Characterization of effective pertinent parameters during fiber laser cutting operation

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Abstract: **Fiber laser for materials processing have undergone a rapid development in the past several years. As fiber laser provides a combination of high beam quality and a wavelength that is easily absorbed by metal surfaces, named future laser is expected to challenge the CO_2 and Nd:YAG lasers in the area of metal cutting. This paper includes laser cutting principle and the principle of fiber laser including the newest development of fiber laser cutting technology. Overture test is made in order to investigate effect of the cutting parameters on cut quality. The experiment is focused on the cut quality with maximum cutting speed and minimum oxygen gas pressure. Cut quality is mainly decided by the kerf width, perpendicularity tolerance, surface roughness and striation patterns. After analyzing cutting result, effective range of parameters was observed as Laser Power (600W – 1000W), Cutting Speed (2500 – 4000 mm/min), Gas Pressure (0.6 – 2.0 Bar) and Duty Cycle (60 – 100 %). A further improvement about the cutting quality might be possible by proper selection of process parameters. In order to investigate cutting performance emphases is on Laser cutting, Fiber laser, cut quality**

I. Introduction

Laser cutting offers several advantages over conventional cutting methods such as plasma cutting. The advantages of laser cutting include high cutting speeds, narrow kerf width (minimum material lost), straight cut edges, and low roughness of cut surfaces, minimum metallurgical distortions, easy integration with computer numerically controlled (CNC) machines for cutting complex profiles and it is a non contact process suitable for cutting in areas with limited access. [1]

Laser is a device made of three parts as shown in Fig. 1:

1. Laser medium is gain medium in which laser is produced.
2. Optical resonator will act as mirror and provide stimulation.
3. Pumping source will provide energy for production of laser.

Laser technology has continued to develop over the years and now many types of lasers are commercially available. The CO_2 laser and Nd: YAG laser is the main lasers used for industrial cutting applications. [2] The new solid-state laser technologies of high power fiber lasers - which offer a combination of high beam quality and a wavelength that is easily absorbed by metal surfaces - are now challenging CO_2 and Nd: YAG lasers in cutting applications.

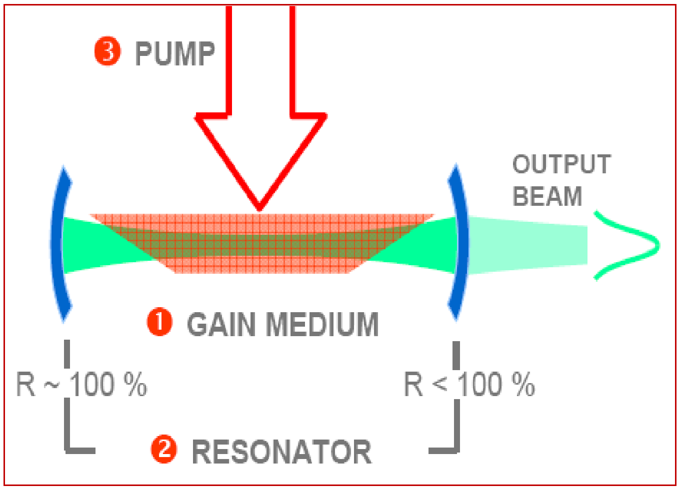

Fig.1 Components of Laser Devices

The output powers of fiber lasers are scalable to the kilowatt range. These systems are promising for cutting applications because their high beam quality enables focusing of the laser beam to a small spot producing high power density that is essential for cutting of metals and enhances higher cutting speeds. [3] This paper consist literature review and experimental work for Laser cutting process and the characteristic properties of the fiber laser cut. Most work reviewed in the literature covered only cutting with the CO_2 laser and Nd: YAG laser and the few that covered cutting with fiber laser considered mostly the cutting speeds without a detailed analysis of the cut quality obtained. In the experimental part of this study, the potential of the fiber laser for cutting applications and the possible consequences of their high beam quality was investigation. The cutting experiments covered cutting of sheet metal using fiber lasers. The cut qualities were analyzed by measuring the kerf width, perpendicularity of the cut edges and the roughness of the cut surfaces. These laser systems are continually being developed and this improved laser performance is also helping in the rapid progress being made in the laser cutting process [4].

II. High Power Fiber Laser

A fiber laser is made from several meters of multi-clad single mode active fiber, side pumped by single stripe multimode diodes. The wall plug efficiency of fiber laser is greater than 20%, which allows the device to be air-cooled. Fig. 2 illustrates the scheme of the clad-pumped fiber laser.

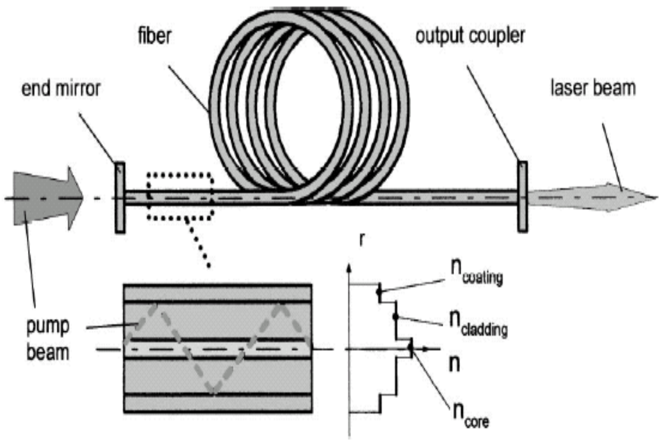

Fig. 2: Scheme of the clad-pumped Fiber Laser [5]

The radiation of the diode lasers is focused into the relatively large non active cladding part of the pump core (diameter of 100µm) from where the diode pump light is then coupled to the active medium in the fiber core (see Fig.2). The pump light, confined in the pump core by a coating with a lower index of refraction, propagates along the optical axis crossing the laser core and exciting there the laser active medium over a length of several meters (up to 50 meters long). Fiber Bragg gratings replace conventional dielectric mirrors to provide optical feedback. Fiber lasers are pumped by semiconductor laser diodes or by other fiber lasers [5].

Summarized Usage benefits of fiber lasers are as:

- Simplicity and Compact size
- High efficiency (CO_2 - 10%, YAG - 2%, Fiber - 25%)
- High reliability with Modular power scaling
- No internal optics to service or align
- Low maintenance resulting in lower maintenance cost
- Solid state laser technology having No moving parts
- High beam quality preserved with fiber optic delivery [5]

III. Laser Cutting Principle

The purpose of experimental method is to investigate the cutting performance and how cutting parameters affect cut quality of fiber laser cutting. Laser cutting is a thermal cutting process as shown in Fig. 3. the principle components includes the lasers power source with some power control, beam guidance train, focusing optics and a means of moving the beam or work piece relative to each other. When the beam is required the beam generated with the laser power source passes to the beam guidance which directs the beam to the focusing optic. The focusing optic is reflective in nature and is consists of parabolic off-axis mirrors. The focused beam then passes through and melts the material throughout the material thickness and a pressurized gas jet. The gas jet is needed both to aid the cutting operation and to protect the optic from spatter. [2]

IV. Laser Cutting Parameters

The process of laser cutting involved many parameters, which can be generally divided into two main categories—beam parameters and process parameters.

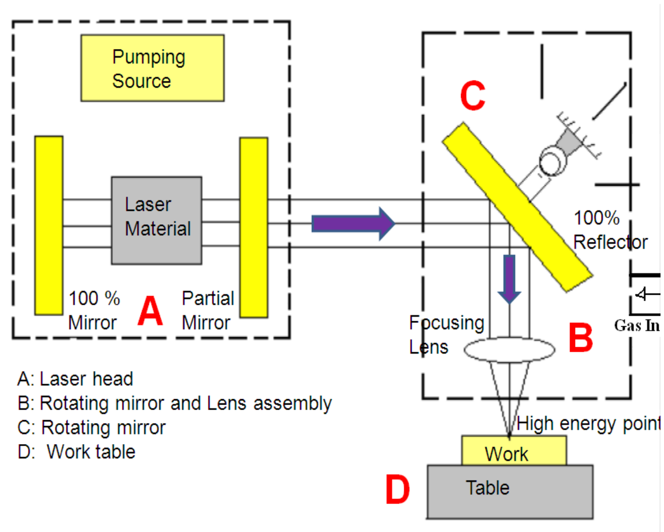

Fig. 3: General arrangement for laser cutting: A: Laser head B: Rotating mirror and Lens assembly C: Rotating mirror D: Work table

A. BEAM PARAMETERS

These are parameters that characterize the properties of the laser beam.

a. Wavelength:

The wavelength plays a most decisive role by involving in energy coupling and the process efficiency, stability and quality. It has important effect on material's surface absorptivity. For a specific material type, there is a certain wavelength which can have the maximum absorption of laser energy with a lowest reflection. Due to the shorter wavelength of fiber lasers (1 µm) leads to the higher absorption in metallic materials as shown in Fig. 4.

b. Power, intensity and spot size

The power of laser system is the total energy emitted in the form of laser light per second. Without sufficient power, cutting cannot be started. The intensity of the laser beam is the power divided by the area over which the power is concentrated. Spot size is the irradiated area of laser beam. In laser cutting application, it is required to focus beam into minimum spot size. Due to the better beam quality of fiber laser with very low divergence, the user can get spot diameters smaller than conventional lasers producing longer working distances.

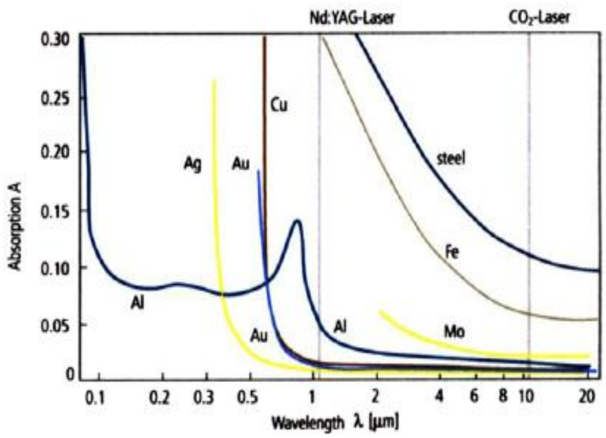

Fig. 4: Absorption of metals as a function of laser radiation wavelength

c. Polarization

Every photon or “light particle” is made up of an electrical and magnetic vector at right angles to each other as shown in Fig. 5a. The polarization can be linear, circular, elliptic or random. The linear polarization means all the photons have their electrical and magnetic vectors aligned parallel to each other, as illustrated in Fig. 5b.

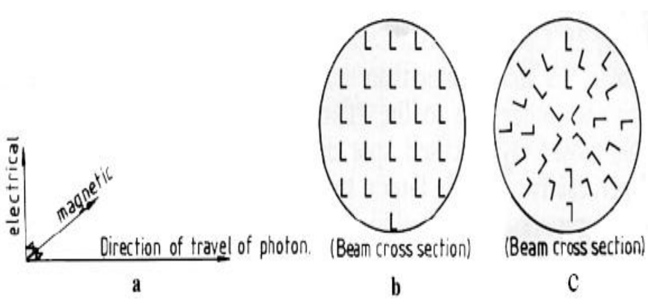

Fig. 5: a. a schematic of electrical and magnetic vectors associated with a photon. b. Linear polarized laser beam c. Circular polarized laser beam.

The electrical and magnetic vectors in the circular polarization are at 90° to the direction of propagation follow a circular pattern as shown in Figure- 5c. When the polarization is simply uncontrolled, polarization is random. Due to the nature fiber laser is randomly polarized.

B. PROCESS PARAMETERS

These are parameters that characterize the properties of the laser beam.

a. Focusing of laser beams:

The focal length of lens is about the distance from the position of focal lens to the focal spot. The focal length of the lens has a large impact on size of the focal spot and the beam intensity in the spot.

b. Focal position:

In order to get optimum cutting result, the focal point position must be controlled. There are two reasons: the first reason is that the small spot size obtained by focusing the laser beam results in a short depth of focus, so the focal point has to be positioned rather precisely with respect to the surface of the work piece; the other one is differences in material and thickness may require focus point position alterations.

c. Process gas and pressure:

An inert gas such as nitrogen expels molten material without allowing drops to solidify on the dross while an active gas such as oxygen participates in an exothermic reaction with the material. The gas also acts to suppress the formation of plasma when cutting with high intensities and focusing optics are protected from spatter by gas flow.

d. Nozzle diameter, stand-off distance

Nozzle is used to deliver the assist gas. The nozzle has three main functions: To ensure gas is coaxial with beam; To reduce pressure to minimize lens movements and misalignments; and to stabilize pressure on the work piece surface to minimize turbulence in the melt pool.

The SOD is distance between nozzle and work piece. SOD is usually selected in the same range as the diameter of cutting nozzle in order to minimize turbulence.

e. Cutting speed

The cutting speed must be balance with the gas flow rate and the power. As cutting speed increases, the cutting time decreases and less time for the heat to diffuse sideways and the narrower the HAZ. When the cutting speed is too low, excessive burning of the cut edge occurs, which degrades edge quality and increases the width of the HAZ.

V. Machine Specification And Cutting Sequence

1. Power: -	10-1000w
2. Speed: -	300-4000 mm/min
3. Pressure: -	0.4-8 bar (oxygen) {for SS N_2 is used for the purpose of good shining}
4. Focusing: -	Travel of 19mm with 125mm lens
5. Frequency: -	5 Hz to 1 kHz.
6. Duty cycle: -	5% to 100% (100% is CW mode and other is pulsed mode.)
7. Polarity: -	Random

Fiber Laser Cutting Sequence:

We have made one general flow chart shown in Fig. 6 for procedure to be followed to get best result in minimum attempt.

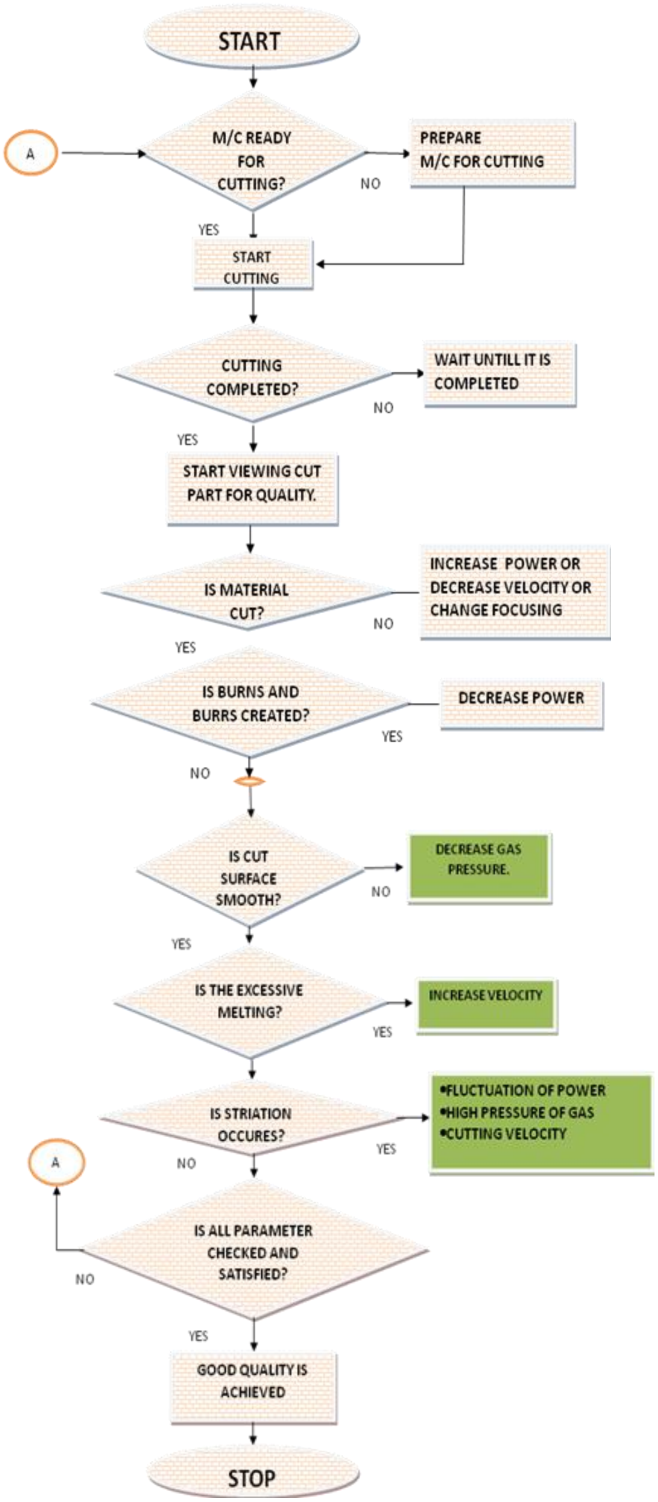

Fig. 6: Flow chart for general procedure

Steps to perform Laser cutting are as follow.

1. Laser head assembly produce Laser in gain medium and gives output at fiber end.
2. The laser output is sent to collimated unit because the beam has more divergence, collimated unit will increase its waist diameter and beam quality will increase this beam is called collimated beam.
3. The beam is then focused and intensifies to set as spot on material.
4. All parametric setting is done before starting of cutting.
5. CNC machine will start and gas pressure is turned on.
6. Laser cutting operation can continue till completion.

VI. Experimental Work

By following the process sequence mention by flow chart, we have performed few experiment and made some observation to see the effect of different parameters on cutting quality for the purpose of future analysis. Machine used to for experimentation work is shown in Fig. 7.

Fig. 7: Experiment set up

During experimentation to cover entire range of different combinations we have varied the parameters - power, gas pressure, frequency, and speed. We achieved different cut quality shown in picture form in Fig. 8.

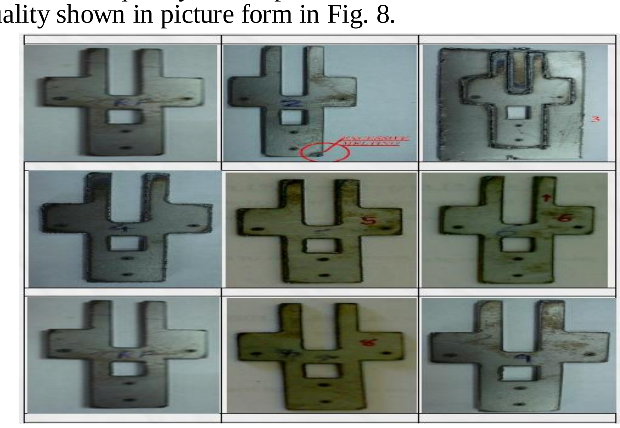

Fig. 8: Photographs of cut components

Observation Table

Table I

CORRESPONDING CUTTING PARAMETERS AND OBSERVATIONS

Sample no:-	Power in watt	Gas pressure-bar	Frequency in HZ	Duty cycle	Speed in mm/min	Observation
1 (R/F)	800	0.8	1000	100%	3800	Good cut quality with less HAZ among all.
2	800	1	1000	100%	3800	Burns, Melting at edges
3	800	0.8	1000	80%	3800	Material welded with bigger HAZ, Poor cut quality
4	800	0.8	1000	80%	2700	More Burrs, HAZ, Striation
5	800	1.4	1000	80%	2700	Burrs, HAZ, Striation (less compared to sample 4)
6	600	1.4	1000	80%	2700	Less striation and HAZ compared to sample 5
7	700	1.4	1000	80%	3000	Striation is more than sample 6 but HAZ is less.
8	1000	0.8	1000	80%	4000	Good Surface finish than sample 7
9	800	0.8	1000	100%	4000	Very few striations, Similar to sample 1, HAZ is more.

VII. CONCLUSION

From above experimental observation we can conclude that various parameters are affecting quality anyhow when they are altered. The high cutting speeds during fiber laser cutting have direct effect of the high power densities facilitated by the high beam quality. So we required to set a set of parameter that will result in good quality of cut of material. We have gone through altering of parameters listed below.

1. Laser Power (600W – 1000W)
2. Cutting Speed (2500 – 4000 mm/min)
3. Gas Pressure (0.6 – 2.0 Bar)
4. Duty Cycle (60 – 100 %)

The cutting results showed that fiber laser have a potential for cutting applications and are capable of competing favorably with the CO_2 laser. It might be possible that the defects observed for thick sheets can be avoided by proper selection of process parameters especially Laser power, cutting speed and gas pressure. We made primary study and made one flow chart to get best quality cut. In industry they are using trial and error method. But it requires number of manual attempts in that they are varying parameters and making experiment until they get best cut.

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