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Identification of Structure of Hydro-Erosion Operation

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BIOGRAPHICAL NOTES

Emil Spišák, prof. Ing. CSc. (born 1955) is professor of Department of Technologies and Materials, Faculty of Mechanical Engineering, Technical University of Košice. He is head of the Department of Technologies and Materials and Vice-Rector for Development and Construction of the University. He served as Vice-Dean for 4 years and Vice-Rector for 8 years. He works in the area of evaluating of material properties, material failures, analysis and quantification of production factors influence in production of thin steel sheet stamping parts, modelling and simulation of technological processes, mainly forming processes. He is national secretary and a member of International Deep-Drawing Research Group. He is author of 5 monographs and more than 200 publications in journals and conference proceedings at Slovakia and abroad. His published works were cited 115 times. He has been worked on 60 grant projects, research tasks and 47 projects solved for industry.

Miroslav Badida, Dr.h.c. prof. Ing. PhD. is a graduate of Mechanical Faculty of Technical University of Košice. His scientific and research work focuses on the field of environmental engineering. An accent is put on the issue of environmental management systems, ecologization of products and their production and life cycle analysis of products. Lately his attention is paid on research in the field of physical factors of working and living environment.

Ján Kmec, doc. Ing. CSc. graduated in the Faculty of Mechanical Engineering, VŠT in Košice, in 1977. At present, he is associate professor at the Department of Technologies and Materials, the Faculty of Mechanical Engineering, TU in Košice. He introduced new technology of water jet cutting as a head designer. He worked in firms as VUKOV Prešov, MVVZ ROBOT Prešov a WATING Prešov since 1981 to 2009. His main research interests are problem of research and optimisation of cutting parameters in the frame of energy - jet progressive technologies. Results of research were published in 2 monographs, in more university text books and scientific publications. He published in more than 100 in home and foreign journals and scientific conferences. He participated as author and co-author in many projects and engineering works.

Lýdia Sobotová, doc. Ing. PhD. is a docent on Technical University in Košice, Faculty of Mechanical Engineering. She graduated at the Faculty of Mechanical Engineering, VŠT Košice in 1983. She received her PhD. Degree from Technical University in Košice in 1992. Her scientific focus is oriented to metal forming, material testing, thermal drilling and progressive mechanical technologies. Today Mrs. Sobotová is an associated professor at the Faculty of Mechanical Engineering and is a member of the Department of Technologies and Materials. She is a co-author of academic textbooks. She has published more than 140 publications in home and foreign journals and conference proceedings. She was also incorporated in various grant research projects and industrial projects.

KEY WORDS
Hydro-Erosion, Water Jet Cutting, Models of Hydro-erosion Dividing

ABSTRACT
The automation of hydro-erosion manufacturing processes comes to increase the demands on engineering works in the preparation of production, at shortening of deadlines for implementation of scientific knowledge into practice, at the design of production processes and at the economization in production processes. This process is associated with extensive utilisation of mathematical methods, using of computational procedures for specific tasks and at the utilisation of methodology of mathematics for methods of formulating solutions. During the solving of problem, there is mostly used: operational analysis, set theory, theory of structures, theory of algorithms and languages.

1. Introduction
Water jet cutting technology (hydro-erosion) presents as unique, for future-oriented technology, with the high possibility of the introduction of automation for high-power cutting for actually all types of materials. The important impulse for utilisation of water jet cutting in the production technology as a tool came from the area of aeroplane design and cosmonautics.

The most important plus of this technology with the comparison of other dividing methods is cold cutting process. This process is used where chip-less, chip and thermal manufacturing techniques give unsatisfactory results from mechanical or physical reasons or where they completely fail. Potential users clearly took the fact about priorities, which present water jet cutting with comparison with other processing possibilities (Kmec et al., 1989; Kmec et al., 1999; Kmec et al., 1999).

2. Method and Structure of Manipulation Operation
New approaches for the examination of technological operations, based mainly on the development of operation structures, can be realized from the point of composition of its elements participated in the operation, where the general model (1) is defined as (Kmec et al., 2008; Kmec et al., 2009; Kmec et al., 2010):

$$Per - S_h^l N_n^l P_m^l - O \qquad (1)$$

where: Per - person; O - object; S, N, P - set of production machinery, tools and fixtures in concrete technological operation; h, n, m - quantitative indicators of value of each part from these sets; l - determinant of quality indicators for each of the means of production.

Based on the approaches to technological operation, in manipulation operation can be differentiated manipulation methods and structures.

2.1 Manipulation method
Manipulation method is joined with the function operation, which expresses how to become the change of object location, its orientation and others. In the Tab. 1 is shown the mentioned classification of automated manipulation methods.

2.2 Manipulation structure
Manipulation structure is the realization of the operation, which can be expressed by the temporal structure of the determined operations and participating components.

Table 1: *The examples of the determination of handling methods.*

Manipulation operation (action)	Method	Technical realisation
1. Grasping and save of object, respectively remove of object, waste	■ by vacuum, ■ magnetically, ■ by elastic force,	gripper fingers, fixture, crane, forklift and other suction gripper, magnetic gripper, elastic gripper
2. Move object	■ by pressure medium, ■ by kinematics mechanism,	hydraulic and pneumatic equipment industrial robots and manipulators
3. Orientation - mechanically	■ mechanized, ■ visual, ■ by contact	manipulator, slip, conveyor, robot-vision, tactical sensors and robots

In the technology of water jet can be the structure development of handling operations based on using of co-dominant area of production equipment, it means, on the shortening of real-time of manipulation operations of final table member XY (robot). It deals with the increasing of covering degree of manipulation operations for increasing of production process (Kmec et al., 2009; Kmec et al., 2010).

The time structure of operation is based on the classification of operating time divided into elements, connected with the functionally compact technological and helpful operations.

The time structure of technological operation can be expressed by term (2):

$$t = \Sigma t_h + \Sigma t_v^p + \Sigma t_v^z + \Sigma t_v^h + \Sigma \tau \ [\text{min}], \qquad (2)$$

where: t_h - main time [min]; t_v^p - secondary time connected with the technology subject of processing [min]; t_v^z - secondary time connected with the technological equipment [min]; t_v^h - secondary time connected with the tools used with technological process [min], τ - overlapped time [min].

The methods of organizing of operation structure models according to structure of time components are presented in the Tab. 2, where were processed in multiple works of professor Buda for machinery cutting technology. Based on these works we can formulate the general models of time structures of technological operations, which consist of:

- ■ *classes of operation,*
- ■ *groups of operation,*
- ■ *subgroups of operation,*
- ■ *organisation of machining sequences and their integration into one or more flows.*

Based on the mentioned classification according to the Tab. 2, we can symbolically explain the structure of manipulation operation for hydro-erosion technology by the help of model (3) and was formulated in the Department of Technologies and Materials, The Faculty of Mechanical Engineering, Technical University in Košice:

$$O - Z_{tz}^k H_{rh}^k P_{pm}^k - D \qquad (3)$$

where: O - operator, service - man; Z - manipulation equipment (pump, XY table, amount of abrasive, program); H - manipulation tool, (cutting head - cutting tool); P - manipulation fixture (loading, positioning, taking of parts and waste); D - part (cut product) - subject of manipulation; tz, rh, pm - quantitative indicator of number of mechanisms, tools, fixtures; k - qualitative indicator expresses the characteristics of manipulation equipment (expresses the innovation degree).

We can differentiate four classes in the structural model of manipulation operation. It is necessary to mention the main determined features, which can characterize the manipulation equipments, fixtures

Table 2: *The classification of operational structures in the connection with production equipment.*

Set up of method	Models of time structures of technological operations and determination of condition variants							
Set up of cutting head as the cutting tool	$t_{n\,rh} \neq 0$				$t_{n\,rh} = 0$			
Set up of material position on the table cutting bath-tube including its taking off	$t_{n\,pm} \neq 0$		$t_{n\,pm} = 0$		$t_{n\,pm} \neq 0$		$t_{n\,pm} = 0$	
Set up of pump, XY table, abrasive amount and cutting program	$t_{n\,tp} \neq 0$	$t_{n\,tp} = 0$	$t_{n\,tp} \neq 0$	$t_{n\,tp} = 0$	$t_{n\,tp} \neq 0$	$t_{n\,tp} = 0$	$t_{n\,tp} \neq 0$	$t_{n\,tp} = 0$
Determination of total time calculation of set up of manipulation operation	d=a+b+c	d=a+b	d=a+c	d=a	d=b+c	d= b	d= c	d= 0
Groups of manufacturing operations	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*

$a = t_{n\,rh}$ - time set up of cutting head as a cutting tool [min],

$b = t_{n\,pm}$ - time set up of material position on the table cutting bath-tube, including with disposal and taking off [min],

$c = t_{n\,tp}$ - time set up of technological parameters including with programming [min],

$d = t_{n\,mo}$ - time set up of whole manufacturing equipment, it means manipulation operation [min].

and tools.

The degree of innovation, as quality indicator, can be specified by components:

- *new handling equipment,*
- *extensive handling devices (renewal),*
- *out-dated handling equipment.*

Each part according to real characterization of handling operation we can characterize by degree of mechanisation, automation, elasticity, reliability and so on.

The classification of manipulated operation classes is following:

1. Without the element class is characterized by operations, in which ones are not manipulation equipments, fixtures and any tools, it means $tz=0$, $rh=0$, $pm=0$.
2. Single element class is characterized by operations, in which ones are used only for one type of manipulation facilities.
3. Two-part class is characterized by operations, in which ones are used for two types of manipulation facilities.
4. Three-part class is characterized by operations, in which ones are used for all types of manipulation facilities as equipment, facilities and tools.

3. Functional Structional Structure of Manufacturing Process

The manufacturing process can be characterized as an activity, in which the semi-product is changing on the final product. The workers transform the semi-product into the final product by help of work equipments in manufacturing process, which in the general represents the technology production.

The technological workplace of hydro-abrasive erosion is possible to characterize by basic bonds between components:

- *input and output links of each components,*
- *degree of mechanization and automation,*
- *degree of standardization,*
- *three-dimensional connections (links) of each components.*

The technological workplace can be characterized by following indicators according to the function:

- *productivity,*
- *quality of technological processing,*
- *economy,*
- *safety, etc.*

Mentioned technological and functional characteristics of technological workplace can be considered as corresponding. Therefore, with regard to design of such workplaces, it is convenient to divide into subsystems, namely:

- *technological system,*
- *inter-operational transport and storage,*
- *operational manipulation,*
- *supplies and distribution of energy,*
- *measurement and control,*
- *guidance /management.*

For functional aspect of automated production systems, it is necessary to explain their basic functional bonds, which can present the following functional structures:

1. Free component arrangement (production equipment) of workplaces, which demonstrate complicated systems of technological processing and control.
2. Functional (technological) design of workplace components, which images some simplification against the free arrangement.
3. Modular arrangement of workplace components, which demonstrates the set of same (identical) multipurpose technological and manipulation subsystems.
4. The cell arrangement of workplace component, which demonstrates the final structure of building of high automated production systems, where are eliminated redundant elements and are optimized internal links.

4. Investigation of Technological Process Possibilities from the View of Practical Using

According to increasing of cutting requirements and increasing of competition in the market, there are started to find another possibilities of power increasing without increasing of shifts, it means by dividing of water jet (Kmec et al., 2009; Kmec et al., 2010).

In the case of dividing of water jet into applications of two cutting heads simultaneously in one or two cutting tables, it is possible to combine cutting heads in variations as the technology producers recommend them.

Dividing of water jet was made in against of idea of producers in firm WATING Prešov, it means cutting with two cutting heads on two cutting tables simultaneously.

There were used combinations of various water nozzle with inside diameter 0,76 mm according to variant I, II and III.

Variant I: 1. table - head 0,20/ 0,76/ 1,05

2. table - head 0,25/ 0,76/ 1,65

Variant II: 1. table - head 0,20/ 0,76/ 1,05

2. table - head 0,30/ 0,76/ 2,37

Variant III: 1. table - head 0,25/ 0,76/ 1,65

2. table - head 0,25/ 0,76/ 1,65

The basic of high press cutting machine is high press pump, the pump with pressure converter multiplicator with oil - hydraulic drive and press accumulator.

The water pressure is transported by high press pipes into cutting head according to Fig. 1 and following with dividing of high pressed water, it means cutting operation with two cutting heads simultaneously. It is shown in Fig. 2, as the possibly models of water jet dividing.

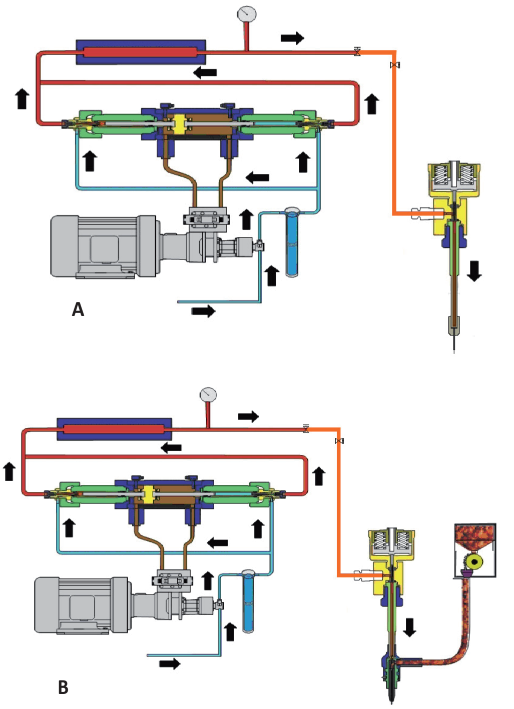
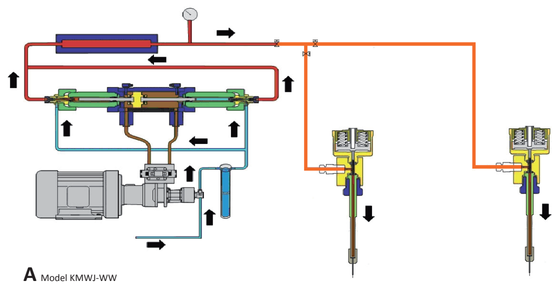
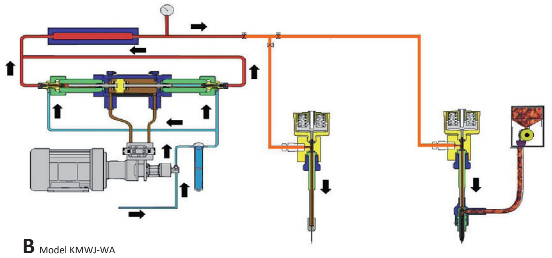


Fig. 1: *Principe of WJM and principe of AWJM : **a)** Hydrodymanic water jet , **b)** Hydroabrasive water jet.*





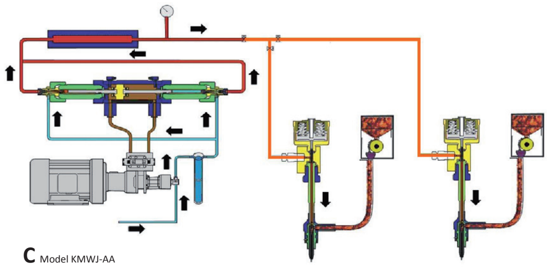


Fig. 2: *Models of water jet dividing into two heads: **a)** Model KMWJ-WW – used principle of WJM + WJM; **b)** Model KMWJ-WA – used principle of WJM + AWJM; **c)** Model KMWJ-AA – used principle of AWJM + AWJM.*

Based on the long practical experiences, the cutting costs for cutting with one cutting head, we can calculate that the cost function must complete include all direct and indirect costs.

Proposed cost function, which was used in the firm WATING Prešov, takes into account all main cost items, for the cutting with one cutting head - models KMN1 is following, formula (4):

$$C_{KMN1} = [CA + CW + CE + CU + CM + CH + CP]\,1/PV \ [\text{€/mm of cutting}] \qquad (4)$$

where: CA - cost of consumption of abrasive material; CW - costs of treatment and water consumption; CE - energy costs (high-press pump, XY table, cooling and air cooling), CU - costs for consumer components, water and abrasive - focusing nozzles, CM - costs of handling and storage (forklift, crane, pallets), CH - other indirect variable costs (wage, sched uled maintenance, amortization, etc.), CP - all other operating costs (overhead, test cuts, preparations, etc.), PV-number of products for cutting one layer (varies according to the number of layers cut).

Following, it is also possible to model the cost function of hydro-erosion jet dividing for cutting with two heads simultaneously. We consider that it is a benefit to future users in practice.Proposed cost function for cutting with two cutting heads simultaneously will take into account all major cost items, which are related to them.

Cost model for cutting with two heads - model KMN2 is following, formula (5):

$$C_{KMN2} = [CA + CW + CH + CP + + 2x(CE + CU + CM)]\,1/PV \text{ [€/mm of cutting]} \qquad (5)$$

where: CA - cost of consumption of abrasive material, CW - costs of treatment and water consumption, CE - energy costs (high-press pump, XY table, cooling and air cooling), CU - costs for consumer components, water and abrasive - focusing nozzles, CM - costs of handling and storage (forklift, crane, pallets), CH - other indirect variable costs (wage, sched uled maintenance, amortization, etc.), CP - all other operating costs (overhead, test cuts, preparations, etc.), PV - number of products for cutting one layer (varies according to the number of layers cut).

Based on the above approaches to dividing of hydro-erosive jet, within the extensive experimental research on material AISI 304 with thickness 15 mm, the high-press water jet was divided according to various flows. Complex identification of technical, technological, measured and evaluated parameters introduces total 25 parameters, which can be compared with each other in various evaluation addictions.

Those models as economic aspects of costs, were have been developed in the Department of Technology and Materials, Faculty of Mechanical Engineering, Technical University in Košice and covers long time practical knowledge obtained in firm WATING Prešov. Similarly, there were obtained interesting results, Fig.3, where is shown the dependence of the cut surface roughness topography on flow and head stroke.

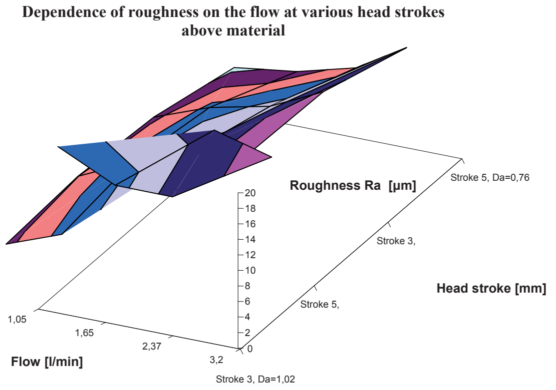


Fig. 3: *Dependence of the cut surface roughness topography on flow and head stroke.*

The interesting detection was the weight consumption of abrasive material, which in the case of cutting with one head or two ones, was smaller about one third. There was testing the influence of the weight of abrasive material at 100 g, 150 g, 200 g and 250 g/min. The finishing evaluation showed enough quality of cut surface at the weight of abrasive material from 180 g to 250 g/min.

The last verification of the quality was made in the samples with thickness of material 8 mm and thickness 30 mm. This choice of parameters was chosen for better preparing of method for identification of technological cutting parameters for thickness range from

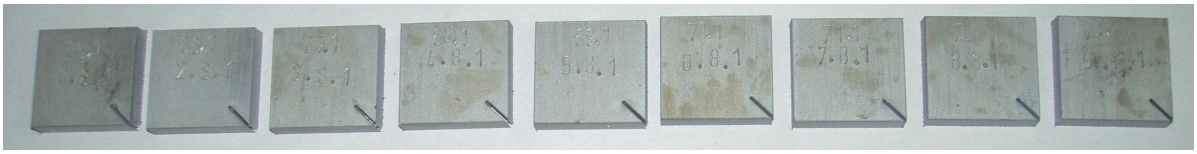


Fig. 3: *Dependence of the cut surface roughness topography on flow and head stroke.*

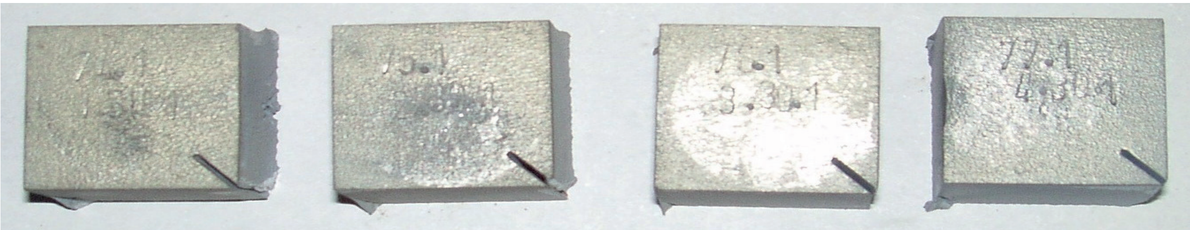


Fig. 3: *Dependence of the cut surface roughness topography on flow and head stroke.*

1mm to 30 mm, for material type AISI 304.

The last aim of work was to prepare and to elaborate the method of determination of technological cutting parameters for each thickness of material AISI 304 and for other types of materials, which are cutting by hydro-abrasive erosion.

The verification of formulated factors was realised on the samples from material AISI 304 with thickness 8 mm. In the Fig. 4 and Fig. 5 are shown the verified samples.

The cutting parameters of shown evaluated samples were written into protocols and their actual evaluations in graphic mode are shown in the Fig. 3.

5. Conclusion

For the present practice, from the point of economical effect of the actual cutting by hydro abrasive erosion, image the mentioned research as the widespread penetration into itself technology of water jet.

The aim of the way was to find the definition of cutting parameters of water jet, which will guarantee technological and economical aspects at the dividing of high-press water into two smaller water flows or at one smaller flow of water.

6. Acknowledgement

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7. Referances

KMEC, J. - BIČEJOVÁ, Ľ. 2008. Rozdelenie vodného lúča do dvoch rezacích hlavíc. In: Operation and diagnostics of machines and production systems operational states : Scientific Papers. Brno :Tribun EU, 2008. p. 100-107. ISBN 978-80-7399-634-5.

KMEC, J. – SOBOTOVÁ, L.: Delenie hydroerózneho lúča. 1. elektronický optický disk(CD-ROM).In: Trendy a inovatívne prístupy v podnikových procesoch : 12. me-dzinárodná vedecká konferencia : zborník príspevkov v elektronickej forme : Košice, december 2009. - Košice : TU, SjF, 2009. – ISBN 978-80-553-0330-7. S. 1-5.

KMEC, J. – SOBOTOVÁ, L.: Lúčové technológie vody, 25 rokov na Slovensku. 1. Elektronický optický disk (CD-ROM). In: Nekonvenčné technológie 2010 : 9. ročník medzinárodnej vedeckej konferencie : Strečno, 22. jún 2010. - Žilina : ŽU, 2010. - ISBN 978-80-554-0222-2. S. 1-8.

KMEC, J. – TVARUŽEK, M. – GREGUŠ, P. 1989. Projekt RTK delenia trecích plechov metódou PASER, ŽĎÁS, a.s. Žďár n/Sázavou., MVVZ ROBOT Prešov, 1989. 54 s.

KMEC, J. – TVARUŽEK, M. – GREGUŠ, P. 1999. Projekt Waterjet cutting systém W 32 BN, H+H Kft. Dunaujvaros, Wating, Prešov 1999.

KMEC, J. – TVARUŽEK, M. – GREGUŠ, P. 1999. Projekt Waterjet slitter union, BELOIT Poland,Wating, Prešov 1999.