Impact Factor (SJIF): 5.301

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 5, Issue 4, April-2018

EXPERIMENTAL ANALYSIS & PERFORMANCE EVALUATION OF HIGH-PRESSURE NOZZLE ASSEMBLY FOR LASER CUTTING OF THICK CARBON STEEL PLATES

Ayyappan T.S [1], Anas A J[2], Thasleem M T [2], Ahmed Shiras[2] , Omer Muhseen J [2]

[1] *Assistant professor, Department of Mechanical Engineering Dhaanish Ahmed Institute of technology, ayyants@gmail.com*

Department of Mechanical Engineering, Dhaanish Ahmed Institute of technology, anas.aj.anas@gmail.com

ABSTRACT

Laser cutting of carbon steel is widely used in various steel fabricating industries because of its high speed, low bleeding and high quality benefits. Currently, a 1 kW CO2 laser with a subsonic nozzle assembly can only be used to cut steel plates up to about 10 mm. In this article, we are aiming at designing and evaluating high pressure supersonic laser cutting nozzle assembly. This makes it possible to cut steel up to 100 mm with a 1 kW CO2 laser. To design supersonic nozzle assemblies, basic equations of gas dynamics and compressible flow were used. The flow of the high pressure gas jet in the nozzle assembly was investigated by practical performance and the structural integrity of the high pressure nozzle assembly was guaranteed using analysis. Nozzle assembly can be tilting its 50% of the draft either side of require cutting plates, whether it is inside or outside the profile. Laser cutting experiments were conducted using supersonic nozzle assemblies developed to demonstrate low carbon steel cutting with a thickness of 50 mm with 1-kW CO2 laser.

Keywords : **Laser cutting, Supersonic nozzle, Thick steel cutting, Tilt nozzle.**

Introduction

Reactive fusion laser cutting of mild steel is extensively used in the manufacturing industries for cutting plates of various size and shapes. The cutting process is achieved through the energy from laser and exothermic reaction of iron with oxygen. In conventional reactive fusion laser cutting process, the laser beam is focused onto the mild steel surface using a subsonic nozzle which also provides a low-pressure jet of oxygen. The oxygen gas reacts with steel at high temperature liberating heat as oxidation is exothermic in nature. The ensuing exothermic chemical reaction is then held in a thermodynamic balance between the heating effects of the laser and the cooling effect of thermal losses to the surrounding steel sheet. Though laser cutting is one of the most used laser-based manufacturing process, the basic laser cutting process remained unchanged since its inception in the 1970s. Most existing and past research on laser cutting process focused predominantly on understanding the basic fundamentals and optimizing the laser cutting parameters.

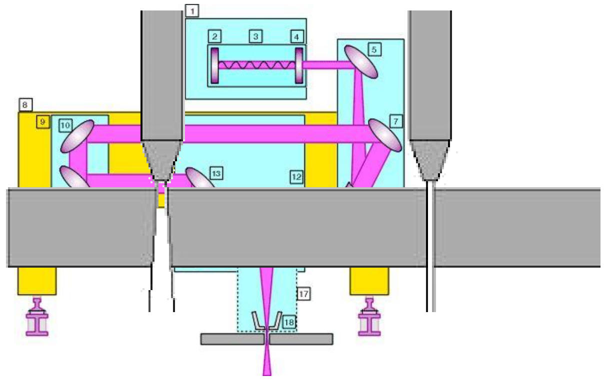
Laser Cutting

The laser cutting process is suitable for cutting carbon sheet from gauge thickness up to about 31.75mm. Beyond the 25 mm, everything has to be just right to make it work reliably, including the material (laser grade steel), gas purity, nozzle condition, and beam quality

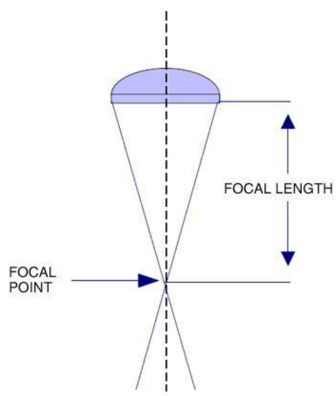
Laser is not a very fast process, because on carbon sheet it is basically just a burning process that uses the extreme heat of a focused laser beam instead of a preheat flame. Therefore, the speed is limited by the speed of the chemical reaction between Iron and Oxygen. Laser is, however, a very accurate process. It creates a very narrow kerf width, and therefore can cut very precise contours and accurate small holes. Edge quality is usually very, very good, with extremely small serrations and lag lines, very square edges, and little to no dross

Laser cutter

The laser cutting process uses a focused laser beam and assist gas to sever metallic plate with high accuracy and exceptional process reliability. The laser beam is generated by a resonator, and delivered through the cutting nozzle via a system of mirrors.



The focusing device consists of either a zinc-selenide lens or a parabolic mirror which brings the laser beam to a focus at a single point. Depending on the laser beam power, the focal length gives the distance of the focal point from the focusing optics.



The focal point is positioned above, on or below the material surface according to the requirements of the material. The high power density results in rapid heating, melting and partial or complete vaporization of the material. The gas flowing from the cutting nozzle removes the molten mass from the kerf.

The machine moves the cutting head over the metal sheet according to the programmed contour, cutting the work-piece from the sheet.

Laser Cutting Methods

Depending on the material to be cut the cutting methods used differ:

Fusion Cutting (high pressure cutting):

- The material is fused by the energy of the laser beam.
- The gas, in this case nitrogen at high pressure (10 to 20 bar), is used to drive out the molten material from the kerf.

- The gas also protects the focusing optics from splashes
- This cutting method protects the cut edges from oxidation and is mainly used with stainless steels, aluminum and their alloys.
- Oxidation Cutting (laser torch cutting):
- The material is heated by the laser beam to combustion temperature.
- The gas, in this case oxygen at a medium pressure (0.4 to 5 bar) is used to oxidize the material and to drive the slag out of the kerf.
- The gas also protects the focusing optics from splashes.
- The exothermic reaction of the oxygen with the material supplies a large part of the energy for the cutting process.

This cutting method is the quickest and is used for the economical cutting of carbon steels.

Parameters Affecting Laser Cutting

The following points are especially important for achieving good cutting results: Laser power

- Pulse frequency
- Type and pressure of cutting gas
- Diameter and type of nozzle
- Distance between the cutting nozzle and the work-piece
- Focal length of the focusing optics
- Focal position
- Cutting speed
- Acceleration
- Material
- Work-piece surface
- Work-piece shape
- Material thickness
- Work-piece support

Laser power

The laser power must be adjusted to suit the type and thickness of the work-piece. A reduction in the laser power may be necessary to achieve high accuracy on complex shaped work-pieces or very small parts. In contrast a laser power of at least 1 kW is needed for cutting carbon steel thicker than 25 mm.

As with the laser power, the pulse frequency can be matched to the relevant machining task. For example, it is recommended small contours are cut with reduced pulse frequency. The pulse frequency is also reduced when piercing in the ramp mode.

Type of gas

The type of material and the requirements of the cutting results determine the cutting gas to be used. A combustible material such as wood must not, for example, be cut with oxygen, as the work-piece would catch fire. Oxygen should only be used for metallic work-pieces with oxide-free edges. Oxygen forms a thin oxide layer during exothermic combustion.

With the laser torch cutting of metallic materials the quality of the applied oxygen is particularly important for the cutting results. Traces of water or nitrogen lead to the formation of burrs. This type of cutting gas contamination may be caused by bottle replacement and the connection of contaminated bottles. Therefore we recommend that the gas is supplied from gas tanks.

Recommended oxygen purity: 99.95 % (3.5)

With the use of oxygen with a purity of 99.5% (2.5) the possible cutting speed is reduced by approximately 10%.

The quality of the cutting gas (N2) is also very important for the high pressure cutting of stainless steel. Even slight traces of oxygen lead to the formation of a fine oxide layer.

Gas pressure

The material thickness of the work-piece must be matched to the gas pressure. When torch cutting,thin metallic materials are cut with a higher gas pressure than thicker materials. The gas pressure must be set very carefully, because the cutting quality is affected by even slight changes in the oxygen pressure.

If the pressure is too low, the fluid slag remains adhered to the base material, forming a permanent burr or closing the kerf again.

If the pressure is too high, the lower edges of the cut are burnt out and often make the cut unusable. In contrast, with high pressure cutting thicker work-pieces are cut at higher gas pressure.

Cutting nozzles and nozzle size

The selection of the correct nozzle for the process is very important. For example, with high pressure cutting, nozzles with a larger hole are used than for standard cutting. A deformed nozzle hole, e.g. oval-shaped after a collision, can as with an eccentric laser beam, lead to directionally dependent cutting errors.

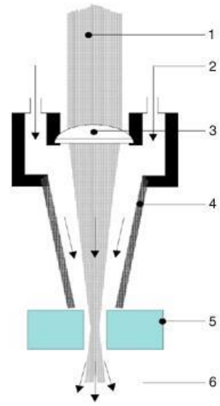
Nozzle distance

The nozzle distance is held at the programmed value with a capacitive height control without touching the work-piece. The nozzle distance between the work-piece and the material surface has a great effect on the cutting quality with laser cutting. The smaller the nozzle distance, the better the cutting quality. But there is the following restriction: To ensure safe cutting, a minimum distance should not be maintained. This minimum distance is approx. 0.025”. For hole piercing the nozzle distance is selected to be the same or larger depending on the material thickness and type of hole-piercing.

Focusing optics

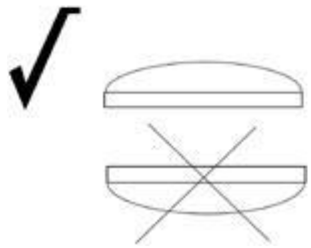
The focusing optic causes the laser beam to be focused into a single spot through the nozzle. The focusing optic is zinc-selenide lens.

1. Laser beam
2. Cutting gas
3. Focusing lens
4. Cutting head / nozzle
5. Work-piece
6. Blow-out molten mass



Focusing lens

The focusing lens must be installation correctly. The surface which curves outwards must always point to the top.



A dirty focusing lens heats up due to more intense absorption of the laser radiation and deforms. This leads to the focal position drifting towards the top.

Important: Heavy contamination can lead to the focusing lens being damaged.

Effects: With increasing cutting length burrs start to form and build up; the kerf and surface roughness increase.

- in carbon steel there is a tendency to cratering
- in the extreme case the work-piece is not fully severed

Focal length and position

ACO 2 laser with a beam power of 1 kW was used as the laser source. The unfocused beam diameter was of 20 mm. A 50-mm focal length ZnSe plano convex lens with 9.65 mm thickness was used to obtain a 3mm-diameter laser beam spot at the work piece surface. The designed maximum pressure of the 9.65-mm-thick ZnSe lens is 16 bar. The focal point of the laser beam lies inside the nozzle assemble, close to the throat area of the supersonic nozzle tip.

The nozzle assembly was considered asa thin shell and the wall thickness was calculated using equation

Circumfeential stress = pD / 2t

Longitudinal stress = pD / 4t

High pressure cutting of stainless steel or aluminum:

The focus is positioned in the sheet.

As a rule of thumb, the focus position can be positioned at about 2/3 the sheet thickness in the sheet.

Therefore, each change of plate thickness normally means a change of focus position.

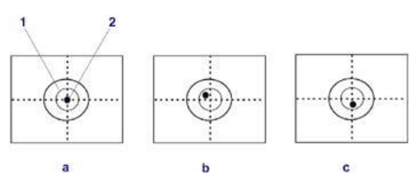
Centering the nozzle

The focusing lens must be set such that the focused laser beam is placed in the centre of the nozzle hole. The focused laser beam may at most be

+0.002" off centre with respect to the nozzle.

With otherwise good cutting quality, a non-centered laser beam can lead to the cutting quality being dependent on direction. In the extreme case the cut is very good in one direction and in the other directions the material is not cleanly cut or even not parted.

With the torch cutting of carbon steel sparks can form on the surface of the sheet when cutting takes place in a direction opposed to the eccentricity.



1 = Nozzle Orifice

2 = Laser Beam

a is centered, b and c are not centered.

Cutting speed

The cutting speed must be matched to the type and thickness of the work-piece. A speed which is too fast or too slow leads to increased roughness, burr formation and to large drag lines.

Acceleration

The acceleration is linked to the machine constants and generally it does not need any attention since it is a setting specific to the machine. With high pressure cutting the acceleration should be limited from about 3.1 sheet thickness, because the cutting process can easily be interrupted if the acceleration is too high.

Material

The characteristics of metallic materials have a decisive effect on how easily they are cut with a laser beam. Thermal conductivity, absorption, reflectance are just a few to mention. These are influenced by the composition of the materials and their production methods.

Thick carbon steel plates:

The types of sheet with a high carbon content hardening of the material along the cut edge should be expected. Steel with a high alloying content is more difficult to cut than sheet with a low content.

Material Thickness and Size

With increasing material thickness the roughness of the cut edges increases for metallic materials and the laser power required for cutting is greater.

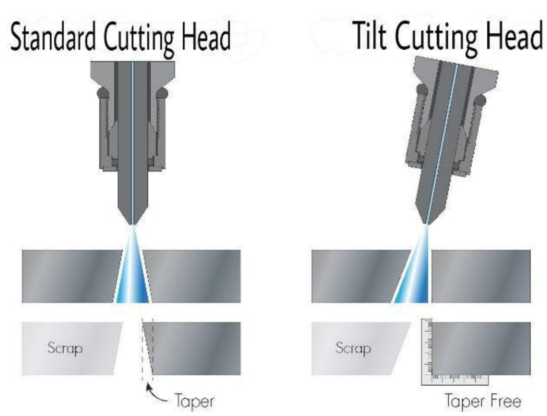
With greater material thicknesses noticeably lower cutting speeds are achieved for the same laser power.

- Supersonic laser cutter can cut up to 75 mm to 100 mm thick carbon steel.
- Longer and larger material are workable.

Work support table

With high pressure cutting interruption of the cutting process may occur when cutting over the work-piece support bars. When crossing the bars small grooves may be produced on the lower edge of the sheet. Splashes produced by cutting into the work-piece support may adhere to the bottom of the work-piece.

Nozzle tilting angle



The effect of nozzle tilting angle on flow separation is by tilting the nozzle with an angle of 25 flow separation disappears inside the cut kerf. When the nozzle is tilted, the effect of impinging jet is much more significant. A detached shock occurs at the entrance of the kerf above the cut front. detached shock is like a normal shock. Jet passing through the detached shock becomes highly compressed and subsonic. At the same time, the incident shock becomes much weaker and the position of the incident shock goes upper than the detached shock. The pressure gradient is positive all the way down the cut front and flow separation does not happen. However, the jet along the cut front becomes subsonic, so the shear force on the dross will be much smaller if a nozzle tilting angle is used in real cutting conditions, which is an aspect to be considered and improved.

Laser cutting system

It is used in the most diverse areas, specifically wherever high accuracy for the component geometry and the cut edge is required. The preferred range for steel sheets is up to a material thickness of 75mm, under certain circumstances up to 100 mm. For this application mainly the CO2 Laser are used. For greater thicknesses, **laser cutting** only makes sense for special applications, more usually other cutting processes

(**oxyfuel** or **plasma cutting**) are used here.

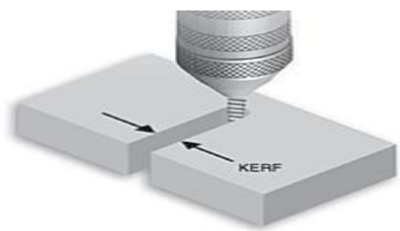
CHARACTERISTICS:

Plate thickness: 0.1 mm up to 100 mm

Typical: 0.5 mm up to 750 mm

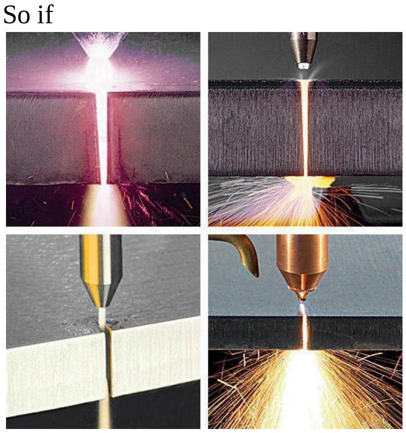
Kerf

Kerf = Width



Kerf is defined as the width of material that is removed by a cutting process. When talking about CNC shape cutting with typical cutting processes, kerf is the width of material that the process removes as it cuts through the plate.

When cutting parts on a laser machine, it want to produce accurate cut parts, with final dimensions as close as possible to the programmed shape. So if

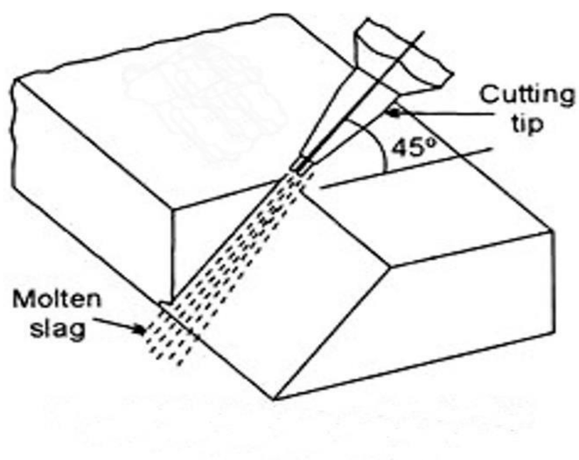


you program a 6” by 6” square, and the plasma arc removes 0.200” of material, as it cuts, then the resulting part is going to be 5.8” by 5.8”. So the actual tool path has to be compensated by 0.100” to the side of the programmed path, all the way around the part.

Not only does kerf width vary from one process to the next, but there are lots of things that affect the kerf width for each process. Of course, as the thickness of material increases, it takes more power to cut through it. In the case of plasma, that means higher current and a larger nozzle. Laser increases power. Oxy-fuel cutting uses a larger nozzle with a wider cutting oxygen stream and hotter preheats. Waterjet uses either a larger nozzle/orifice combination, or a slower cutting speed. Regardless of the process, as the plate gets thicker, the kerf gets wider.

There are variations within each process too. For example, when plasma cutting, the actual kerf width depends not only on the cutting current, but also on the torch height, speed, and gas settings.

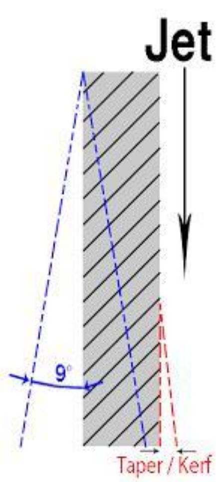
Kerf offset adjustment



Kerf offset is traditionally adjusted by the machine operator. Prior to running a program, the operator must enter the kerf width so that the machine can calculate the actual tool path required to cut the part to the correct dimensions.

Modern thermal cutting and waterjet machine controls will also allow the kerf width value to be included in the part program, or to be called from a process database stored in the CNC. This makes it much easier for operators, since they don’t need to look up the values for each material type and thickness they cut, but rather they simply select the material type and thickness, then the CNC looks up all of the process variables in the database.

Zero Taper or Taper Free Cutting



Our machine,advanced Tilt cutting head. This allowed us cut virtually zero taper edges with most material upto 10 mm thick. Our normal cutting thickness ranges from 0.010 to 100mm. Taper doesn't disappear. It is moved to the scrap part of the material,leaving your part with square, taper-free edges.

Tilt Features

- Easily make interlocking pieces, dovetail fittings, and lead ins without taper to reduce secondary machining
- Continuously adjusts at thousands of points per inch along path
- Automatic re-squaring feature ensures nozzle is square to the table
- Faster cutting of high precision taper free parts with no need to slow down to eliminate tape
- Faster cutting due to "tilt forward" capability
- Programmable manual tilt up to ±45° for the maximum tilt angle

Software

From preparing quotations to post calculations, from design of the parts to the creation of nested plans, the transfer of the plans to the machines and finally the cutting of the parts, you have perfect information management. This guarantees efficient production with the highest quality standards whether it be with small batch quantities in engineering and plant construction or with just in time order based production with ever changing quantities in a job shop. Because quality, timing and the price is right, your competitiveness is as well.

Production oriented information technology

Omni Win is a modern and flexible design and nesting software, which adapts intelligently to your machine and your cutting needs. It takes over all cutting tasks for order-based production with CNC thermal cutting machines. OmniWin is effective and economical for small production runs in the machine and manufacturing industry, as well as in just-in-time manufacturing with changing quantities at custom cutting operations. OmniWin is the ideal tool for production planning with thermal cutting for oxyfuel, plasma and laser cutting with CNC machines.

Omni Bevel is the professional software product for bevel cutting. lt represents straight cuts, cylindrical holes, exact bevel angles and parts with absolute dimensional accuracy. The application is also characterized by enormous flexibility. Almost all possible technology parameters and operation details can be adjusted.

Comparison

Compare over plasma cutting operation this condition reduce the possibilities of taper while cutting

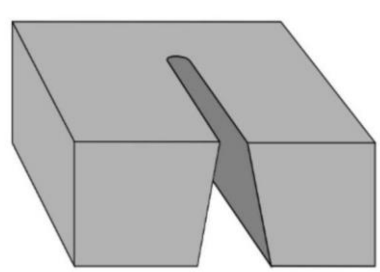


Table. Current scenario of plasma cutting Kerf and Taper

	4 mm plate	8 mm plate	12mm plate
Kerf (mm)	2.078	2.029	2.435
Taper (mm)	0.645	1.112	1.190

While the major chance for arise taper zone on laser cutting work is only 0.5 mm

Advantages

Net Shape Machining:

Laser machine advanced Tilt cutting head, this allowed us cut virtually zero taper edges with most material up to 100 mm. Finish product is achievable without secondary machining process.

Quality Edge Finish:

Compared to oxyfuel and plasm cutting. Laser cut edges are smooth, polish like and considered finish cut (no burr, slag and discoloring). Secondary operations are not needed.

Stacking of materials:

We are capable of stacking multiple sheets, to cut at the same time, to reduce cutting time.

Conclusion

1.The CO2, 1 KW Laser cutter also suitable to cut low thickness of carbon steel plates with more accuracy

2. Due to its unique tilt arrangement of rotated nozzle, made taper cut only on the scrap section minimum deviation of 0.5 mm.

3.No other secondary operations are not require for workpiece.

References

[1] S. Marimuthu, "Design and evaluation of high-pressure nozzle assembly for laser cutting of thick carbon steel plates" pg no 1-2

[2] http://esab.com Article – Laser cutting.

[3] Local bodies Industrial survey.

[4] http://schgo Zero Taper or Taper Free Cutting