nm} & y_n \end{matrix} \qquad (2)$$

Because model is oversimplified transformation of cutting process, it will not be aggregate of independent variables entire. It means, that on the values of independent variables y_j $(i = 1,2,\ldots,n)$ can influence also values, which are not included in the model (1). About these variables we will be suppose, that they are changed only in small scope. Their summary influence can be expressed like effect of one variable with values identically equaled to one. Such variable is called fictive. In the model (1) we allocate her parameter a_0 and we will be consider her like zero variable.

5. ECONOMICAL ASPECT – MODELLING OF CUTTING COSTS

In every industrial application should realize choosing of cutting parameters with AVL in respect of operation costs (i.e. those parameters, with which could be cut material with prescribed accuracy and quality of surface on cutting edge at minimal able operation costs).

Cost function should regard only main variable costs with such way:

$$C = CA + CW + CE + CU + CH \qquad [\text{SKK/mm}] \qquad (3)$$

where: CA are costs for abrasive material consumption, CW are costs for water modification and consumption, CE are costs for energy, CU are costs for abrasive (focusing) and water nozzles (tubes), CH are other indirect variable costs (e.g. wages, maintenance, amortization etc.).

6. CONCLUSION

In our case it goes about comparison and evaluation of eight constant parameters and ten variables at samples cutting, and seven parameters measured on the cut samples.

By the combination of mentioned parameters we have expected large amount of results and compact view on the till now few researched parameters, i.e. cutting performance, its quality and effect – overall technological aspect with regard to economical aspect of water-jet cutting process, at water stream dividing, respectively at change or decreasing of high-pressure water flow.

Evaluation process and conclusions formulation and knowledge for current praxis, from point of view lonely hydro abrasive water-jet cutting, represents relatively large intersection into the water jet technology with the aim to find way of defining cutting parameters, at lower water flow. Production processes take place in all social-economical systems. Single technological processes in engineering production can be considered as deterministic.

Particular factors of technological process have generally defined effect on its result. For quantification of various effects is advantageous to describe technological process by the mathematic model. Modeling of technological process allows performing experiments without real intervention into the operation.

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