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MODERN CUTTING PROCESSES - COMPARATIVE ANALYSIS

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Abstract: *This article presents a comparative analysis of the main processes of modern cutting: water jet, plasma and laser cutting. Technical characteristics and the profitability of these cutting machines will be reported. This article also presents the evolution of cutting speed for carbon steel, a stainless steel and aluminum, processed with a laser power of 4000 W, a plasma jet, current intensity 200 A, respectively with a jet of water with the power of 50 hp. Next, it is presented a comparative set regarding the costs of the modern cutting machines. It is presented the typical criteria used for most process evaluations.*

Key words: *laser, plasma, water jet, cut, cutting speed, costs, material.*

1. INTRODUCTION

Today's industrial production is characterized by cycles of design production shorter and a big variety of products to cover the growing needs of the beneficiaries. Usability of technologies for sheet processing has grown in recent years, in detriment of other technologies, because the processing of sheets give manufactures a less limited design and the ability to produce parts easier, cheaper, which fit to the technical and quality requirements of the customers. The choice of cutting process is based on the precision of cutting parts, the hardness of the material and the energy consumption of the process.
Next, the paper will present the techniques of the main methods of modern cutting.

2. MODERN CUTTING PROCESSES

2.1. Laser cutting

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing application. Laser cutting works by directing the output of a high-power laser, by computer, at the material to be cut. The material then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

There are three main types of lasers used in laser cutting. The CO2 laser is suited for cutting, boring, and engraving. The neodymium (Nd) and neodymium yttrium-aluminum-garnet (Nd-YAG) lasers are identical in style and differ only in application. Nd is used for boring and where high energy but low repetitions are required. The Nd-YAG laser is used where very high power is needed and for boring and engraving. Both CO2 and Nd/ Nd-YAG lasers can be used for welding.

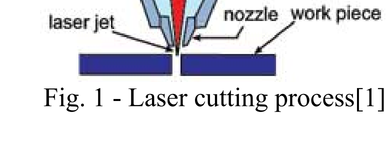


Fig. 1 - Laser cutting process[1]

The basic mechanism of laser cutting is extremely simple and can be summarized in figure 1.

A high intensity beam of infrared light is generated by a laser. This beam is focused onto the surface of the work piece by means of a lens. The focused beam heats the material and establishes a much localized melt (generally smaller than 0.5mm diameter) throughout the depth of the sheet. The molten material is ejected from the area by pressurized gas jet acting coaxially with the laser beam. Carbon or mild steels are generally cut in a jet of pure oxygen. The oxidation process initiated by the laser heating generates it is own heat and this greatly adds to the efficiency of the process. This localized area of material removal is moved across the surface of the sheet, thus generating a cut. Movement is achieved by manipulation of the focused laser spot (by CNC mirrors) or by mechanically moving the sheet on a CNC X-Y table. Fully robotic systems are available for profiling three dimensional shapes. Nd: YAG lasers can utilize optical fibers rather than mirrors but this option is not available for the longer wavelength CO2 laser.

The cut width (kerf width) is extremely narrow (typically 0.1 to 1.0mm). Very detailed work can be carried out without the restrictions of a minimum internal radius imposed by milling machines and similar mechanical methods.

Although laser cutting is a thermal process, the actual area heated by the laser is very small and most of this heated material is removed during cutting. Thus, the thermal input to the bulk of the material is very low, heat affected zones are minimized and thermal distortion is generally avoided.

Laser manufacturing activities currently include cutting, welding, heat treating, cladding, vapor deposition, engraving, scribing, trimming, annealing, and shock hardening.

2.2. Plasma cutting

Plasma (arc) cutting was developed in the 1950s for cutting of metals that could not be flame cut, such as stainless steel, aluminium and copper. The plasma arc cutting process uses electrically conductive gas to transfer energy from an electrical power source through a plasma cutting torch to the material being cut. The plasma gases include argon, hydrogen, nitrogen and mixtures, plus air and oxygen.

Normally, a plasma arc cutting system has a power supply, an arc starting circuit, and a torch. The power source and arc starter circuit are connected to the cutting torch through leads and cables that supply proper gas flow, electrical current flow, and high frequency to the torch to start and maintain the process. The arc and the plasma stream are focused by a very narrow nozzle orifice

The basic principle is that the arc formed between the electrode and the work-piece is constricted by a fine bore, copper nozzle. This increases the temperature and velocity of the plasma emanating from the nozzle. The temperature of the plasma is in excess of 20 000°C and the velocity can approach the speed of sound. When used for cutting, the plasma gas flow is increased so that the deeply penetrating plasma jet cuts through the material and molten material is removed in the efflux plasma. The plasma arc cutting process is illustrated in *Fig. 2*.

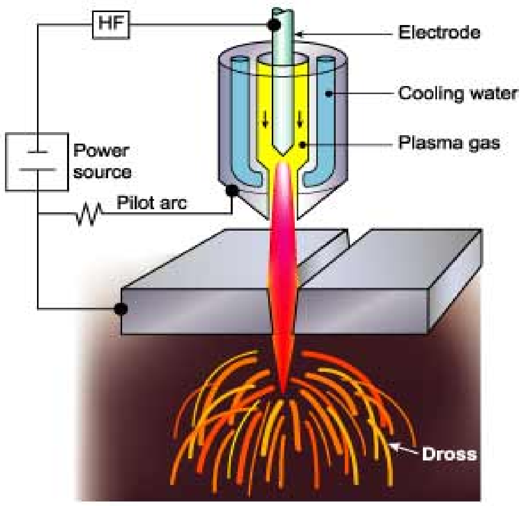


Fig. 2 - Plasma cutting process [2]

In the conventional system using a tungsten electrode, the plasma is inert, formed using either argon, argon-H_2 or nitrogen. However, oxidising gases, such as air or oxygen, can be used but the electrode must be copper with hafnium. The plasma gas flow is critical and must be set according to the current level and the nozzle bore diameter. If the gas flow is too low for the current level, or the current level too high for the nozzle bore diameter, the arc will break down forming two arcs in series, electrode to nozzle and nozzle to work piece. The effect of 'double arcing' is usually catastrophic with the nozzle melting.

The quality of the plasma cut edge is similar to that achieved with the oxy-fuel process. However, as the plasma process cuts by melting, a characteristic feature is the greater degree of melting towards the top of the metal resulting in top edge rounding, poor edge squareness or a bevel on the cut edge. As these limitations are associated with the degree of constriction of the arc, several torch designs are available to improve arc constriction to produce more uniform heating at the top and bottom of the cut, like: dual gas, water injection, water shroud, air plasma and high tolerance plasma.

2.3. High tolerance plasma

In an attempt to improve cut quality and to compete with the superior cut quality of laser systems, High Tolerance Plasma Arc cutting (HTPAC) systems are available which operate with highly constricted plasma. Focusing of the plasma is effected by forcing the oxygen generated plasma to swirl as it enters the plasma orifice and a secondary flow of gas is injected downstream of the plasma nozzle. Some systems have a separate magnetic field surrounding the arc. This stabilizes the plasma jet by maintaining the rotation induced by the swirling gas.

The advantages of HTPAC systems are: Cut quality lies between a conventional plasma arc cut and laser beam cut; Narrow kerf width; Less distortion due to smaller heat affected zone.

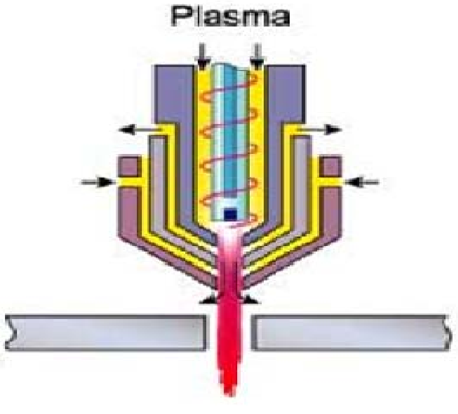


Fig. 3 - High tolerance plasma cutting process [2]

2.4. Water jet cutting

Abrasive water-jet cutting is gaining popularity as a means for cutting a wide variety of materials. Ease of programming and the jet’s ability to cut almost all materials and any thickness make it suitable for all shape cutting applications except extremely hard materials. Its most significant attribute as an accurate cold cutting process allows it to cut metals without leaving a heat affected zone.

Abrasive waterjet cutting utilizes a high velocity coherent stream of water and abrasive that can be used to cut almost all materials. Water at 40,000 to 55,000 psi accelerates through a sapphire, ruby or diamond orifice. The stream passes through a mixing region where the vacuum, induced by the stream, sucks in abrasive. Momentum of the water stream accelerates and entrains abrasive as it passes through the nozzle. The stream exits the nozzle as a three phase mixture of air, water and abrasive particles with a cutting diameter of 0.020” to 0.060”. The high velocity abrasive particles impact on the kerf face and do the actual cutting. Kerf material is removed as microchips, with no negligible affects on the material.

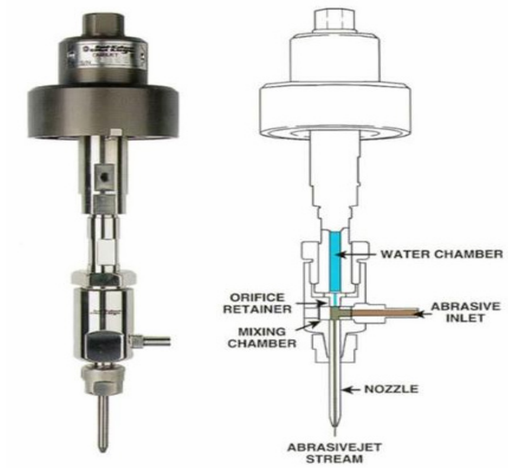
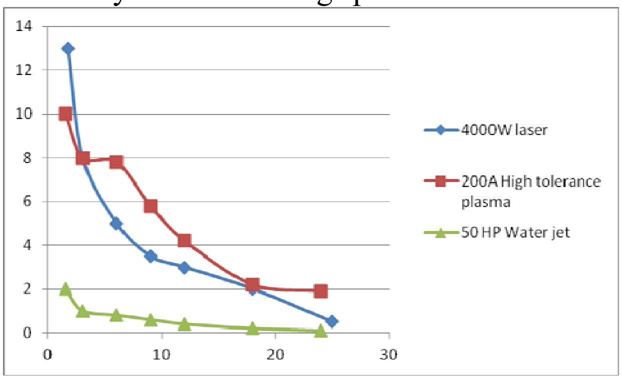


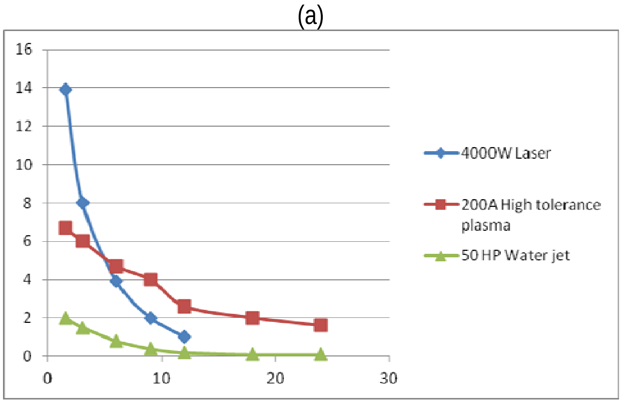
Fig. 4 - Water jet cutting process[3]

3. CUTTING SPEED AND COSTS

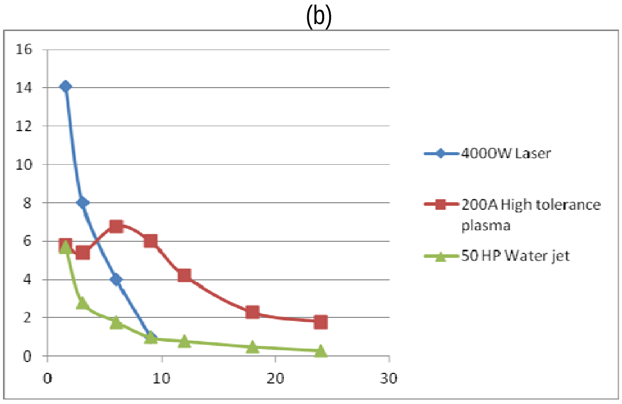
In terms of cutting speed, specialized studies indicate, for all materials prepared, a high speed laser cutting of small thickness of material. For the larger thickness of material, however, the highest speeds are recorded for plasma cutting. Fig 6, a,b,c shows the evolution of cutting speed for carbon steel, a stainless steel and aluminum, processed with a laser power of 4000 W, a plasma jet, current intensity 200 A, respectively with a jet of water with the power of 50 hp. It should be added here that the plasma cutting systems sometimes cut metal table thinner at lower speeds because choosing lower amperage, lead to obtain the desired cut quality and precision. On the Ox axis is represented the material thickness in mm, and on the Oy axis the cutting speed in mm/s.



(a)



(b)



(c)

Fig 6. - The evolution of cutting speed for: a - carbon steel, b- stainless steel, c – aluminum [4]

Can see that whatever of thickness of cutting piece, highest precision (lowest tolerance) is obtained at laser cutting, while the large amount of heat generated at plasma cutting lead to lower accuracy. On the Ox axis is represented the material thickness in mm, and on the Oy axis the precision of cut in mm.

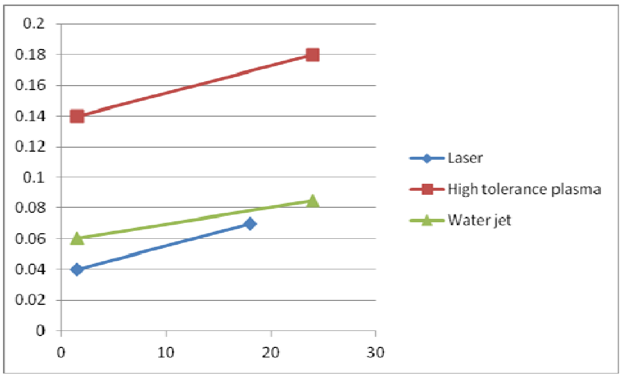


Fig.7 – Accuracy of cut depending on thickness, for cutting with a laser power of 4000 W, with a jet of plasma with the intensity of current 200 A, respectively with a jet of water with the power of 50 hp. [4]

Regarding the specific costs, Fig 8 presents a view of comparative set by taking into account an installation with a work area by 1.8 x 3.6 m.

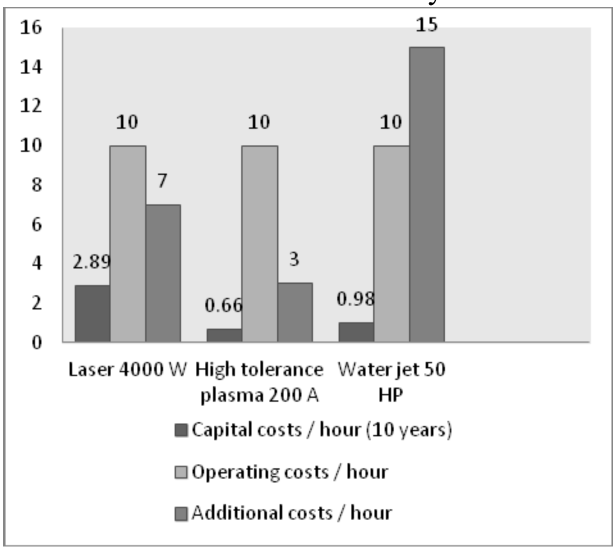


Fig. 8 - Comparative set regarding the costs of the modern cutting machines for a laser power of 4000 W, a jet of plasma with the intensity of current 200 A, respectively for a jet of water with the power of 50 hp.

It is found that, in case of cutting table relatively thin metal, laser cutting equipment is the best in terms of accuracy, speed and quality cutting surface results but the main disadvantage is high cost.

With the number of CNC cutting methods available to today's fabricator, including laser, plasma and water-jet based systems, making the correct choice between these technologies can sometimes be daunting. However, when application requirements such as part accuracy, process speeds and material demands are compared against the abilities of these sometimes competing methods, a careful evaluation will often lead to selecting the best cutting method. Typical criteria used for most process evaluations include the following: materials to be processed; range of material thickness; part accuracy desired; production rate desired; operator skill requirements; capital costs; operating costs.

While a laser cutter can produce part accuracies approaching 0.001” with a very good surface finish, there are limits to the materials it can reliably process in this high tolerance range. Those limits include types of materials, thickness limitations and material quality. While a high definition plasma cutter would be unaffected by a coating of scale and rust on 1/2" mild steel plate, a laser cutter would struggle and end up scrapping a lot of parts. An abrasive waterjet cutter can produce parts from 2” stainless steel to within 0.003” but its cutting speed for 11 gauge stainless steel would be less than one-fifth the rate of a laser cutter. In another example, a 200 amp high density plasma system can cut 0.5” mild steel at twice the rate of a laser cutter; however, the part accuracy would not be as good as the < 0.003” parts produced by the laser cutter. As with any machine tool purchase, getting the correct CNC cutting system for the job begins with letting the application drive the purchase .[5]

4. COMPARATIVE ANALYS

Next, we will compare the CO_2 laser cutting process, water jet cutting process and plasma cutting process based on several criteria’s.

The biggest initial capital investment is on CO_2 laser, 415 000 euro. On the second place is the water jet machine, 235 000 euro. The smallest investment it is on a plasma cutting machine 200 000 euro, with 50% less then laser cut machine and 10% less then water jet cutting machine. On the laser machine the parts that will wear out are: protective glass, gas nozzles, dust and particle filters. On the water jet machine those are more expensive: Water jet nozzle, focusing nozzle and all high-pressure components, such as valves, hoses and seals. The plasma machine has less part that will wear out: the cutting nozzles and the electrodes.

4.1. Water-jet Cutting Considerations

Although the water-jet cutting process is compatible with a vast amount of materials, there are limitations to consider. Experts note that the pure cutting process should not be applied to diamonds, which are too dense, or tempered glass, which will crack when under pressure. Additionally, the process is not efficient when it is used for fabric or material bundles, as the jet stream loses power after cutting through the first several layers of material. It is also helpful to note that water jet may be slower than the speed of a laser cut component.

4.2. Plasma Cutting Considerations

It is essential to consider plasma cutting limitations, specifically when compared to other processes. For example, plasma cutting machinery may cost more than other cutting methods such as oxy-fuel cutting. In addition, keep in mind that the edges of the processed material may be rough, specifically with thicker materials. Professionals also note that warping may occur, when processing intricate parts. Additionally, whereas laser and water-jet cutting may be used to achieve fine precision cuts, the CNC plasma cutting process is most effective for cutting 2D shapes that require less intricate details.

4.3. Laser Cutting Considerations

As with all cutting procedures, it is essential to consider safety precautions and wear appropriate gear when processing materials with laser tools. Although lasers work with a number of metals, they are not suitable for reflective materials, such as aluminum and copper alloys. In order to avoid partial burring on thin work pieces, a proper application distance must be applied when processing the material.

5. CONCLUSION

This article aims to present a comparison of modern cutting techniques such as: water jet cutting, laser cutting and plasma cutting. Technical characteristics were described of each process.

Laser cutting process is more advantageous when it is aimed to reduce deformation and reduce heat affected zone.

Whatever of thickness of cutting piece, highest precision (lowest tolerance) are obtained at laser cutting, while the large amount of heat generated at plasma cutting lead to lower accuracy.

In case of cutting table relatively thin metal, laser cutting equipment is the best in terms of accuracy, speed and quality cutting surface results but the main disadvantage is high cost.

There are presented some considerations of those processes.

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7. REFERENCES

[1] http://www.aviationmetals.net/valueadded. php

[2] http://tigmigarc.co.uk/plasma.html

[3] http://www.waterjetcuttingworld.com

[4] Ing Cristina Maria Biris - *Contributii privind optimizarea constructiva si functionala a sistemelor de debitare cu comanda numerica* – teza de doctorat 2008

[5] http://www.cncmi.net/Waterjet%20vs.htm

[6]http://www.teskolaser.com/laser_cutting2.html

[7] www.scribd.com

[8] www.waterjets.org

[9] www.kmtwaterjet.com

[10] www.sciencedirect.com

[11] http://www.vibrationschool.com/

[12] European Standard 13306

[13] http://www.vibrotestdiagnostic.ro

[14] http://www.dinamice.ro/mentenanta

PROCEDEE DE DEBITARE MODERNE – ANALIZĂ COMPARATIVĂ

Rezumat: În acest articol este prezentată o analiză comparativă a principalelor procedee de debitare moderne: tăierea cu jet de apă (abraziv), cu plasmă şi cu fascicol laser. Sunt relatate caracteristicile tehnice, precum şi rentabilitatea acestor maşini de debitare. Acest articol prezintă, de asemenea, evoluția vitezei de tăiere pentru oțel carbon, oțel inoxidabil şi aluminiu, prelucrate cu laser de putere de 4000 W, cu un jet de plasmă, de intensitate de 200 A, respectiv cu un jet de apă cu puterea de 50 CP. De asemenea este prezentat un set comparativ privind costurile maşinilor de tăiat moderne.

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