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Lukas Kudrna

Jiri Fries*
ORCID ID: 0000-0001-9776-6878

Marek Merta
VŠB-Technical University of Ostrava, **Czech Republic**

THE DESIGN OF A CNC MACHINE FOR CUTTING WITH A PLASMA ARC

Development of new technologies, the increasing intensity of competition and increasing globalization pose businesses against increasingly difficult requirements, especially the aspect of quality production is here important element (Grabowska 2018). Particular industry sectors and enterprises have own quality management systems (Gajdzik, Sitko 2014) for both products and maintenance, or in the a broader view of technology management (Gajdzik 2014). The basis for changes in knowledge and know-how. Knowledge from various areas of enterprise functioning is useful if it is used to implement the adopted strategies and management systems (Gajdzik 2008). The basic version of a CNC cutting machine is triaxial (X, Y, Z). The Z axis is only used to set the correct height of cutting (Fig. 1, Fig. 2).

Fig. 1 A developmental functional prototype of a CNC machine

* jiri.fries@vsb.cz

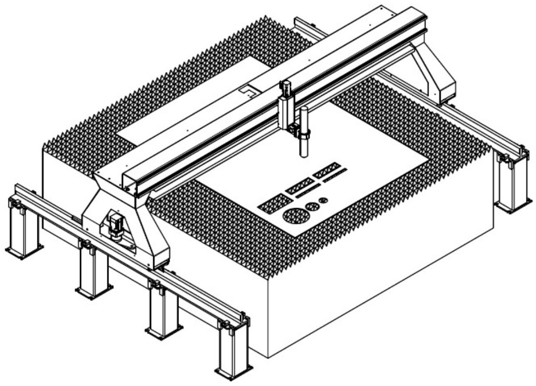

Fig. 2 Prototype model

More advanced CNC cutting machines can have up to 6-axes and they can be used for technologically demanding applications, such as pipe cutting, profiles and chamfer cutting to prepare surfaces for welding. In some applications a plasma torch can be positioned on a robotic arm.

One important feature of any CNC machine is its stiffness and its feed speed. The machine feed must be smooth and must comply with the given trajectory of a cut. If the structure is insufficiently rigid, a sudden change in the direction of the trajectory would lead to vibrations, which would be transferred onto the torch, and thus they would influence the cut. It follows that this machine portal must be rigid and lightweight in order to obtain its easy and smooth control. When the weight of the portal is higher, greater demands are placed on its drive. The motors must be sufficiently powerful to be able to decelerate and accelerate smoothly with that portal (Kudrna et al., 2017).

THE PRINCIPLE OF CUTTING WITH PLASMA

The principle of cutting (Fig. 3) is based on melting and on the partial evaporation of the material under extremely high temperatures, which may in exceptional cases reach up to 20,000°C. This is due to the flow of plasma gas through the electric arc, burning between an electrode, which serves as a cathode, and a cutting material that has the characteristics of an anode. There the gas particles are dispersed, forming the plasma arc. The melted material is blown from cutting kerf using the dynamic effect of plasma, which reaches a speed of up to 2,000 m/s at the outlet of a torch. Thus it is the conversion of electrical energy into heat, and the cutting process itself is a combination of heat and the kinetic effect of plasma (Procházka et al., 2017).

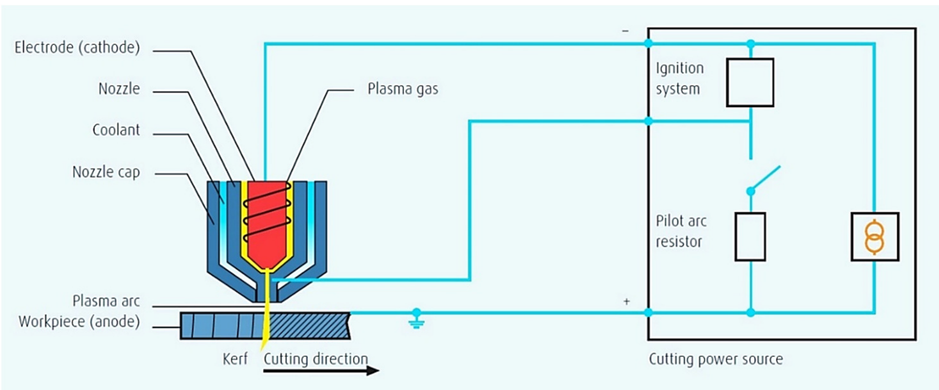

Fig. 3 The principle of plasma cutting with a transferred arc

Source: (Linde, 2011).

For the cutting operation the most frequently used solution is a connection with a transferred arc, but we can also find connections with a non-transferred arc:

- **Transferred arc** – it burns between a cut material and an electrode. It is suitable for cutting electrically conductive materials. This method is called PAM (Plasma Arc Machining) and in comparison with the non-transferred arc it provides higher productivity.
- **Non-transferred arc** – it burns inside the torch, namely between an electrode and a nozzle, where there are large thermal stresses appearing, as well as faster wear, over the PAM method. PBM (Plasma Beam Machining) abbreviation is used here. The process of cutting gradually uses both methods of arc combustion. The first step is to ignite a secondary, or otherwise non-transferred arc, and after that the cutting transferred arc

Generally, the cutting method with plasma is characterised by high cutting speeds, and associated narrow areas affected by heat. As to the quality of the cut the plasma can be classified rather into the pre-production phase of technological processing, and thus it is suitable to produce semi-finished products. This is due to the greater roughness of cutting edges. Nevertheless, modern plasma cutting machines allow for an increased regulation of the plasma arc, providing a better quality for the cut (Kudrna et al., 2017).

PLASMA CUTTING PHASES

The very start, before a plasma arc is ignited, can be divided into several phases:

- First phase (Fig. 4) – The gas inlet into the torch is opened. This phase serves only to stabilize the velocity of the gas.

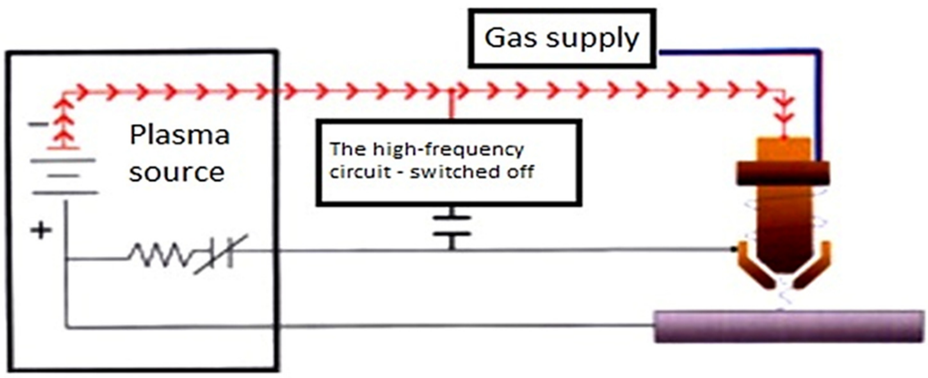

Fig. 4 First stage

Source: (Hypertherm, 2017).

- Second phase (Fig. 5) – The high frequency circuit is activated, which results in the creation of an electric arc, burning between the nozzle and the electrode. Gas passing through this arc is ionized, and it becomes electrically conductive, creating a conductive environment between the material and the torch. Due to the influence of the streaming gas this electric arc is gradually transferred onto the cut material, and the plasma arc is created.

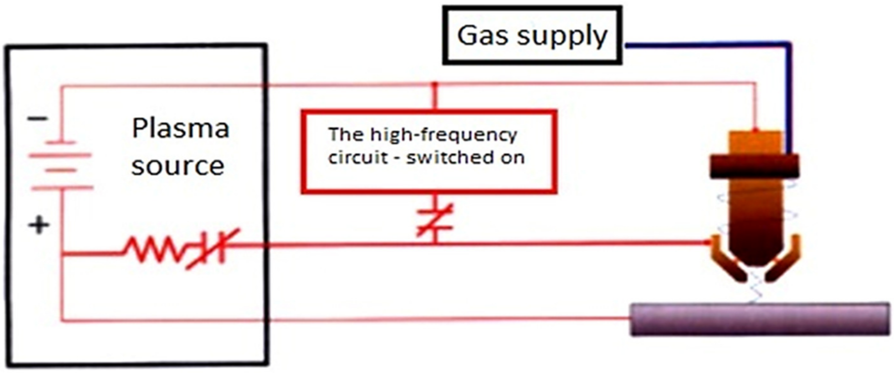

Fig. 5 Second stage

Source: (Hypertherm, 2017).

- Third phase (Fig. 6) – As soon as the flow of the stream is recorded passing through the cut material, the high frequency circuit is disconnected, and the ionization of the streaming gas is maintained only using the plasma arc.
- Fourth phase (Fig. 7) – Then, the cut material is melted, and this material is blown off by the streaming gas. The torch begins to move.
- Fifth phase – At the end of the cutting process, when the plasma arc goes out, the gas still streams for a certain period of time. The role of this phase is to cool the torch and thus extend the life of the consumable elements (Kudrna et al., 2017).

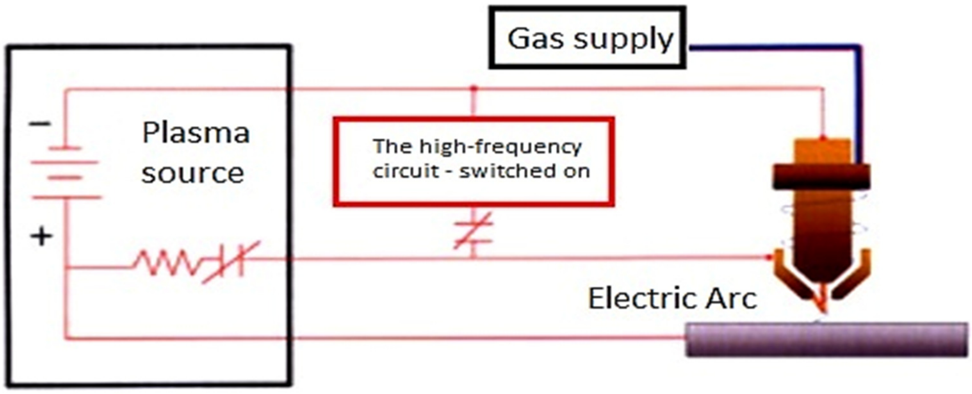

Fig. 6 Third stage

Source: (Hypertherm, 2017).

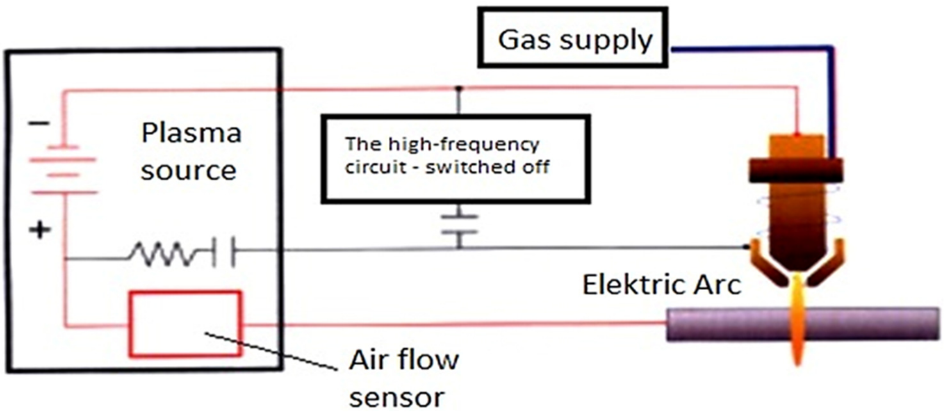

Fig. 7 Fourth stage

Source: (Hypertherm, 2017).

THE PARAMETERS OF CUTTING WITH A PLASMA ARC

The cutting process itself is preceded by assembling the torch, followed by the process of adjusting its parameters. All recommended values are provided by the producers of plasma sources, and they vary depending on the grade and thickness of the cut material. Their correct setting has a major impact on the quality of a cut and its productivity, and last but not least, on the life of the consumable elements.

– Proper assembly of the torch – the correct combination of its parts must be used, in accordance with the quality and thickness of the material cut. For the torch we change/assemble: an electrode, a nozzle, a vortex ring, and all the corresponding covers. All these can be found in the tables provided by its manufacturer.
– The gas selection – to obtain a good quality of cut and the good lifetime of the consumable parts, we must use gasses with high purities. For nitrogen the lowest recommended purity is 99.995%, and for oxygen it is 99.5%.
– The compensation of the cut - by setting the compensation or technological allowance to the cut, the torch is moving at a certain distance from the component (Fig. 8), in order to maintain a desired dimension. The cut compensation is always positive, and the inner contours are cut in the opposite direction compared to the outer contours. The outer shapes are cut clockwise, and the inner shapes anticlockwise (Žitňanský et al., 2013).

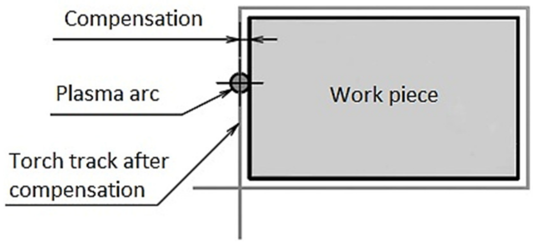

Fig. 8 Compensation

– The cutting speed – has an impact on the quality of the surface, on the width of the cutting kerf, and on the size of the heat-affected areas
– The cutting stream- the thickness of the cut material has a fundamental influence on the cutting stream. The greater the thickness of material, the greater the cutting current.
– The height of the torch – by the correct setting of the torch height we can achieve an almost perpendicular cut (Fig. 9).

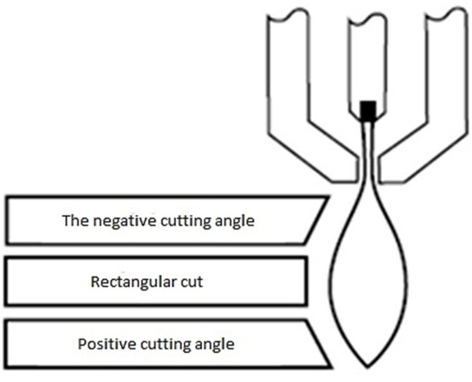

Fig. 9 Height adjustment

Source: (Hypertherm, 2016).

- The gas pressure - the gas pressure directs the plasma arc. If the pressure is lower, the plasma arc at the outlet nozzle is larger in diameter with a lower thermal energy, which is undesirable.
- The entries and exits from the cut – the entry into the cut (penetration of the material) is always chosen outside the contour of the cut workpiece so that it is not visible on the final shape (Fig. 10). Similarly, it is true for the exit from the external contours. The torch leaves the contour at the end of the cut so that switching off the arc does not affect the place on the final cut. The so-called ‘exit after contour’ is selected for cutting inner slots, where the plasma arc is switched off early (approximately at the point of entering the contour).

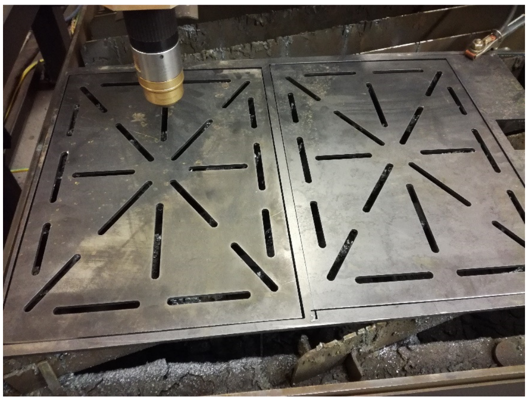

Fig. 10 Burnouts with visible exits outside the contour (at the bottom edge of the material)

INFLUENCES ON PLASMA CUTTING

Technology

The resulting plasma cut quality is influenced by many factors, some of which can be eliminated already when purchasing a cutting machine and the type of plasma source. Other problems can be eliminated with the proper operation of the machine and by setting the parameters of plasma cutting itself.

Machine design

One of the most important parameters of plasma cutting is the speed and its observance not only on straight cuts but also in curves, holes and corners. In these locations, the machine must accelerate and decelerate to adhere to the prescribed trajectory and not be driven away from it, and it must not overrun corners and cause vibrations that would be transmitted to the torch and thus to the cut. The laws of physics imply that the lower the weight of the machine, the easier and better to navigate the movement. On the other hand, however, its rigidity is required in relation to the portal dimensions and on the other hand, in the case of combining with autogenic cutting its robustness due to thermal load. The influence of the heat generated by autogenic cutting also requires a greater distance of the portal from the burnt sheet (the cutting table), and thus it also extends the plasma torch mounting distance to the point of cutting. The long arm is then much more prone to vibrations, especially at higher plasma cutting speeds and frequent changes in the cutting direction. It follows from the above that, for large machines, the costs of drives and their control are rapidly rising, especially if a high-quality cut is required for smaller details, openings and corners.

Cutting table

Concerning the design of the cutting table, the cutting quality can be influenced by the type of support plates and their fixed attachment in guide grooves. On the one hand, the ribs must have a sufficient load capacity in regard to the thickness of the cut material, and on the other hand, the contact surface of the ribs and burnt material should be as small as possible, i.e. the ribs should be of the thinnest material. A suitable solution for plasma cutting for thinner sheets is using ridge-shaped ribs, where the contact is practically only at one point. Unsteady fastening of the ribs on the table can cause a motion of the entire sheet due to heat, and thus change the dimensions of the whole burnouts. The flatness of the table alignment is also important so that the sheet is lying across the surface in a horizontal plane. A fixed connection of the table to the filtration unit (via a suction pipe) can cause that the vibrations from the fan can be transferred to the table and then to the material to be cut (Beňo et al., 2016).

Perpendicularity of the torch

Perpendicular adjustment of the torch against the cut sheet directly influences the perpendicularity of the cut. It should be borne in mind that, in particular, thin sheets can be corrugated and thus it is important in which place we position the torch perpendicularity (Lomozník et al., 2017).

Plasma unit type

Plasma units have various torch and source designs due to their types, and they can use different types of gas for cutting. Units that use only air for cutting (or eventually nitrogen), usually have a simple torch design and the same is true for consumable parts. Thus, they are usually cheaper both during purchase and operation. However, the cutting quality is much lower compared to units using different gases. This is especially visible for the perpendicularity of the cut (chamfering) and the purity of the lower cutting edge (scales).

Material quality

Material quality significantly influences the resulting cutting quality and the life of consumables (Krauze ed al., 2015, Bołoz, 2018). Rust and thick scale can cause large burrs in the top and the bottom edge of the cut, and it is necessary to reduce the cutting speed to obtain a better quality of the cut. Due to these "specks of dirt" the torch lights poorly and there is enormous wear or tear of the consumable parts (Trochta et al., 2017).

Cutting direction

Most plasma sources today use vortex burner technology, which, due to its construction, causes the gas to rotate and to be channeled. This fact makes the left side of the cut more bevelled than the right side. The right side is then the side of the burnout, and the left side is the material waste. It is thus clear that the external shapes of the burnouts must be cut clockwise, and the inner shapes anticlockwise. The direction of the cutting is usually specified in the program, which is prepared in the CAD/CAM system.

Quality and wear of consumable parts

Due to the large number of manufacturers of non-original consumable parts, their quality may vary. Poor quality consumable parts can reduce the reliability of plasma arc ignition, reduce the cutting quality or even damage the plasma torch. Consideration should be given to whether this risk is proportionate to their lower purchase price. Using these parts may also result in the loss of the warranty for a torch or for the entire plasma source.

With the number of material penetrations and with the higher length of cutting, consumable parts wear out, especially nozzles – the burning of slots, electrodes – hafnium loss and caps – burning and melting the metal. The lifetime of consumable parts is influenced by the purity of the cut material, by the quality of the gases and compressed air used, by regularly cleaning the caps and observing the prescribed cutting parameters. The internal cooling of the torch or directly consumable parts also has a significant impact on the life of the consumable parts. The life of the consumable parts in the water-cooled torches is up to a few times longer than in those cooled by air or cutting gas (Kotus et al., 2011).

Penetration of thicker materials

When cutting thicker materials using plasma, the penetrated material shows a larger spatter (discharge) of the liquid metal from that place (Fig. 11). This may clog or damage the torch consumable parts. For this reason, the penetration height is chosen higher than the height of the torch above the material during cutting. However, the length of the burner from a material too large can cause the pilot arc to not be transferred to the material and the cutting arc does not ignite.

Fig. 11 Material spattered during penetration

This happens mainly for thicker materials, where a large distance of the burner from the material is required, due to a large amount of leaking metal. Here, a so-called controlled penetration is recommended, when the torch is set first to the ignition height and after transferring the main arc to the material the torch moves away from the material to the so-called penetrating height. During this move, the machine is already moving along the pre-set trajectory. After the set time for the penetration has elapsed, the torch moves down into the set cutting height. Due to the thickness of the material, it is also necessary to choose the corresponding length of travel. The values of both ignition and penetration heights can be found in the user manual of the plasma source manufacturer.

CONCLUSION

This article deals with the issues present when a material is cut using CNC machines. The basis of good quality cutting with the plasma arch is the machine design itself, which has at least three feed axes (x, y, z). There are also machines with six axes that are used to process technologically demanding applications, such as cutting pipes, profiles and with bevel angle to prepare weld surfaces. In addition, the article describes all five phases of plasma cutting. Another important part of the article describes materials that can be cut by the mentioned technology. It depends not only on the chemical composition but also on the thickness of the given material. For example, when the material is thinner than 1.5 mm, laser cutting is suitable, and when the material is at a greater thickness of approx. 30 mm, oxygen (OXY) cutting is advisable. Obviously, it depends on plasma source performance. An integral part, if not the main one, are the parameters of cutting. The cutting parameters must be correctly adjusted before the process and in this case, it all depends on a well-trained operator of the device. For advanced CNC machines, some parameters are guided by the software. The last chapter shows how to obtain a good quality of burnouts using the device. These are parameters that directly affect the quality of the cut and are based on knowledge and expertise from the practice.

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Abstract. This article discusses plasma cutting technology and its influences on the quality of the resulting cut. Plasma or a plasma arch consists of positive and negatively charged particles, excited and neutral atoms and molecules. As it contains free particles, it is electrically conductive and thus subject to the effects of the electrical and magnetic field. The basis of CNC machine design is described in the article, which has at least 3 axes (x, y, z), but there are also more technologically demanding applications, such as pipe cutting, profile and cutting using chamfer to prepare surfaces for welding, where these multi-axis devices are frequently used. The principle of plasma cutting and the plasma cutting phase is described in this article. The materials that can be divided by a plasma arc are described in detail, including graphs displaying the dependence of sheet thickness on the cutting speed. The article describes and lists the gases that are used in plasma-arc cutting, such as oxygen, argon, hydrogen and nitrogen. Important components of plasma cutting technology are the parameters that can be adjusted and set before the cutting so that the cut is of good quality. The most comprehensive chapter deals with the influences that affect plasma cutting quality. Cutting quality can be influenced by a number of factors. Everything starts with the proper choice of a CNC machine and a plasma source. The quality also depends on the expertise and experience of the machine operator and the setting of the plasma cutting parameters. This issue of influences on the plasma cutting quality is based on long-term experience in the field of the thermal cutting process.

Keywords: torch, plasma arc, cutting parameters