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WATERJET MACHINING

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Professional paper

Material processing by separation of particles with traditional processes using cutting tools is not the only method of metal processing. The material may also be removed from the product using mechanical, thermal, electrical and chemical energy. Most of these procedures had been known for some period of time ago, but some of technologies were not extensively applied in practice. In the paper is described the procedure of cutting of the materials using a water jet, whose application for hard materials demands abrasives to be added into the water stream.

Key words: *processing, cutting, water jet*

Obrada vodenim mlazom

Strukovni članak

Obrada materijala odvajanjem čestica tradicionalnim postupcima upotrebom reznih alata nije jedini postupak obrade metala, već se materijal s obratka može odstraniti i djelovanjem toplinske, električne ili kemijske energije. Iako su postupci i tehnike obrade poznate otprije, pojedine tehnologije se nisu u većoj mjeri koristile u praksi. U članku je opisan postupak rezanja materijala vodenim mlazom kojem se u primjeni za rezanje tvrđih materijala potrebno u mlaz dodati još i abrazivno sredstvo.

Ključne riječi: *obrada, rezanje, vodeni mlaz*

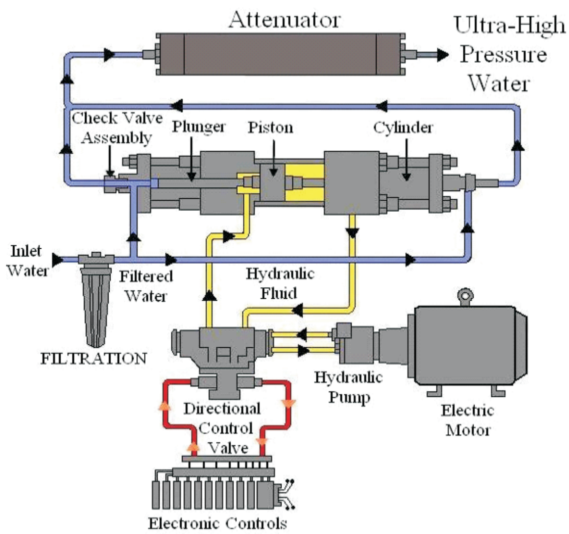
1 Uvod
Introduction

The increasing complexity of shapes and requirements for exact dimensions of products that need to be produced, as well as economic sustainability of production is forcing the researchers and industrial designers to develop and implement new, modern technologies of machining materials. The use of older machines for large-scale serial production is slowly being discontinued with increased use of new, more modern machines for mid-scale and small-scale serial production. With fast development of IT and other technologies, preconditions were met for using increasingly more precise machines, suitable for automation. The speed of cutting has doubled in the last fifty years [1]. One of the procedures which showed rapid development in the last decade is water machining.

The comprehension of the amount of energy that can be transmitted by water, achieved by observing natural phenomena along with some experiences in use of water in the mining industry, incited the designers of machining apparatuses to consider water not only as the source of life, but as a useful medium for cutting materials. Directing a large amount of energy onto a small area a strong waterjet was created, generated by a water pump. The effect was further enhanced by decreasing the size of the aperture of the jet. A water cannon used in Siberia around 1950 for digging up ore was among the first practical uses of water jets. In 1982, a company by the name of WTI (Waterjet Technology Inc.) discovered and patented a procedure where an abrasive (sand particles) was added to the waterjet prior to its leaving the nozzle. The procedure was named *Abrasive Waterjet Cutting.* Although waterjets can be used in multiple material processing tasks (polishing, drilling, turning work) it is nowadays mostly used for cutting.

2 Pure waterjet cutting
Rezanje vodenim mlazom

Pure waterjet cutting, with no abrasives added, is mostly used in cutting softer materials (paper, wood, flooring, leather, sponge). Figure 1 shows a schematic of the system and individual components.



Slika 1. *Shematski prikaz rezanja vodenim mlazom* [2]
Figure 1 *Schematic representation of waterjet cutting* [2]

The central assembly of the machine is a high-pressure pump, pushing hydraulic fluid into the pressure intensifier. Inside the pressure intensifier a plunger pressurizes water to 3800 bar, which then passes through a pulsation compensation unit, dampening the effect of pressure fluctuation in the system, caused by plunger movement. A pressure intensifier can be unidirectional or bidirectional (Figure 2), with a check valve at each end, rendering re-flux of liquid back into the intensifier impossible.

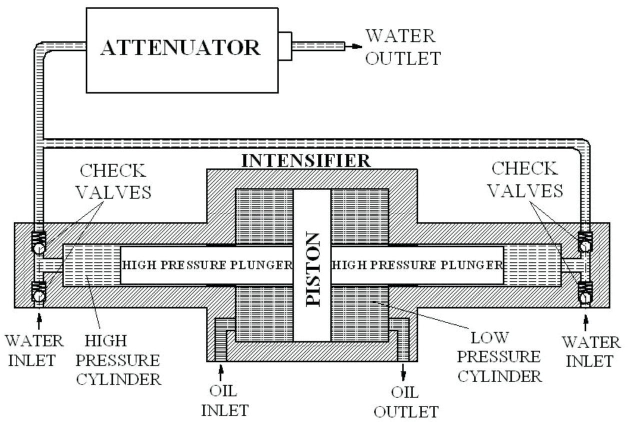


Figure 2 *Intensifier*
Slika 2. *Pojačivač tlaka*

The tubing through which pressurized water reaches the cutting head are made of thick, stainless steel. The inner diameter of the tubing is approximately 3 mm, the outer diameter 10 mm. From the pulsation compensation unit the water enters the cutting head (Figure 3), comprised of several parts, the most important being the orifice, which can be made of diamond or artificial sapphire.

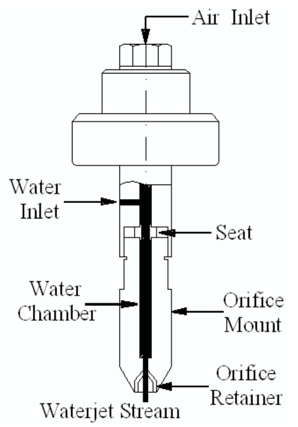


Figure 3 *Pure waterjet cutting head* [3]
Slika 3. *Mlaznica* [3]

Diamond orifices are better and more durable, but up to 10 times as expensive as the sapphire ones. In the orifice, the diameter of the waterjet is reduced from 3 mm to 0,5 mm or less, thus producing a jet of small diameter, but high speed (up to 5500 km/h). Microswitches carry information on plunger position to the control assembly, which changes the direction of the plunger as necessary via a switching scheme. Tap water can be used as the working medium, following a process of filtration for the purpose of removing impurities.

Water pressure, orifice diameter and jet speed are the predominant factors influencing the efficiency and quality of results in waterjet machining. The volume of the waterjet, according to Bernoulli's equation for non-compressible liquids, is calculated according to the following expression [5]:

$$Q_{\mathrm{m}} = 24 \cdot c_{\mathrm{s}} \cdot d^2 \cdot \sqrt{0{,}22 \cdot \frac{p}{\rho}} \tag{1}$$

where:
Q_{m} – volume of waterjet flow, $\mathrm{m^3/s}$
c_{s} – orifice coefficient, -
d – orifice diameter, m
p – water pressure, Pa
ρ – water density, $\mathrm{kg/m^3}$.

Volume and pressure of waterjet flow have different effects on cutting. Increasing the pressure and reducing the orifice diameter, a greater cutting depth is achieved at a constant volume of waterjet flow.

3 Abrasive waterjet cutting
Rezanje abrazivnim vodenim mlazom

The equipment used in abrasive waterjet cutting is similar to that used in pure waterjet cutting, except for the fact that abrasive material is mixed into the waterjet, thus producing an abrasive waterjet [2] (Figure 4).

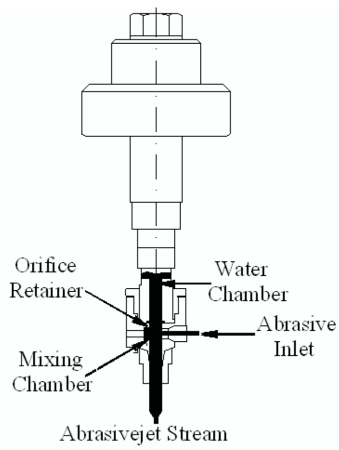


Figure 4 *Abrasivejet cutting head* [4]
Slika 4. *Mlaznica s miješanjem abraziva* [4]

Particles of the abrasive, mixed with water, impact the material surface, producing cracks, from which the water removes further material. The market knows two types of abrasives: one type is produced by crumbling rock into particles of desired size, the other by sifting sea sands. The edges of crumbled rock particles are more jagged and thus more suited to rough cutting, while the sand from the sea is more suited to finishing surfaces, due to more rounded shape of the particles. According to particle size, abrasives can be divided into those suitable for rough cutting (bigger particles), and those suitable for finer cutting (smaller particles).

Cutting efficiency depends on the velocity of the abrasive waterjet, calculated by the following expression [5]:

$$v_{\mathrm{A}} = \eta_{\mathrm{T}} \cdot \frac{v_{\mathrm{o}}}{1 + \frac{\Phi_{\mathrm{mA}}}{\Phi_{\mathrm{mW}}}}, \tag{2}$$

where:
v_{A} – velocity of abrasive particles, m/s
η_{T} – mixing efficiency, -
v_{o} – velocity of waterjet prior to mixing, m/s

Φ_{mA} – mass flow of the abrasive, m^3/s
Φ_{mW} – mass flow of the waterjet, kg/s.

Consumption of the abrasive can significantly impact the cost of the machining, thus demanding lessening the volume of abrasive in machining softer materials. Nominal consumption is in the order of 24 kg/h, and the abrasive used can be recycled and reused. Cutting speed depends on the thickness, type and hardness of the material.

***Table 1** Cutting speed* [4]
***Tablica 1.** Brzine rezanja* [4]

Machining parameters	Orifice diameter, mm	0,23		0,33		0,46		0,56	
	Amount of abrasive added, kg/min	0,23		0,68		0,91		1,46	
	Water pressure, bar	3100		2400		2400		2400	
Mat. thickness, mm		1,6	3,2	6,4	12,7	19	25,4	50,8	100
Cutting speed, mm/min	Brass	762	457	254	102	25	13	8	3
	Aluminium	2030	1270	762	457	305	203	152	102
	Copper	1020	559	305	152	75	38	15	3
	Carbon steel	1270	762	508	305	203	152	75	25
	Tool steel	762	635	435	330	254	191	127	25
	Corrosion -resistant steel	762	610	486	254	152	102	57	25

The best surface quality is achieved on the top side of the material [7]. There is some loss of quality in the bottom side, due to decreased pressure of the waterjet and aberration at higher feedrate (Figures 5 and 6).

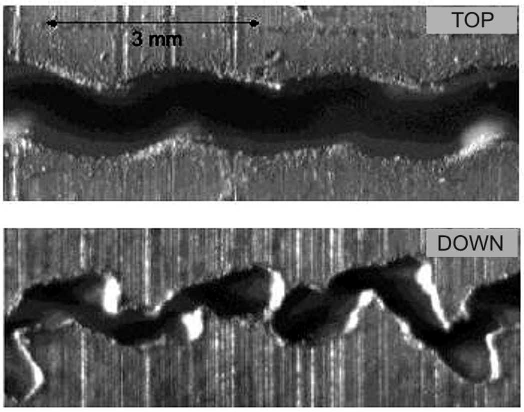


***Figure 5** Shape of cutting surface* [5]
***Slika 5.** Izgled površine reza* [5]

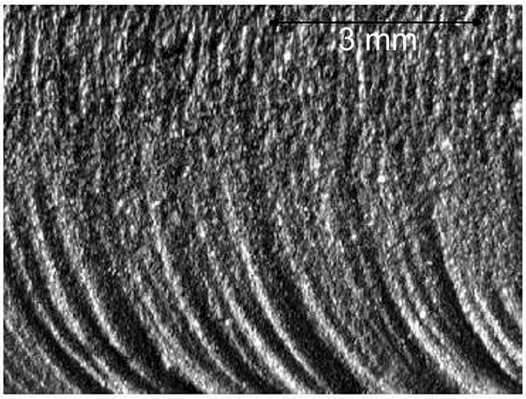


***Figure 6.** Stream alteration* [5]
***Slika 6.** Otklon mlaza* [5]

The coarseness of the machined surface depends on the machining parameters; distance between the cutting head and the machined object, feedrate and working pressure (Figures 7, 8, 9). Quality of the cut surface is usually expressed in height of profile irregularities measured in 10 points *Rz* [6]. The material used in the study was aluminium, 25 mm thick, tensile strength 90 N/mm^2.

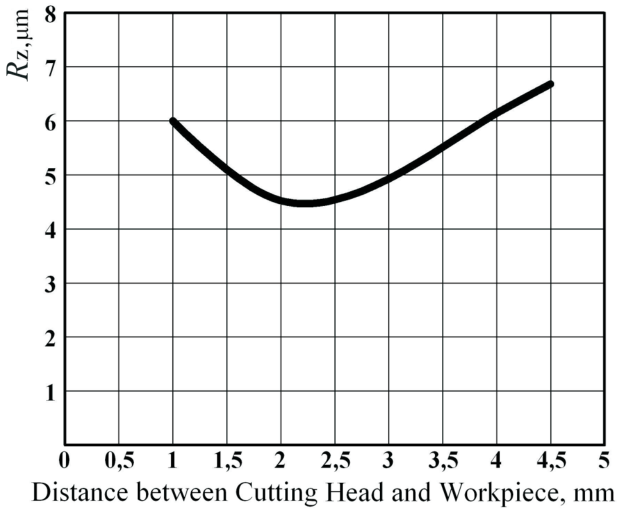


***Figure 7** Dependance between Rz and the distance between cutting head and workpiece* [8]
***Slika 7.** Ovisnost Rz o udaljenosti između mlaznice i radnog komada* [8]

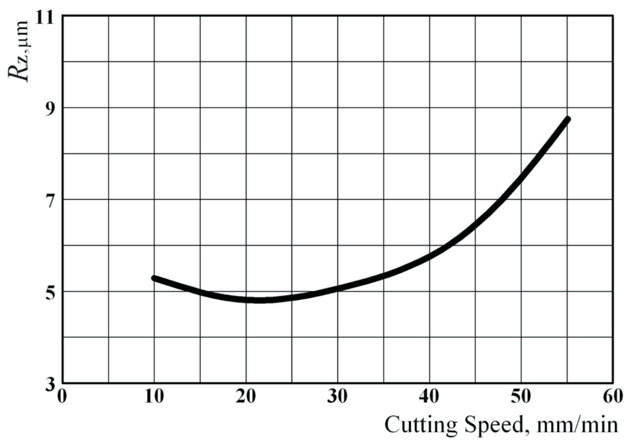


***Figure 8** Relation between Rz and the feedrate* [8]
***Slika 8.** Ovisnost Rz o posmičnoj brzini* [8]

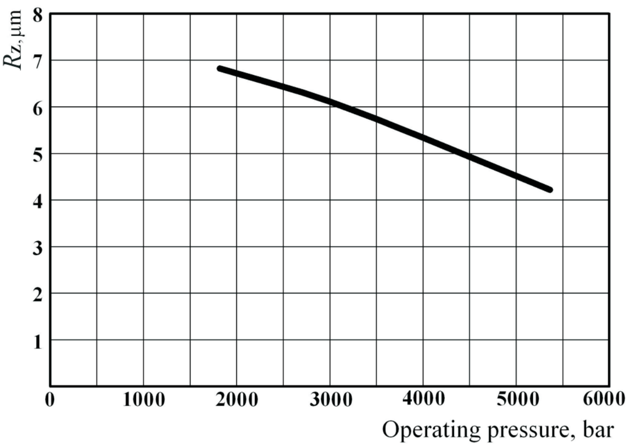


Figure 9 *Relation between Rz and the operating pressure* [8]
Slika 9. *Ovisnost Rz o radnom tlaku* [8]

Figures above clearly show that the greatest influence on the cut surface quality is exerted by feedrate.

4 Waterjet machines
Strojevi za obradu vodenim mlazom

Waterjet machines can be CNC operated, which means that a computer calculates the position and path guiding the tool along one or more axes (Figure 10), while newer machines are equipped with robotic arms guiding the tool along all 6 axes with 0,2-0,3 mm precision and path repeatability of ±0,05 mm.

The desired piece is drawn in 2D or 3D using a CAD programme, transferred into the control box of the machine. Before starting the machining, material type and thickness data as well as desired precision need to be entered, while the CNC calculates the other machining parameters (cutting speed). Virtually all geometrical shapes can be cut, the only limitation being small bore diameters, which have to be bigger than the waterjet diameter.

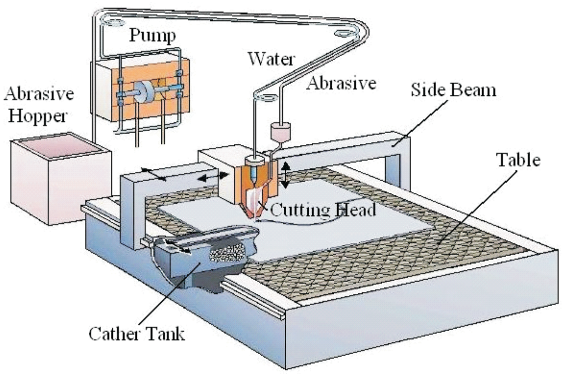


Figure 10 *Waterjet machine* [5]
Slika 10. *Stroj za rezanje vodenim mlazom* [5]

Material clamping is relatively simple, since due to small forces exerted (in machining along one or two axes) additional clamps are not necessary. Quality of the machined surface (stated as the roughness of the cut surface) depends mainly on cutting speed, which in turn, according to Table 1, depends on the type and thickness of material.

As an example, cutting tool steel 25 mm thick with 40 mm/min federate produces machining quality of Ra=3,2 µm and cutting precision of ±0,1 mm, thus being suitable for cutting larger module gears and chain sprockets for greater pitch chains.

5 Advantages and weaknesses of waterjet machining [6]
Prednosti i nedostatci obrade vodenim mlazom [6]

a) Advantages of waterjet machining:
- The amount of heat generated in the process is not significant, a fact of special importance in cutting alloy steels
- No dust particles which represent a breathing hazard are formed
- Due to small diameter of waterjet loss of material is limited
- Short machine setup times
- Easy automation of the procedure
- No sharp edges after cutting
- One tool is used for cutting material of different thickness and composition (aluminium, steel, glass)
- Environmentally acceptable procedure – natural materials are used, namely water and sand, and there are no waste impurities (oil, emulsions).

b) Weaknesses of waterjet machining:
- Furrowed surface due to waterjet energy decrease along the depth of the cut; the solution is in reducing cutting speed (feedrate) or raising pressure.
- In linear cutting at speed the cut gets a "V" profile
- In cutting inner angles at speed, waterjet may produce notches in the material
- In cutting circles and arches at speed, waterjet may deviate
- Corrosion-prone materials need to be protected from corrosion after cutting
- Pressure losses between the pump and the cutting head reduce cutting speed
- Machining very hard materials is difficult or impossible
- Limitations in machining spatial (3D) shapes.

6 Conclusion
Zaključak

Waterjet cutting is a relatively new technology of machining, with first industrial uses occurring during the 80's of the past century. It is predominantly used in cutting material that is hard, even impossible to cut by other means. Research is being conducted and improvements made on cutting heads, abrasives, machine construction and pressure increases in view of making the procedure more economically viable in comparison with traditional cutting processes. Efforts are being made to replace Garnet (a type of mineral), Mohs hardness 8, priced around USD 600/metric ton with ground glass, Mohs hardness 6, priced around USD 50/metric ton. The procedure is applicable in other technical applications as well, such as surface machining intended to increase wear resistance, cutting material in honeycomb pattern, polishing, drilling and turning work. Combining conventional machining processes with waterjet machining economically viable production procedures can be designed, characterized by exactness and efficiency.

7
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