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TECHNO-ECONOMICAL COMPARISON OF CUTTING MATERIAL BY LASER, PLASMA AND OXYGEN

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Original scientific paper
This paper compares three of the most common processes: laser, plasma and oxygen cutting in terms of economical point of view. It illustrates the introduction of thermal cutting methods into the manufacturing of the companies with an emphasis on their productivity. This comparison can be carried out only to a limited extent what is given by many factors.

Keywords: *cutting cost, productivity, plasma, laser, oxygen*

Ekonomska usporedba rezanja materijala pomoću lasera, plazme i kisika

Izvorni znanstveni članak
U članku se uspoređuju tri najčešća procesa: rezanje laserom, plazmom i kisikom s ekonomskog motrišta. Članak prikazuje uvođenje metoda toplinskog rezanja u proizvodnju poduzeća s naglaskom na njihovu produktivnost. Ova usporedba može se provoditi samo u ograničenom opsegu, što je dano pomoću mnogo faktora.

Ključne riječi: *troškovi rezanja, produktivnost, plazma, laser, kisik*

1 Introduction

Due to the world economic crisis, industrial sector records a decrease in production. As the result of the crisis, many manufacturing companies seek to minimize their costs, in order to maintain a competitive presence on the market. One of the first operations in the manufacture of components is the cutting of materials. Historically, the development of material cutting technologies has been improved. From classic – conventional technologies that are based on the plastic deformation (breaking, torsion) and the material cutting technologies (by a wedge, or a grinding tool), it has been moving to new technologies that are based on the evaporation of material (plasma, laser) and physical-chemical methods of material cutting [1]. The non-traditional cutting processes have been developed in response to new and unusual machining requirements that could not be satisfied by conventional methods. These requirements and the resulting commercial and technological importance of the non-traditional processes include [2]:

- the need to machine newly developed metals and non-metals (having special properties such as high strength, high hardness, high toughness),
- the need for unusual and/or complex part geometries that cannot easily be accomplished by conventional methods,
- the need to avoid surface damage that often accompanies the stresses created by conventional machining.

2 Current state of the problem

The objective of this paper is to show a cost estimation that can provide cost information throughout the metal cutting processes. The broad definition of costs is related to the economic resources (manpower, equipment, real facilities, supplies and all other resources) necessary to accomplish work activities or to produce work outputs [11]. Usually, costs are expressed in terms of units of currency. Therefore, costs are the amount of money representing the resources spent for the production of output. Total product costs are composed of several different cost items. Two general cost classifications are on the one hand direct versus indirect costs and on the other hand variable versus fixed costs. Direct costs are costs that can be identified specifically and consistently with an end objective (such as a product, service, software, function, or project), while indirect costs cannot be identified specifically and consistently with an end objective [10]. This means that direct costs can be allocated directly, i.e. the allocation base is known, whereas for the allocation of indirect costs an allocation base has to be defined [12]. Variable costs are costs that change with the rate of production or the performance of services [11]. In this paper is given only a short introduction. The fundamentals of laser beam cutting have been described in detail in several texts [6, 7, 8]. Laser beam cutting belongs to the group of thermal cutting processes. The laser beam is focused on the workpiece, heats it up locally and induces a phase transformation of the material. The material is blown out of the developing cut kerf by the normally coaxial gas jet that is added to support the process [3]. The plasma cutting process has made astonishing progress in the last thirty-five years, particularly in the last five years. The plasma arc cutting is an erosion process that utilizes a constricted arc in the form of a high – velocity jet of ionized gas to melt and sever metal in a narrow area. The arc is concentrated by a nozzle into a small area of the workpiece. The metal is melted by the intense heat of the arc and then removed by the jet gas stream from the torch nozzle. Plasma arc cutting can be used on almost any material that conducts electricity, including those materials that are arc resistant to oxyfuel gas cutting [4]. The oxyfuel gas cutting includes a group of cutting processes that use controlled chemical reaction to remove preheated metal by rapid oxidation in a stream of pure oxygen. This process begins by raising the temperature of 760 °C to 870 °C with an oxyfuel gas flame. Upon reaching this temperature, the surface of the metal will appear bright red. A cutting-oxygen stream is then directed at the preheated spot, causing rapid oxidation of the heated metal and generating large amounts of heat. This heat supports continued oxidation of the metal as the cut progresses. Combusted gas and the pressurized oxygen jet flush the molten oxide away, exposing fresh surfaces for cutting. The metal in the path of the oxygen jet burns. The cut progresses, makes a narrow slot, or kerf through the metal [5]. When oxygen and plasma cutting, it is also necessary to mention their versatility mainly when using the hand cutting equipment, what is not possible by laser. A high flammable gas and open flame represents a fire hazard and that means the user is faced with a higher cost related to premises insurance. Plasma reduces these risks because there is no need to use an open flame or flammable gas. The heat generated by plasma is more concentrated and significantly reduces the risk associated with the formation of hot metals during cutting. Welding and thermal cutting of materials especially by oxy – acetylene flame cutting is in the Fire and Rescue statistics a long- term problem. Therefore, the companies in Slovakia using these thermal cutting technologies must follow the law No. 314/2001(SG) about the protection against fire and decree No. 121/2001 (SG) about the fire prevention.

3 Experimental set up

To compare the above mentioned cutting technologies in terms of the economical comparison, a structural steel of EN S355J0 was used. It is a non - alloyed fine - grained structural steel with the guaranteed cold weldability. It is suitable for welded structures with higher strength, for machinery parts, and transport equipment, for the production of low- stressed rotating parts. The chemical composition of the used material is listed in Tab. 1.

Table 1 Chemical composition of the used material EN S355J0, wt. %

C	Mn	Si	P	S	N
Max. 0,20	Max. 1,60	Max. 0,55	Max. 0,04	Max. 0,04	Max. 0,009

The samples were cut with a size of 150 × 150 mm in three different thicknesses of 10 mm, 15 mm, and 20 mm. The cutting process was carried out at optimal machine settings, i.e., the settings proposed by a control system after entering the parameters of the cut material. When cutting these samples by oxygen (by cutting machine Multitherm 3100 from the Messer Cutting System corporation), by plasma arc (plasma cutting machine Advanced HD 3070) and by laser (laser cutting machine Platino 2040/ CP 3500), the parameter settings of each machine were recorded.

4 Economic considerations of the cutting methods

Another area to consider productivity is the number of parts that can be produced in a given period of time. One factor that is critical to the number of parts produced is speed. The maximum cutting speed, applied to all thicknesses was achieved when plasma cutting, that means the shortest production time. By laser cutting, there is a linear reduction in cutting speed with an increase of the material thickness. The oxygen cutting technology was almost a four times slower process, and there were achieved minimum changes in cutting speed. To figure out how many parts of the used size can be cut by these three technologies, we can use speed factor for the productivity comparison (Tab. 2). Due to the cutting speed it is possible to calculate the number of parts produced per hour. The speed plays the biggest role in the laser, plasma and oxygen cost. Plasma and laser machines have faster cycle times and a greater number of parts.

Table 2 Productivity comparison in terms of the number of produced parts

Technology	Thickness (mm)	Cutting Speed (mm/min)	Linear length of cut (mm/hour)	Number of parts produced per hour
Multitherm 3100	10	561	33 660	56
	15	503	30 180	51
	20	471	28 260	47
HD 3070/ PLS P6001.20	10	2300	138 000	230
	15	1200	72 000	120
	20	1000	60 000	100
Platino 2040/ Trumpf 4030)	10	1500	90 000	150
	15	1100	66 000	110
	20	760	45 600	76

As it is seen by the table given above, plasma produces the greatest number of parts in one hour of cutting (230). Laser is the next fastest process by producing 150 parts and oxygen cutting is the slowest process producing 56 parts per hour (the number of parts varies due to the different thickness of material). Based on the given data, we can get the real cost per hour. The calculation models have been derived from general calculation models used in manufacturing economics. Costs for one work of equipment N_{t} can be expressed from:

$$N_{\mathrm{t}} = \frac{N_{\mathrm{z}}}{t_{\mathrm{ABC}}}, \tag{1}$$

where N_z represents the total annual costs of equipment and t_{ABC} is the number of operating hours per year (usually 2000 hours per year and shift). To determine cost per part, there is a need to divide the operating cost for one hour (Tab. 2) by the number of parts produced in that hour. Following that, it is necessary to know the operating cost for one hour of the used cutting machines. The given operating costs can vary:

- oxygen produced the maximum of 56 parts at a thickness of 10 mm, which equates to 13,7 cents per part,
- plasma produced the maximum of 230 parts at a thickness of 10 mm, for a cost of 13,5 cents per part,
- laser produced the maximum of 150 parts at a thickness of 10 mm, for a cost of 28,5 cents per part.

5 Results and discussion

The "typical cutting" costs were estimated on the basis of the given parameters and were discussed with the experts in cost evaluation of each organisation, so it greatly depends on location. Costs for gas, power, and torch consumables were calculated using the most recent rates for large industrial accounts. When laser, plasma or oxygen cutting is the chosen cutting method for a cost calculation, a few variables specific to that cutting method have to be taken into account, see Tab. 3. All of these main features affecting the cutting process were used for the sample with a thickness of 10 mm and for one piece of cut sample. It was found out that the total cutting cost involved in the different cutting methods was nearly equivalent for plasma and oxygen. The most expansive method to produce one piece of sample was the laser cutting. The variables such as: number of operating hours, insurance, and cost for required space, maintenance or depreciation were calculated as the default values. These are used as the fixed variables affecting the rate per machine hour. As it can be seen, the laser cutting process has the highest operating cost, which is 42,08 € per hour. Then follows the plasma cutting with the operating cost of 31,09 € per hour while the oxygen cutting process has the lowest operating cost. The cost of labour slightly differs, and this value mainly affects the total cost to produce a piece of product.

Table 3 Estimating the cutting costs

Technology	Plasma	Laser	Oxygen
Cost of gases	4,08 €/h	7 €/h	3,7 €
Cost of electricity	8,1 €/h	7,5 €/h	-
Number of machine hours per year	1600 h	1600 h	1600 h
Cost of interest	6750 €/year	9500 €/year	1250 €/year
Cost of depreciation	27 000 €/year	38 000 €/year	5000 €/year
Cost of insurance	6750 €/year	9500 €/year	1250 €/year
Cost of space	3840 €/year	3840 €/year	3840 €/year
Cost of maintenance	5400 €/year	7600 €/year	1000 €/year
Rate per machine hour	31,0875 €/h	42,775 €/h	7,71 €/h
Number of tips	1	1	1
Cost of tips	2,6 €/h	0,2 €/h	0,25 €/h
Number of cathodes	1	-	-
Cost of cathodes	1,2 €/h	-	-
Number of lenses	-	1	-
Cost of lenses	-	0,8 €/h	-
Total lenght of cut	0,60 m	0,60 m	0,60 m
Total time of cut starts	0,001 h	0,0008 €/h	0,0027 h
Total time of cutting	0,0043 h	0,0066 h	0,015 h
Total cost of labour	7,46 €/h	8,77 €/h	7,57 €/h
Total cost of gases	0,0175 €/h	0,0462 €/h	0,055 €/h
Total cost of electricity	0,0348 €/h	0,05 €/h	-
Total cost of machine hours	0,133 €/h	0,2823 €/h	0,12 €/h
Total cost of tips	0,011€/h	0,00132 €/h	0,00375 €/h
Total cost of cathodes / lenses	0,00516 €/h	0,00528 €/h	-
Total cutting cost	7,66 €/h	9,16 €/h	7,75 €/h
Power per hour (at the same thickness)	139,53 W/h	90,91 W/h	40 W/h
Price per meter (at the same thickness)	0,055 €/m	0,1 €/m	0,19 €/m

When evaluating the total cutting cost for laser, the equation (2) was used:

$$C_{\text{lab tot}} + C_{\text{el tot}} + C_{\text{gas tot}} + C_{\text{mh tot}} + C_{\text{ip tot}} + C_{\text{lens tot}} = C_{\text{tot}}. \quad (2)$$

To evaluate the cost for plasma cutting, the equation (3) was used

$$C_{\text{lab tot}} + C_{\text{el tot}} + C_{\text{gas tot}} + C_{\text{mh tot}} + C_{\text{ip tot}} + C_{\text{cat tot}} = C_{\text{tot}}. \quad (3)$$

Total cutting cost for oxygen cutting can be estimated as follows:

$$C_{\text{tot}} = C_{\text{lab tot}} + C_{\text{cgas tot}} + C_{\text{mh tot}} + C_{\text{tip tot}}. \quad (4)$$

All the equations were based on the literature review [8].

6 Conclusion

Each of these methods has its advantages and shortcomings and which one to choose depends only on the specific business needs. The well - chosen cutting technology clearly affects the inputs and outputs of the entire production process. From the preceding case study it is evident that each process has a different significant cost set associated with it. The calculations were made to see in which cases the cutting method is a viable option. The model presented in this paper is very limited and is applied to one type of material of three different thicknesses. In comparing cutting costs associated with plasma, oxyfuel, and laser cutting, it is important to account for labour costs, operating costs, and depreciation. From Tab. 3 can be stated that the maximum power per hour (at the same thickness) was needed for plasma cutting and the minimum for oxygen cutting. This also corresponds to the price of one running meter of cut for a customer. From this point of view, plasma cutting is the most economically advantageous. Based on this plasma cutting is 1,82 times cheaper than laser and 3,45 times cheaper than oxygen. As we have estimated, the operating cost for oxyfuel cutting is quite low, 4 times lower than plasma and 6 times lower than laser. When estimating the productivity of these three processes, it must be taken into account the total time of cutting per hour that relates to the cutting speed and also the total time of cut starts. This variable consists of total time of cut starts per hour that is evaluated by multiplying the number of cut starts per part that in our case had a value of one, by the time of cut starts, penetration and movement and the number of parts that had also a value of one. Only the time of cut starts, penetration and movement has changed as follows: oxygen – 10 s (with online preheating), plasma – 4 s and laser – 3 s. The total cut of cutting by laser is about 35 % less than by plasma and about 56 % less than oxygen. The time for preparation, on the basis of which is evaluated the total labour cost, was considered to be one hour. This time includes the time for NC programming, material handling, its preparation such as control of material, loading a plate on the portal, removal of small inequalities and so on. What has not been mentioned yet is that all of the calculations were made with 80 % utilisation of machine and with the machine life time expectancy of 10 years. Doing the cost comparison of these three processes is very difficult, because of differences in consumable life. There is no problem to compare the cost for electricity or gas, but the cost for consumables as the variable cost is difficult to compare, because nobody can exactly predict the real consumables life in operation. The maximum cost for consumables was reached for plasma cutting process – 3,08 €/h that includes the cost of cathodes and tips. The consumables for laser cutting are 1 €/h including the cost of lens and tips. The minimum cost for consumables was reached for oxygen cutting and that was 0,25 €/h. When laser cutting, the given tip life was 1000 h/tip, for oxygen cutting it was 80 h/tip and plasma 10 h/tip. We have been working with the theoretical data given by manufactures of consumables, under ideal conditions, with no need to change the consumables.

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