

# Optimization Dragline on Parameter and Gas Cutting of Laser Beam Machining in SS400 Steel using Taguchi L<sub>16</sub> Methods

Rifky Yusron<sup>1\*</sup>, Bambang Tjiroso<sup>2</sup>, and Kukuh Winarso<sup>3</sup>

<sup>1</sup>Department of Mechanical Engineering, Faculty of Engineering, Universitas Trunojoyo Madura, 69162 Bangkalan, Indonesia

<sup>2</sup>Department of Mechanical Engineering, Faculty of Engineering, Universitas Khairun Ternate, 97751 South Ternate, Indonesia

<sup>3</sup>Department of Industrial Engineering, Faculty of Engineering, Universitas Trunojoyo Madura, 69162 Bangkalan, Indonesia

**Abstract.** Laser cutting is sustainable non-conventional machining. Unlike wire-EDM, laser cutting have ability to process conductive or non-conductive material without adding any conductive layers before. Laser cutting not depends on any tool supplies. In laser cutting operation, energy consumption being main issue. Less error on dragline and surface roughness in laser cutting process is essentials, to meet them need right setting variable process to produce optimal response. Material using 6mm SS400 steel. Variable observed on this research are laser power output has 4 levels 1820W, 2080W, 2340W and 2600W. Cutting gas pressure has 4 levels 0.5 bar, 1 bar, 1.5 bar, and 2 bar. Gas cutting has 2 kind they are Helium (He) and Dinitrogen (N<sub>2</sub>). Taguchi L16 (4<sup>2</sup> 2<sup>1</sup>) applied as research design. this research observing perpendicular on edge of laser cutting. The aim of this research is to provide optimum parameter combination of cutting parameter and gas cutting, so as to produce lowest cutting deviation. For manufacturing industries, this can minimize finishing process and number of product rejection. The highest cutting-edge deviation is 0.1125mm, achieved at combination gas pressure 1.5 bar, 2600W power output and Helium gas cutting on second replication. The lowest cutting-edge deviation is 0.0165, achieved at combination gas pressure 0.1 bar, 2600W power output and dinitrogen gas cutting. Based on Taguchi L16 recommendation optimum combination is gas pressure 1 bar, 2080W power output and using dinitrogen gas cutting. On this combination achieved cutting-edge deviation is 0.0158mm. it was 7% lower than the lowest combination.

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\* Corresponding author: [rifky.myusron@trunojoyo.ac.id](mailto:rifky.myusron@trunojoyo.ac.id)

# 1 Introduction

Metal machining process is one of the key processes who conducted in the metal manufacturing industry. They certainly required it to meet produce quality components and tight production time [1]. Manufacturing industries spent serious investment in metal machining tools, and it increases year by year. Their product quality and process can be judged by it. The various reasons why metal machining is hard to resist by the manufacturing industries are their capability to process high precision part with tolerances of 50µm and surface roughness of 1µm. Another reason why it very versatile complicated free-form shapes with many features, over a large size range, can be quick, cheap, and simply by controlling and integrable with automation. Some manufacture rather investing to metal machining tool rather than by investing dedicated mouldings, forming or die casting tool. because machining is also capability to process metal with similar accuracy compare to them.

One of metal cutting processes that common on manufacturing industry in recent years is laser cutting process [2]. The laser cutting process is a thermal cutting process with high productivity in terms of plate cutting, it make that process will be faster and accurate cutting results [3]. Laser cutting is sustainable non-conventional machining doesn't need expensive and replaceable tools and they doesn't produce force during machining process that can damage workpiece [4]. There are many types of laser cutting process solid laser, liquid laser and gaseous laser cutting among which solid state lasers CO<sub>2</sub> based laser cutting are mostly used for steel machining beside O<sub>2</sub> or Nitrogen based laser cutting machining. Because their high power and suitable properties needed for the cutting of the material [5]. Beside cutting operation, laser cutting also capable for drilling, micro machining, welding, sintering and heat treatment [6].

The gas pressure when cutting is depend on material thickness, furthermore gas pressure factor is more important when cutting with oxygen gas than cutting with nitrogen gas, a higher gas pressure using to cut thin specimens and vice versa [7]. And the addition of this gas supply will compensate for the lack of oxygen gas, which may cause higher cutting speeds. During laser cutting operations, the gas pressure factor is inversely proportional to the thickness of the material [8]. Oxygen and nitrogen gas are common using laser cutting operations to produce high quality cutting product, require purity of the gas consumptions [9]. When using nitrogen, addition of oxygen gas may increase oxidation in cutting edge of workpiece. When using a constant laser power, a higher cutting speed requires a purer oxygen cut gas level to prevent burrs from occurring or appearing on the work piece [10]. Oxygen gas mixed with nitrogen gas or water vapor from cutting process may produce a burr itself. in laser cutting process, there are several parameters who can be benchmark: slag thickness, kerf width, surface roughness, and dragline.

This research is focused on observing parameters on laser beam machining, especially gas pressure and

power output on SS400 steel. In addition, it aims to find out which of the two factors contributes to the dragline deviation during the laser beam cutting process. this will contribute to the operator so that in cutting operations using laser on ss400 steel. this will save further finishing costs, so it can reduce production costs. So far, research on optimization parameters of laser sharpening grinding wheels has been carried out last year [11], from research revealing a good correlation between the simulation and experimental data. In a word, the numerical model established in this paper can be conveniently used in the optimization of the process parameters in the laser sharpening grinding wheel. The brass content in SS400 steel material has a tendency to bend infrared waves including lasers [12], thus allowing dragline deflection which results in the cutting result being not perpendicular.

# 2 Methods

Material using on this research is SS400 steel. Mechanical properties of this material yield strength 283 N/mm<sup>2</sup>, ultimate strength (423 N/mm<sup>2</sup>) and Elongation 25 %. Specimen dimension length 20mmx width 20mmx thickness 6mm. Element composition in SS400 steel shown on table 1.

**Table 1.** Material properties of SS400

Elemen	Percentage
Carbon	0.713%
Mangan	0.889%
Phosphor	0.012%
Sulphur	0.010%
Brass	0.045%
Silicon	0.019%

Material cutting use Laser Beam TLF2600W Turbo. Research variable observed on this research are gas pressure with four level and power output 3 level. That shown on Table 2. Combination from table 2 optimising be matrix orthogonal as shown on table 3. Constant parameter during cutting process are:

- Nozzle diameter: 1,4 mm
- Cutting Speed: 1,5 m/minute
- Focus point position: ± 3 mm
- Cutting height: 1,5 mm
- Cutting angle: 180°

**Table 2.** Constant Parameter

Level	Gas Pressure (bar)	Power Output (W)	Gas
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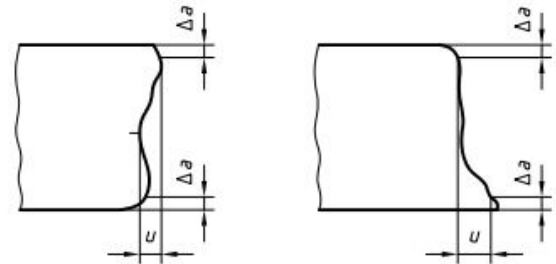
1	0.5	1820	He
2	1	2080	N2
3	1.5	2340	
4	2	2600	

**Table 2.** Matrix Orthogonal L16 (4<sup>2</sup> 2<sup>1</sup>)

Combination	Gas Pressure	Power Output	Gas
1	1	1	1
2	1	2	1
3	1	3	2
4	1	4	2
5	2	1	1
6	2	2	1
7	2	3	2
8	2	4	2
9	3	1	2
10	3	2	2
11	3	3	1
12	3	4	1
13	4	1	2
14	4	2	2
15	4	3	1
16	4	4	1

Table 3 display about matrix orthogonal on this research. Each combination parameter has 3 replication, three times replication aims to get a standard value with a good correlation coefficient and to avoid data error. the selection of gas pressure and power output parameters to the maximum limit aims to

obtain the characteristics of deviation of cutting edge. in the manufacturing industry the application of high gas pressure and power output minimizes cutting time, but produces work pieces that are not perpendicular. so this research can make feedback for industries who deal with these conditions. Dragline error of laser cutting measuring followed SFS – EN ISO 9013 standard. Measurement tool using Industrial Magnifier Lens Mustool G1200 assist with Computer Allied Dimensions software. Scheme SFS – EN ISO 9013



**Fig. 1.** Scheme of SFS-EN ISO 9013 dragline measurement. Source: [www.iso.org/standard/29998.html](http://www.iso.org/standard/29998.html)

### 3 Result and Discussion

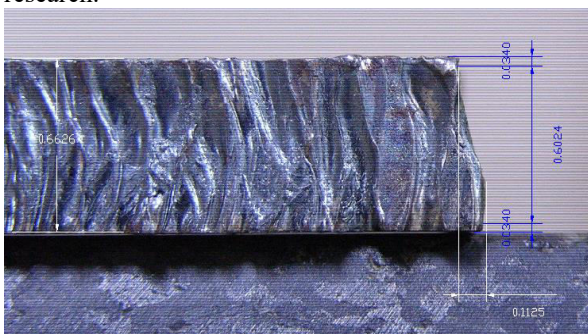
Experiment of laser beam cutting parameter setting had result of dragline error on SS400 steel shown on Table 3. Further analyse variable gas pressure and power output has significant level. we conducted two-way ANOVA test. Result of two-way ANOVA test shown on Table 4. Based on table 3, a chart is made to monitor the trend of the gas pressure and power output parameters using polynomials. In this case, the average value of each replication per combination variable is taken.

**Table 2.** Research result

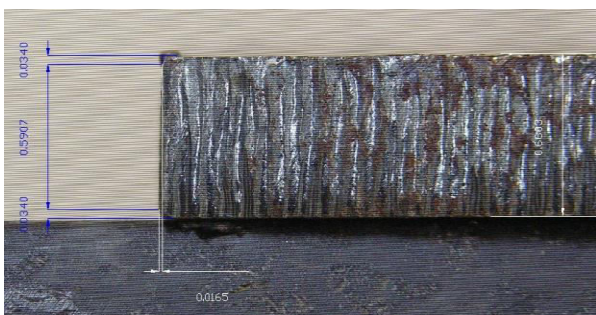
Combination	Replication 1	Replication 2	Replication 3	Average
1	0.0195	0.0265	0.0268	0.0243
2	0.0514	0.0523	0.0342	0.0460
3	0.0318	0.0438	0.0531	0.0429
4	0.0751	0.0482	0.0611	0.0615
5	0.0253	0.0332	0.0239	0.0275
6	0.0316	0.0404	0.0261	0.0327
7	0.0392	0.0253	0.0435	0.0360
8	0.0550	0.0342	0.0165	0.0352
9	0.0226	0.0186	0.0220	0.0211

Combination	Replication 1	Replication 2	Replication 3	Average
10	0.0436	0.0293	0.0494	0.0408
11	0.0726	0.0979	0.0583	0.0763
12	0.1125	0.0710	0.0656	0.0830
13	0.0908	0.1010	0.098	0.0966
14	0.0800	0.0720	0.0610	0.0710
15	0.0685	0.0705	0.0670	0.0687
16	0.0980	0.0870	0.0900	0.0917

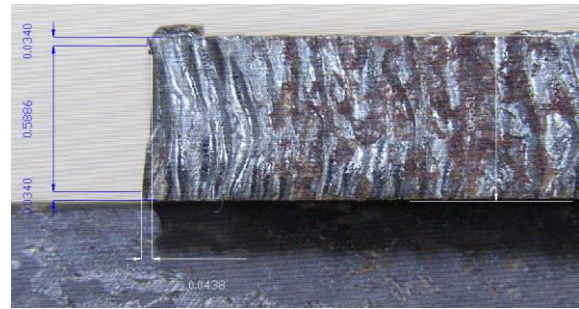
Based on table 4 among specimen had cutting-edge deviation ( $\Delta u$ ) average close 10-1mm. this reveals that the cutting results in all combinations have an accuracy level that is in accordance with the specifications of the Laser Beam TLF2600W Turbo machine. based on table 4 it can be seen that the highest cutting-edge deviation is 0.1125mm, achieved at the combination of gas pressure 1.5 bar, 2600W power output and Helium gas cutting on second replication. The lowest cutting-edge deviation is 0.0165, achieved at combination gas pressure 0.1 bar, 2600W power output and dinitrogen gas cutting. Figure 2 shows the results of the cutting edge conducted by laser beam machining, it also displaying the deviation on value of  $\Delta U$  in this experiment. The highest cutting edge is shown in Figure 2 and the lowest is shown in Figure 3. Figure 4 to 7 display some result of laser beam cutting on this research.



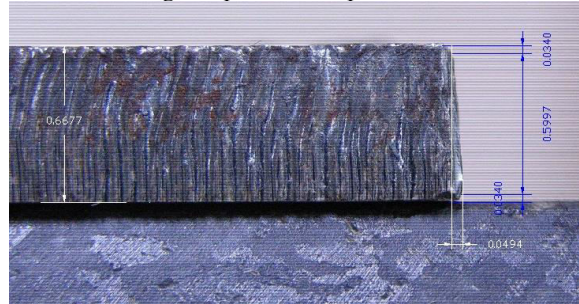
**Fig. 2.** maximum cutting-edge deviation on specimen 12 replication 1



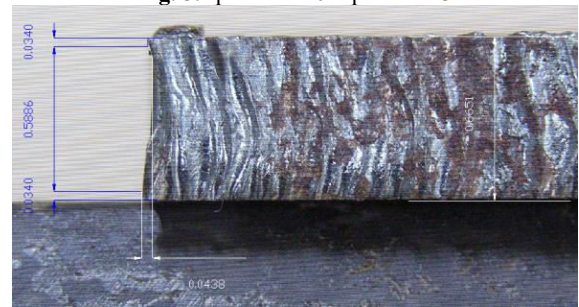
**Fig. 3.** minimum cutting-edge deviation on specimen 8 replication 3



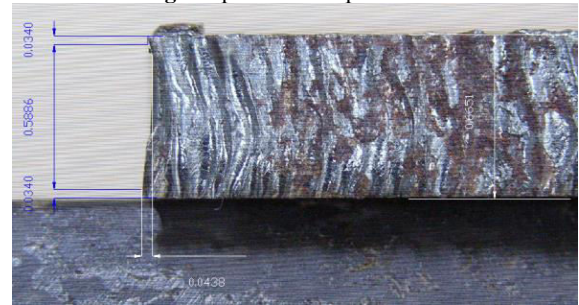
**Fig. 4.** Specimen 2 replication 2



**Fig. 5.** specimen 10 replication 3



**Fig. 6.** specimen 3 replication 2



**Fig. 7.** specimen 7 replication 3

Based on the data from table 3, the variables of gas pressure, power output and gas cutting were analysed using Taguchi L16, so that the optimal combination of these cutting parameters can be defined simultaneously. in this study using the quality control rule used is smaller better, the smaller cutting edge shows the results of net shape cutting quality. it minimizes or even eliminates the finishing process. The results of the optimal parameter combination of cutting pressure, power output and cutting gas on the cutting-edge deviation response are shown in Figure 8 and 9. Figure 8 shows the optimal parameter combination based on the Mean and Figure 9 shows the results of the optimal parameter combination based on the S/N ratio shown in Figure 2b.

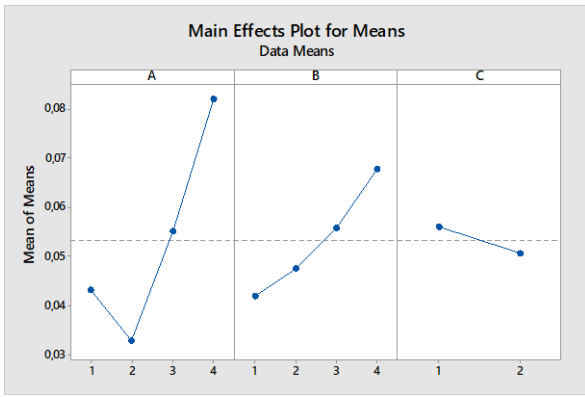


Fig. 8. Optimal parameter combination based on the Mean

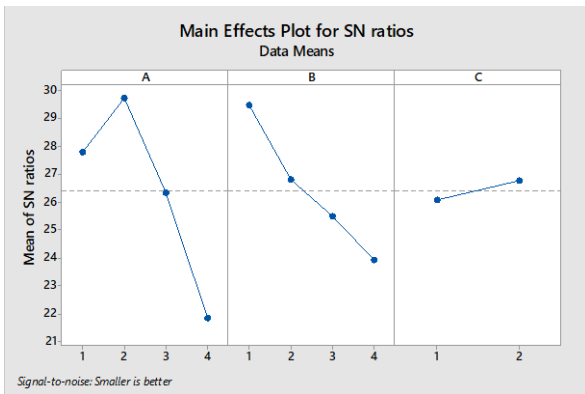


Fig. 9. Optimal parameter combination based on the S/N Ratio

Figure 5 display about optimum parameter on this research based on S/N ratio and mean, both image show that parameter optimal is gas pressure on level 1, power output on level 2 and gas cutting on level 1. Based on Taguchi  $L_{16}$  recommendation optimum combination is gas pressure 1 bar, 2080W power output and using dinitrogen gas cutting. On this combination achieved cutting-edge deviation is 0.0158mm. it was 7% lower than the lowest combination, as shown on figure 11.

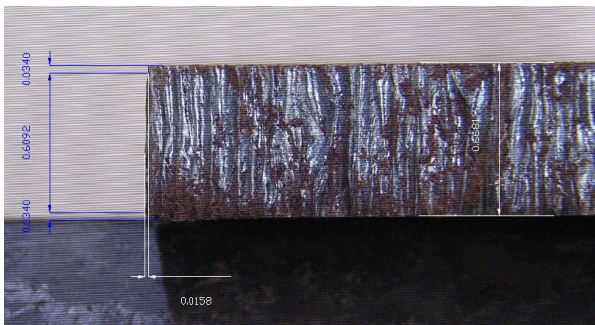
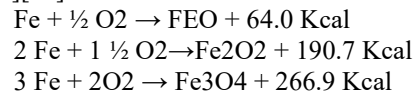


Fig. 10. Result of confirmation experiment based on optimal parameter

Source	DF	Seq SS	Contribution	Adj SS	F-Value
A	3	0.005376	57.40%	0.005376	6.08
B	3	0.001512	26.14%	0.001512	1.71

Source	DF	Seq SS	Contribution	Adj SS	F-Value
C	1	0.000120	10.28%	0.00120	0.41
Error	8	0.002359	5.18%	0.002359	
Total	15	0.009366	100.00%		

Based on general linear model ANOVA test in Table5, parameter A (gas pressure) is the most influenced parameter followed by parameter B (power output) and last influenced parameter is parameter C (gas cutting). Gas pressure had 54.40%, while power output is 26.14 % then cutting gas is 10.28%. This ANOVA test using 95% confidence level. Based on data in table 3, tendency of influence gas pressure and power output on dragline deviation is directly proportional. This can be seen from the tendency of graph to increase along with addition of gas pressure in laser cutting. This happens because the cutting gas used is oxygen gas which will react with the material in the form of low carbon steel when the heat generated by the laser touches the workpiece and forms iron oxide. Because the melting point of iron oxide is lower than that of steel. it melts and is blown away by the pressure of the cutting gas. It confirmed on this research [13] [19][20]. The oxidation process is estimated by following this chemical reaction below [21][22]:



On 0.5 bar cutting gas pressure. the dragline deviation is smaller than the larger pressure. This is might amount of oxygen at a pressure of 0.5 bar is suitable for the thermal reaction that occurs so that the energy produced is also suitable for melting the material. Meanwhile. when the cutting gas pressure is 1 - 2 bar. deviations continue to increase because the amount of energy produced will be greater and the heat capacity will increase so that the heat absorbed by the material will spread around the kerf and cause the surrounding kerf to melt. This is similar with mathematical model in the following research. It can also be seen that the laser power output has an effect on the deviation of the perpendicular of the cutting results. Laser power output is 2340W the average value of the deviation of the perpendicular is large. Then the laser power output of 1820 W has an average deviation of perpendicular which is quite large below the average deviation value of the laser power output of 2340 and 2600 W. Then the laser power output of 2080W has the lowest average deviation value. This happens because when the laser power output is 2080W, the heat generated is suitable for heating the workpiece so that the resulting melt is perfect so that the cutting parameters in the form of irregularities are quite low. Meanwhile, when the laser output power is 2340W and 2600 W, the heat generated is too large so that the part of the workpiece around the kerf melts where it should not melt and a large deviation is generated because of

it. When the laser power output is 1820W, the heat generated is not enough for the melting process so that there is a part of the workpiece in the kerf that should have melted not melted, resulting in a large enough deviation.

## 4 Conclusion

This research providing cutting gas pressure, power output and gas cutting influences the cutting-edge deviation of the perpendicular of the laser cutting results on SS400 steel. The interaction between the cutting gas pressure, laser power and gas cutting output significantly affects the deviation of the laser cutting results in SS400 steel is directly proportional. optimum parameter on this research based on S/N ratio and mean, recommendation optimum combination is gas pressure 1 bar, 2080W power output and using dinitrogen gas cutting. On this combination achieved cutting-edge deviation is 0.0158mm, reduce 7% than initial experiment. Recommendation for future study is using material with different carbon and brass compositions steel material, further more application cryogenic cooling system in laser cutting.

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