

Determination of Main Laser Processing Technical Parameters in Wood Manufacturing

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Abstract. According to the laser cutter larch, this study has determined the reasonable process parameters such as focal length, light intensity, and optimized laser processing technology parameters to provide test methods. Firstly, for the cutting seam state analysis the precautions of software settings have been put forward. General rules of variations of process parameters in laser technology were determined through the orthogonal test method, and designs a three-dimensional curves, to observe the interaction of different factors, and then used two factor completely random repeat test method, to determine the reasonable parameters of intensity, The results showed that the reasonable process parameters: focal length is 6mm and focal intensity is 32% or the focal length is 6.5mm and focal intensity is 50%, last the cutting seam depth is about 5~6mm.

Introduction

With the adjustment of forestry structure in China, woodiness material processing is seeking to break through the traditional way, applying new technology and new method of the industry. Laser processing has many advantages such as high efficiency, high resource utilization, no stresses and deflection, easy to realize all sorts of complicated design processing[1], high precision, low noise, less pollution, and even wood-plastic composite materials can be processed by selective laser sintering(SLS)[2-4], so it has great development potential[7].

The laser cutting of timber is different from that of metal. The characteristics of different kinds of timber vary a lot. Even to the same tree species, because of different growing region, different timber direction and different storage conditions, there will be a lot of processing differences. And because wood is a kind of flammable material, should be take care to avoid causing fire, thus result into the complexity of parameters determination in laser cutting process. In actual production, experimental cutting is usual, in order to cut off timber, high laser intensity is also used, the life of laser tube is usually shortened because of improper utilization, furthermore wood is easy to carbonize and even burn and cause danger. Thus, this paper takes larch for example, conducts laser cutting experiments, and aims to optimize processing parameters.

Materials and methods

Testing equipment.

CMA1390 CO₂ laser cutting machine, cutting width: 1300mm×900mm. Laser generator, power: 130W, output maximum working current: $I_m = 50\text{mA}$, total power: 1.25KW, maximum cutting speed: 800mm/s. Supporting software: SmartCarve4.3 (identification file extension: dxf, lowest version: 2004). Because of narrow kerf width, it is not easy to measure, we use VHX-2000 super-depth microscope (precision: 1μm) to measure the depth(kerf depth: represented with a) and the width of kerf(kerf width, represented with b) after a lot of experiments.

Testing materials.

Larch, dry wood, specimen size: 1000mm×90mm×10mm. Each with the cutting kerf length of 100mm, grain cutting. A cutting sample is shown in figure 1.

Preliminary test analysis and test data.

There are a lot of main technical parameters about laser cutting, such as power, air flow, nozzle diameter. This paper mainly focuses on cutting speed(v), focal length(f), the maximum and minimum laser intensity (in percentage, corresponding to working current I_m). To avoid effects on machine parts by setting acceleration, we use the default acceleration.

Although SmartCarve4.3 software has drawing function, it is very simple, so we draw graphs in AutoCAD, change them into .dxf files, and then import to SmartCarve4.3 software. We observed in the experiment that, when using AutoCAD to draw, the line width setting had no obvious effect on cutting width (there are some differences in measurement data, but no significant regularity, it may be the result of uneven cutting affected by other cutting process parameters), but repeated line drawing in CAD has a great influence on cutting, because every repeated line drawing will cause repeated laser cutting one more time. And repeated line drawing in SmartCarve4.3 software is different from that in CAD, while SmartCarve4.3 can not check out repeated lines, the orientation in CAD is very convenient, so repeated line drawing is very common, and this is a main factor affects kerf depth of cutting. As repeated lines have no display effect in AutoCAD, it is very important for designers using CAD to delete repeated lines in time.

It was found in the experiment that, even the same kerf has different width, generally varies within 1mm, a few difference reaches more than 2mm (should be caused by voltage instability or uneven wood material, we regarded it as gross error). At first we measured each cutting kerf for many times and calculate the average value, but after careful observation of the cutting process, we think this is because that it is impossible for machine parts to start and stop immediately when cutting, laser tube cutting speed is not uniform in the working process, especially in single cutting, short cutting and fast cutting, uneven kerf depth is more obvious. In multiple cutting, kerf depth difference is small. On the other hand, kerf depth is larger at start point, smaller at stop point, it illustrates that cutting state may also affected by cutting machining path settings in SmartCarve4.3. Therefore, we re-measure the kerf depth and take the depth of midpoint as the measurement result.



Fig.1. State of specimen

Figure 1 (a) shows the front and back panel of of cutting sample. It was found in the experiment that a lot of kerf were cut through on both ends, the circled black spot indicates that the sample was cut through for several times on the back panel, which was very obvious. The trace of single cutting through is not so obvious, and can only be seen with light transmission method. This is because the minimum laser intensity was set bigger, and the machine operation speed is 0 at start and stop time(the critical value), so the laser tube stay too long at certain part, causing wood gasification and cutting through. It is suggested to improve the difference between the minimum and the maximum laser intensity to about 10-20%, but it should not be too large, because by observing kerf depth during measurement, we found that the bigger difference in laser intensity, the greater uneven in kerf depth, at the same time it also has effect on the life expectancy of laser tube.

Figure (b) shows the kerf width and depth status observed and measured with the VHX-2000 super-depth microscope. There are burning marks in the kerf width edge, and the kerf depth is usually V-shaped. When focal length is about 7mm, the difference between top and bottom kerf width is very small. If the focal length is too big or too small, it will make the V-shape very significant, and kerf width will increase.

The experiment data is show in table 1 (odd line is single cutting measurement data, even line is five times cuttings measurement data) :

Table1. Laser cutting data of Larch

N u m	cutting speed	laser			seam depth	seam width	N u m	cutting speed	laser			seam depth	seam width	N u m	cutting speed	laser			seam depth	seam width
		intensity (%)	focal length f	focus depth a					intensity (%)	focal length f	focus depth a					intensity (%)	focal length f	focus depth a		
	(mm/s)	max	min	(mm)	(mm)		(mm/s)	max	min	(mm)	(mm)		(mm/s)	max	min	(mm)	(mm)		(mm)	(mm)
1				7	2.67	0.15	19			7	2.78	0.1	37			7	2.77	0.1		
2					7.43	0.2	20				7.49	0.15	38				9.33	0.15		
3					1.4	0.21	21				2.02	0.2	39				1.75	0.17		
4	20	15	11		5.75	0.3	22	40	35	11	6.08	0.2	40		60	55	11	6.25	0.2	
5					1.72	0.12	23				1.74	0.18	41				1.55	0.13		
6				4	8.05	0.18	24			4	8.06	0.15	42			4	8.87	0.12		
7				7	2.12	0.1	25			7	2.45	0.1	43			7	2.45	0.1		
8					6.81	0.12	26				8.31	0.1	44				8.28	0.15		
9					2.13	0.22	27				1.93	0.22	45				1.95	0.24		
10	200	40	35	11	6.6	0.28	28	400	60	55	11	7.09	0.23	46	600	20	15	11	5.95	0.25
11					2.17	0.14	29				1.59	0.17	47				2.02	0.14		
12				4	6.7	0.18	30			4	6.84	0.2	48			4	7.76	0.13		
13					3.06	0.1	31				2.47	0.11	49				2.43	0.1		
14				7	8.23	0.11	32			7	7.45	0.14	50			7	7.33	0.17		
15					1.81	0.17	33				1.46	0.21	51				1.45	0.18		
16		60	55	11	6.95	0.28	34		20	15	11	7.27	0.28	52		40	35	11	5.46	0.24
17					3.28	0.17	35				1.33	0.16	53				2.12	0.12		
18				4	7.88	0.15	36			4	8.85	0.19	54			4	6.68	0.1		

Data processing and analysis

Because of interaction and mutual influence among various factors, it's not easy to find the law. We need to find out the primary and secondary factors influent kerf depth(a) and kerf width(b) at first, then arrange succeeding experiments, thus optimize laser cutting parameters step by step. Take the line of 5, 7, 15, 21, 29, 31, 37, 45, 53 in table 1 to make a L9(34), and apply orthogonal experiment analysis to it, we got the range of kerf depth speed $R = 0.397$, the range of laser intensity $R = 0.040$, the range of focal length $R = 0.643$, as to horizontal average, the difference of average is not very large except focal length. Relatively, when speed is 600 mm/s, laser intensity is 40%, focal length is 7 mm, the total performance is good(the productivity is high under this condition, but if speed reduced, kerf depth will increase), by calculating variance, we got significances: $F_{\text{focal length}} = 2.226$, $F_{\text{speed}} = 0.764$ $F_{\text{laser intensity}} = 0.09$. It can be seen that focal length has a great influence on kerf depth, while speed has mild influence, and intensity has little influence.

Similarly, for single cutting, we got the range of kerf width speed $R = 0.03$, the range of laser intensity $R = 0.017$, the range of focal length $R = 0.1$, but from the point of horizontal average, as the size of kerf width is tiny, kerf width vary rate caused by focal length changes can reach more than 100%, thus the influence is very huge. Relatively, when speed is 200 mm/s, laser intensity is 40%, and focal length is 7 mm, kerf width will be small. By calculating the variance and analyzing, we got significances: $F_{\text{focal length}} = 2.824$, $F_{\text{speed}} = 0.176$, $F_{\text{laser intensity}} = 0$. It can be seen that focal length has a big influence on kerf width, speed has a little influence and laser intensity has little influence.

Similarly, for five times cutting, we got the range of kerf depth speed $R = 0.907$, the range of laser intensity $R = 1.61$, the range of focal length $R = 1.11$, from the point of horizontal average, the influence of laser intensity on kerf depth of multiple cutting varies a lot. Relatively speaking, when speed is 200 mm/s, laser intensity is 60%, focal length is 7 mm, we got the maximum kerf depth. By calculating the variance and analyzing, we got significances $F_{\text{focal length}} = 0.796$, $F_{\text{speed}} = 0.528$, $F_{\text{laser intensity}} = 1.676$. It can be seen that laser intensity has a great impact on kerf depth in mutiple cutting.

Likewise, for five times cutting, we got the range of kerf width speed $R = 0.043$, the range of laser intensity $R = 0.05$, the range of focal length $R = 0.05$, from the perspective of horizontal average, relatively speaking, when speed is 200 mm/s, light intensity is 40%, focal length is 7 mm, kerf width is small. By calculating variance and analyzing, we got significances: $F_{\text{focal length}} = 1.091$, $F_{\text{speed}} = 0.818$, $F_{\text{laser intensity}} = 1.091$. It can be seen that to multiple cutting, the influence of different factors on kerf width varies a little. And multiple cutting can make kerf width evenly on the direction of kerf depth, V-shape be weakened, but ablation will be more obvious than single cutting.

Orthogonal experiments are mainly to analysis the influence law of various factors, and can provide just a few experimental data. By analysis of the experiments, only the significance of focal length near the threshold, the significances of other factors are not obvious. In order to find out the influence law of various factors on kerf depth, determine detail processing parameters of laser cutting larch under some combination conditions, and to provide reference data for engineering practice, in fact we carried out more tests than which need for orthogonal experiment, as shown in Table 1. Because the large amount of data, we designed out a three-dimensional graph of influences of various factors on kerf depth(kerf width graph can also be drawn likely), as shown in Figure 2 (a). Observing the graph from a certain plane, we can see the interaction law of other two factors when one factor is fixed. In order to avoid the confusion of too much line and for the convenience of observation, we can remove other curves when observing the effect of one factor, Figure 2 (b) shows the influence of laser intensity on kerf depth when speed is fixed in YOZ plane. If connect 3 points not in a plane, it represents the cross effect of various factors (not shown in the figure). Figure 2 (c) shows the influence of focal length and speed when laser intensity is 40%, the influence of other conditions can also be handled likely.

From Figure 2 we can see: 1) in plane with constant speed and parallel to YOZ plane, kerf depth is big when focal length is about 7 mm, and the carbonization phenomenon is lighter in general, it indicates that laser focusing effect is good at this distance, and the beam of laser is thin, with good energy concentration, larch will soon gasify before it can burn; 2) in plane with constant focal length and parallel to XOZ plane, kerf depth is big when speed is 400mm/s (when light intensity is 60%, focal length is 4, the lower speed the bigger kerf depth). The difference varies due to different laser intensity. 3) when other conditions are fixed, it is not the stronger laser intensity the bigger kerf depth, the law is not regular, this is not the same as people's conventional understanding; 4) when $v = 200$, $f = 4$, and $v = 600$, $f = 11$, there will be sudden change in kerf depth. But under this condition, carbonization and kerf width are obviously V-shaped; 5) when laser intensity is 40%, $v \leq 400$ mm/s, $f < 7$ mm, kerf depth varies little, but if $f > 7$ mm, kerf depth will reduce, it shows that reasonable focal length should be among 4-7 mm. 6)if speed is too fast, wood cannot promptly gasify when cutting, so kerf depth changes little, it makes the interaction between laser intensity and focal length not significant.

In addition, under the same conditions, multiple cutting has a great influence on kerf depth, but not simply times the the kerf depth of single cutting. Multiple cutting does not impact kerf width very much, its influence extent needs further research. From data in the table, we can see that when focal length is 4 mm, kerf width of multiple cutting is smaller than that of single cutting, this is because the kerf width of multiple cutting is even, and the kerf width of single cutting is V-shape. Beyond reasonable scope of focal length, increasing focal length has greater influence on kerf width than decreasing focal length, the kerf width is more even, and avoiding chips splash polluting lens.

Comprehensively analysis, the selected cutting speed is higher in this case; it weakens the interaction of focal length and laser intensity, especially the effect of laser intensity. To increase kerf depth, it is suggested to reduce the speed, and set laser intensity to about 40%, focal length to 4-7 mm.

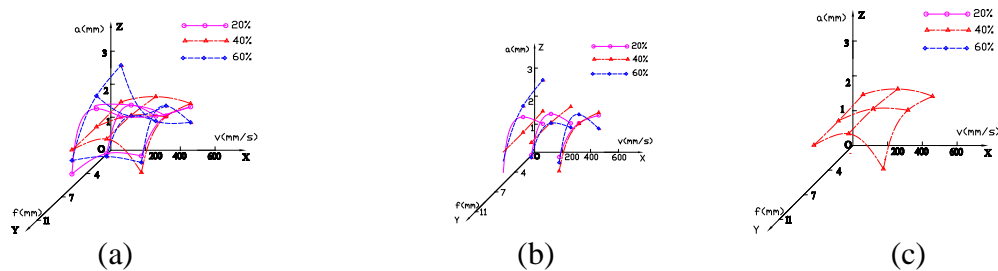


Fig.2. Three-dimensional curves of the effect of different factors

Conclusions

1) Repeated line drawing decides cutting frequency and has great impact on processing, and repeated line checking function of SmartCarve4.3 software cannot handle this situation.

2) When other conditions fixed, it is not the greater the laser intensity, the bigger the kerf depth, there is not a regular law, this is different from common understanding. If laser intensity and focal length are too big or too small, kerf width increases, carbonization becomes significant. At the same time, in order to obtain a large kerf depth when speed is 100 mm/s, the resonable range is: focal length between 5-6.5 mm, laser intensity between 30-50%, and we can get the best result when focal length $f = 6$ mm, light intensity is 32%, and kerf depth will be among 5-6 mm.

3) The uneven depth of a kerf is mainly caused by the speed changes occurred at start and stop time during the operation of laser tube. We can reduce the minimum laser intensity, but it should not be too small, the advisable difference between maximum and minimum intensity is 10-20%. If the maximum intensity is very high, it can be adjusted by setting the acceleration, thus even the kerf depth, but this approach may easily change machine operation inertia and make it unstable, so should take care.

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