

ABRASIVE WATERJET CUTTING COST

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ABSTRACT:

Cost estimation and costing are critical for manufacturing industries. Of vital interest to the manufacturing are production costs and production rates. Abrasive waterjet cutting is now a widely accepted process in industry for machining metals, and other materials. The process is based on the erosion of material by abrasive particles accelerated by high pressure waterjet. Knowledge of a waterjet system's investment and operating costs should form the basis for evaluating its profitability. The cost ranges provide a basis for the cost estimation prior to plan of buying order of abrasive waterjet machine. The high investment and operating costs must be justified according to economic criteria with corresponding financial advantages. In this paper is presented the method for determination the abrasive waterjet cutting cost.

KEYWORDS: metal cutting, abrasive waterjet, cost

1. INTRODUCTION

Production managers in industries set up production plans based on factory profit. They calculate profit from cost accounting after products are manufactured. The abrasive waterjet cutting process provides many unique capabilities and advantages that can prove very effective in the cost battle. Beyond cost cutting, the abrasive waterjet process is recognized as the most versatile and fastest growing process in the world. Abrasive waterjet removes material without heat. In this cold cutting process, the supersonic waterjet stream accelerates abrasive particles and those particles erode the material. Ease of programming and the abrasivejet ability to cut almost all materials and any thickness make it suitable for all shape cutting applications. Application of abrasive waterjet cutting machines made possible good quality of products, flexibility of production and enlargement of economy. For many potential users of abrasive waterjet cutting machines, it is strategically important to invest in future technology and, if finances allowed, just to accept the financial risk. As one of the fastest growing machine tool industries, waterjet cutting has proven to save time and money. The high investment and operating costs for waterjet cutting machines, compared to conventional cutting machines, must be justified according to

economic criteria with corresponding financial advantages. Only a detailed analysis of the technology solution together with an exact estimate of the part costs expected during production provides an acceptable basis for an investment decision.

If the finished product is presently being cut using laser, plasma or oxyfuel, and no secondary work is needed to the part after being cut, it is unlikely waterjet will be an economical solution. In many cases, waterjet now costs less than laser. Although abrasive waterjet should be considered for all applications, it will not replace conventional cutting methods such as stamping, laser or plasma cutting. It will continue to experience increasing use for cutting a wide variety of specialty materials. ([1], [5], [6], [9],[10])

2. PARAMETERS INFLUENCED TO ABRASIVE WATERJET CUTTING AND COST

Abrasive waterjet cutting process depends on a large number of process parameters such as water pressure, orifice diameter, standoff distance, abrasive rate, cutting speed etc. A common misconception in abrasive water jet cutting is that it is best to use as little power, as little pressure, as little abrasive as possible to get the job done. Water pressure, orifice/nozzle size combination, pump power capacity and abrasive flow rate have a

pronounced effect on cutting speed, cut edge quality and part cost. The power in the abrasive jet at the exit of the nozzle is a function of pressure, flow and nozzle size. Power output is more sensitive to changes in nozzle diameter than pressure: doubling the nozzle diameter increases the jet power by a factor of 4, whereas doubling the pressure increases the power by a factor 2.8.

The pump is the determining factor in the operating costs for the waterjet cutting. The key parameter that controls cutting speed is the water orifice diameter or, indirectly, the water flow rate. The other two parameters that greatly influence the speed are the system pressure and the abrasive flow rate. However, the optimum values of these parameters are not totally independent. The optimum abrasive flow rate can be related to the water flow rate. These two parameters, i.e. water orifice diameter and system pressure also mostly influence the operating costs.

Water pressure has a great influence on the cut quality. Higher pressures result in faster cutting and smoother edges, but require higher maintenance cost and more power from the water pump. Most in abrasive waterjet cutting circles follow a simple rule: the higher the pressure, the higher the cutting speed, the lower the costs. Productivity rises with pressure, but maintenance rises with pressure, too.

To cut as fast as possible, the system should be operated using the maximum pump power available. To select the right pump we have two options. If we are cutting prototypes parts and do not foresee heavy production requirements, then a large pump is likely waste of capital. If we are to perform industrial production of high volume parts and are in the fortunate position of being able to afford the ideal machine, then a larger pump with multi-head cutting capability is the right choice. A variety of pump sizes are present in table 1. The most common pump size is the 37 kW (50 HP) pump powering one head. The order of popularity follows 75 kW (100 HP), 18 kW (25 HP), and 112 kW (150 HP). Over 60% of all pumps produced today are of 37 kW or 75 kW. Since 1999, there has been a steady increase in the number of multi-head systems using 75 kW pump and even higher. The upgrade to 75 kW costs a little more (22500 EUR to 37500 EUR), but are

more productive than 37 kW single head systems.

Table 1. Variety of pump sizes

Pump power	Output (L/min)	Orifice diameter (mm)	Multi-head options
18 kW (25 HP)	2.25	0.25	One head
37 kW (50 HP)	4.50	0.35	2 x 0.25 mm
56 kW (75 HP)	6.75	0.43	3 x 0.25 mm
75 kW (100 HP)	9.00	5.30	4 x 0.25 mm or 2 x 0.35 mm
112 kW (150 HP)	13.50	7.10	6 x 0.25 mm or 3 x 0.35 mm or 2 x 0.45 mm

Abrasive constitutes 2/3 of the machine operating cost of the equipment. In abrasive waterjet cutting it is often thought that to reduce the abrasive flow rate saves money. On the contrary, it wastes money. There is a peak performance point that abrasive waterjets operate. As abrasive flow rate is increased cut speed goes up and cost per meter goes down. Cut speed and cost per meter are both at their optimum. This fact is independent of the material of workpiece, or the power of the system. When you include all overhead the cheapest cutting is always found at the fastest possible speed. In figure 1 is shown cutting speed versus abrasive flow rate.

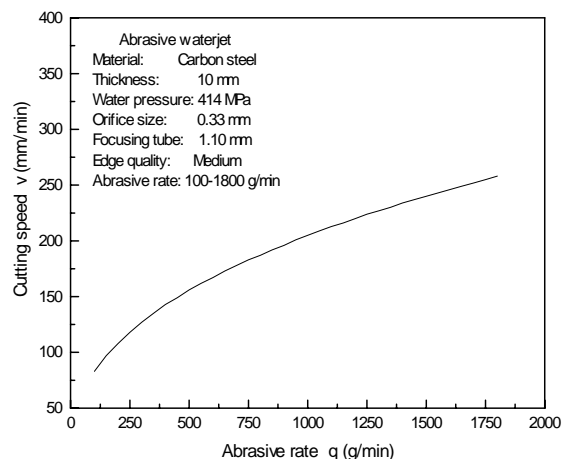


Fig. 1. Cutting speed vs abrasive rate
Orifice/nozzle size combination has an influence on cut speed. The orifice size

dictates the volume of water output by the cutting head. Larger orifices will typically produce a faster cut but will require more pump power. Generally a nozzle (focusing tube) which is about three times larger than the orifice provides optimal cutting efficiency, balancing cost and cutting speed. Typical orifice/nozzle combinations are: 7/21 (0.17/0.54 mm), 10/30 (0.25/0.76 mm), 14/43 (0.35/1.10 mm), 18/63 (0.45/1.60 mm) for water pressure of 380 MPa, and 6/21 (0.15/0.54 mm), 9/30 (0.23/0.76 mm), 13/43 (0.33/1.10 mm), 18/63 (0.45/1.60 mm) for water pressure of 414 MPa. Generally when cutting with a single head and a 37 kW (50HP) pump the 14/40 (0.35mm/1.10mm) orifice/nozzle combination is used. When cutting with two heads and a 37 kW pump the 10/30 orifice/nozzle combination is used.

The abrasive used in abrasive waterjet cutting is hard sand that is specially screened and sized. The most common abrasive is garnet. Different mesh sizes are used for different jobs: 120 mesh - produces smooth surface, 80 mesh - most common, general purpose, 50 mesh – cuts a little faster than 80, with slightly rougher surface. Smaller abrasive grains (120 mesh or smaller) will produce a slightly slower but slightly smoother surface (as compared to 80 or 50 mesh).

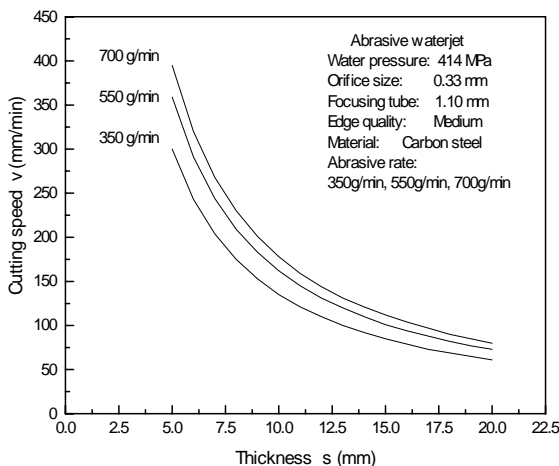


Fig. 2. Cutting speed vs thickness for various abrasive rates

Cutting speed is the key parameter to reduce the operating cost. The key is to cut as fast as possible, fastest cut speed - lowest cost per meter. The speed at which the waterjet can cut through material will vary based on a variety of parameters. Cutting speed depends

on the material, the thickness, the quality of the edge finish and tolerance. Cutting speed varies and as a function of the geometry of the part. Cutting speed increases as the abrasive flow rate increases, figure 2, and as the water pressure increases, figure 3.

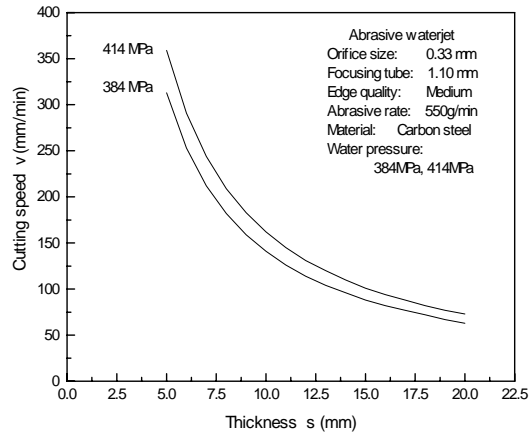


Fig. 3. Cutting speed vs thickness for various water pressures

Maintenance is one of the parameters influenced to cost. Like any other machine, machine for abrasive waterjet cutting has parts that wear and must be replaced occasionally. Maintenance of a waterjet primarily revolves around servicing and changing consumable items in the cutting head and the pump.

Table 2. Lifetime of wear parts

Consumables	Approximate hours of cut time
Orifices Ruby/Sapphire	40 hours
Diamond orifices	300 to 1000 hours
Nozzles	80 to 120 hours
Inserts	400 hours
High-pressure seals	250 hours
Low-pressure seals	1000 hours

In the cutting head, orifices, nozzles, wear inserts, needle and seats, and abrasive delivery tubes will wear out. The pumps will need high-pressure seals, check valves and low-pressure seals serviced and changed as they wear. Consumption of wear parts vary by machine and application. In table 2 is shown a general guide of the consumables involved with abrasive waterjet cutting as well as the average lifetime of those parts. Maintenance costs go up with pressure and

speed. So waterjet users try to cut fast, but not too fast. ([3],[4],[7],[8],[11],[12])

3. MATHEMATICAL MODEL FOR DETERMINATION COST

Three categories make cost of waterjet cutting: depreciation cost, operating cost, and labour cost.

Depreciation cost is associated with the equipment purchase. It is the initial price of the equipment amortized over a specific amount of time. Since depreciation cost is fixed, they occur whether the machine is working or idle. The investment costs of a machine are a function of the power of the pump, the size of the workpiece and the number of axes required to manipulate the workpiece around while performing the operation. The investment costs do not only depend on the size of the working area already on the required acceleration and speed characteristics as well as the accuracy of the positioning systems. Depending on the technical requirements, the investment costs can differ considerably even if the size of the working area is the same. While the investment cost of a waterjet machines is high, improved productivity and product quality, combined with low tooling and maintenance costs, often make a system economical, especially for companies that produce a wide range of parts.

Operating cost is associated with operating the process, including electrical energy consumption, water consumption, abrasive consumption, wear parts consumption, and maintenance and repair. These costs occur only when the machine is operating. The operating cost depends from specific applications. Operating cost includes cost of power, water, high-pressure seals, check valves, orifice, mixing tube, abrasive, inlet water filters, long term spares (hydraulic pump, high-pressure cylinders, etc). It does not include labour, lease or depreciation, facilities, or other overhead costs. The average operating cost for abrasive waterjet is about 20 EUR per hour.

Labour cost is associated with running the machine, including the time to handle raw material, finished parts and remnants, and attending the machinery while it's running. To place a value on these costs, it must know the hourly cost of an operator, the amount of

time it takes to run a part on machine, the percentage of time allotted for machine setup, and the percentage of time an operator actually attends the machine. These factors all may be unique for each application or facility.

Cost of abrasive waterjet cutting can be calculated based on investment, operating and labour costs.

Abrasive waterjet cutting cost per hour can be calculated by equation [2]:

$$C = C_i + C_o + C_p \quad (1)$$

Where C (EUR/h) is abrasive waterjet cutting cost per hour, C_i (EUR/h) is investment cost, C_o (EUR/h) is operating cost, C_p (EUR/h) is labour cost.

Investment cost is related to depreciation period of waterjet cutting machine. Investment cost can be calculated by equation:

$$C_i = \frac{I}{D \cdot L_a} \quad (2)$$

Where I (EUR) is capital investment cost of water jet cutting machine, D (year) is depreciation period, L_a (h/year) is machine utilization.

The calculation for operating cost is specific to the waterjet process. Operating cost comprises costs of electrical energy consumption, cutting water consumption, abrasive consumption, wearing parts consumption, and maintenance of machine:

$$C_o = C_e + C_w + C_a + C_r + C_M \quad (3)$$

Where C_e (EUR/h) is cost of electrical energy, C_w (EUR/h) is cost of water, C_a (EUR/h) is cost of abrasive, C_r (EUR/h) is cost of wear parts, C_M (EUR/h) is maintenance cost.

Cost of electrical energy can be calculated by equation:

$$C_e = c_e \cdot E \quad (4)$$

Where c_e (EUR/kWh) is unit cost of electrical energy, E (kW) is electrical power consumption.

Water cost can be calculated by equation:

$$C_w = c_w \cdot Q_w \quad (5)$$

Where c_w (EUR/m³) is unit cost of water, Q_w (m³/h) is water consumption.

Abrasive cost can be calculated by equation:

$$C_a = c_a \cdot Q_a \quad (6)$$

Where c_a (EUR/kg) is unit abrasive cost, Q_a (kg/h) is abrasive consumption.

Cost of wear parts can be calculated by equation:

$$C_r = C_1 + C_2 = \frac{c_1}{L_1} + \frac{c_2}{L_2} \quad (7)$$

Where C_1 (EUR/h) is water orifice wear cost per hour, C_2 (EUR/h) is abrasive nozzle wear cost per hour, c_1 (EUR/part) is water orifice

price, L_1 (h/part) is water orifice lifetime, c_2 (EUR/part) is abrasive nozzle price, L_2 (h/part) is abrasive nozzle lifetime.

Maintenance cost can be calculated by equation:

$$C_M = \frac{M}{L_a} \quad (8)$$

Where M (EUR/year) is maintenance costs per year, L_a (h/year) is machine utilization.

Abrasive waterjet cutting cost per hour, according equations from (1) to (8) can be done by equation in form:

$$C = \frac{I}{D \cdot L_a} + c_e \cdot E + c_w \cdot Q_w + c_a \cdot Q_a + C_r + \frac{M}{L_a} + C_p$$

Table 3 Cost calculation example of abrasive waterjet cutting

Elements of costs	Abrasive water jet cutting		
	37 kW (50 HP)	37 kW (50 HP)	75 kW (100 HP)
Pump power	37 kW (50 HP)	37 kW (50 HP)	75 kW (100 HP)
Pressure	380 MPa	414 MPa	414 MPa
Orifice/nozzle	14/43	14/43	14/43
Cutting speed	9.3 m/h	11.7 m/h	11.7 m/h
Investment cost	I=120 000 EUR	I=120 000 EUR	I=150 000 EUR
Depreciation period	D=5 years	D=5 years	D=5 years
Machine utilization	L _a =4000 h/year	L _a =4000 h/year	L _a =4000 h/year
Investment costs	C _d =6 EUR/h	C _d =6 EUR/h	C _d =7.5 EUR/h
El. power consumption	E=45 kW	E=45 kW	E=85 kW
Unit cost of el. energy	c _e =0.105 EUR/kWh	c _e =0.105 EUR/kWh	c _e =0.105 EUR/kWh
Costs of electrical energy	C _e =4.72 EUR/h	C _e =4.72 EUR/h	C _e =8.92 EUR/h
Water consumption	Q _w =0.20 m ³ /h	Q _w =0.24 m ³ /h	Q _w =0.24 m ³ /h
Unit cost of water	c _w =0.5 EUR/m ³	c _w =0.5 EUR/m ³	c _w =0.5 EUR/m ³
Costs of water	C _w =0.10 EUR/h	C _w =0.12 EUR/h	C _w =0.12 EUR/h
Abrasive consumption	Q _a =33 kg/h	Q _a =42 kg/h	Q _a =42 kg/h
Unit cost of abrasive	c _a =0.7EUR/kg	c _a =0.7EUR/kg	c _a =0.7EUR/kg
Costs of abrasive	C _a =23.10 EUR/h	C _a =29.40 EUR/h	C _a =29.40 EUR/h
Orifice wear cost	C _n =0.060 EUR/h	C _n =0.078 EUR/h	C _n =0.078 EUR/h
Nozzle wear cost	C _m =0.60 EUR/h	C _m =0.78 EUR/h	C _m =0.78 EUR/h
Costs of wear parts	C _r =0.66EUR/h	C _r =0.86EUR/h	C _r =0.86EUR/h
Maintenance cost per year	M=5000 EUR/year	M=5000 EUR/year	M=5000 EUR/year
Maintenance cost	C _M =1.25 EUR/h	C _M =1.25 EUR/h	C _M =1.25 EUR/h
Labour cost	5 EUR/h	5 EUR/h	5 EUR/h
Waterjet cost per hour	40.83 EUR/h	47.35 EUR/h	53.05 EUR/h
Waterjet cost per meter	4.39 EUR/m	4.05 EUR/m	4.57 EUR/m
Material of workpiece: carbon steel; Thickness: 10 mm			

Manufacturing cost can be calculated by equation:

$$C_m = C \cdot t_m \quad (9)$$

Where C_m (EUR) is manufacturing cost, t_m (h) is manufacturing time.

Manufacturing time can be calculated by equation:

$$t_m = \frac{L}{v} \quad (10)$$

Where L (m) is length of cut, v (m/h) is cutting speed.

Abrasive waterjet cutting cost per meter is established as:

$$C' = \frac{C}{v} \quad (11)$$

Where C' (EUR/m) is abrasive waterjet cutting cost per meter.

Table 3 show cost calculation example of cutting by abrasive waterjet.

4. CONCLUSION

Abrasive waterjet machining is an attractive process. Waterjet can cut or erode through virtually any material known, making it one of the most versatile machines available. It is capable of producing high precision parts that usually requiring no further processing. Abrasive waterjet cutting is now the most cost effective method to cut steels.

Knowledge of investment and operating costs represents a base for investment in abrasive waterjet cutting machine. For different abrasive waterjet cutting machines typical investment costs and operating costs depend from pump power and important system components. The high investment and operating costs, compared to conventional methods, must be justified according to economic criteria with corresponding financial advantages. Presented cost model includes the specific parameters of abrasive waterjet cutting process. Cost calculation example of cutting carbon steel by abrasive waterjet show that cost per meter decreases as water pressure increases. Cost per meter of 75 kW multi heads systems is little more then 37 kW single head systems.

REFERENCES

- [1] Davorin KRAMAR, Miha JUNKAR, *The Development of a Software Tool for the Selection of Contour-cutting Processes*, Journal of Mechanical Engineering 49 (2003) 6, p. 346-365
- [2] Davorin KRAMAR, Miha JUNKAR, *Laser and Abrasive Waterjet Cutting Economics*, International Sheet Metal Review, 2, p. 38-41
- [3] Miroslav RADOVANOVIC, *Estimate of Cutting Speed by Abrasive Waterjet Cutting*, The 31st Internationally Attended Scientific Conference "Modern Technologies in the XXI Century", Bucharest, Romania. 2005, p. 8.196-8.203
- [4] Miroslav RADOVANOVIC, Predrag DASIC, Michal STEFANEK, *Some Possibilities for Determining Abrasive Waterjet Cutting Parameters*, 13. International Scientific Conference "CO-MAT-TECH 2005", Trnava, Slovakia, 2005, p. 969-976
- [5] Miroslav RADOVANOVIC, *Precision Cutting by Abrasive Waterjet*, Scientific Conference "Manufacturing and Management in 21st Century", Ohrid, Republic of Macedonia, 2004, p. 94-99
- [6] Miroslav RADOVANOVIC, *Abrasive Waterjet Machining*, Seventh International Scientific Conference "Smolyan-2005", Smolyan, Bulgaria, 2005, p. 229-234
- [7] Miroslav RADOVANOVIC, *Determining of Cutting Data by Abrasive Waterjet Cutting*, XII International Science and Engineering Conference "Machine-building and Technosphere of the XXI Century", Sevastopol, Ukraine, 2005, p. 221-225
- [8] Miroslav RADOVANOVIC, *Comparison of Advanced Machining Processes for Contour Cutting of Plate*, International Conference "Computing and Solutions in Manufacturing Engineering CoSME '04", Brasov, Romania, 2004, p. 437-442
- [9] Waterjet Seminar, Flow International Corporation, 2002, www.flowcorp.com
- [10] Tim HESTON, *Abrasive Waterjet Takes off*, Fabricating&Metalworking magazine, October, 2005
- [11] Abrasive Waterjet Cutting, Application and Capability, AccuStream, www.accustream.com
- [12] Abrasive Waterjet Cutting Speed Calculator, KMT Waterjet Systems, www.kmtwaterjet.com

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