Research on Gain Uniformity of Laser Non-imaging Rod Amplifier

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ABSTRACT

According to the problem of gain medium cross section high illumination and non-uniformity, which is caused by the laser rod amplifier non-imaging pump style. Orthogonal test design method is used to research the effect of absorption coefficient, gain medium radius, number of xenon lamps, center distance of xenon lamps and gain medium on gain uniformity. The rod amplifier which is made up by the above four elements, its gain medium cross section illumination distribution is simulated by ASAP. The results show that center distance of xenon lamps and gain medium, number of xenon lamps have very little influence on the gain uniformity. When absorption coefficient equal to 5.1 cm^{-1}, gain uniformity will reach the optimum. Under the circumstance of other three elements are equal, the bigger is the gain radius, the smaller slope reflection curve, and the better gain uniformity.

Keywords: non-imaging, rod amplifier, gain uniformity, gain medium, xenon lamp, illumination, absorption coefficient, orthogonal test design method

1. INTRODUCTION

In the high power laser facility, laser amplifier's gain and gain uniformity are key consideration target factors during the design progress[1-3]. High gain is important to the pump energy supply and cooling system, and gain uniformity is the key to the good beam quality. Non-imaging pump cavity which can transfer the xenon lamp radiation to Nd:glass rod surface with maximum efficiency and enhance amplifier's gain properties is designed by the edge-ray principle, namely, ray of lights as an analogy to the phase space, and we consider only the xenon lamp's edge ray, all we require is that the boundary be transferred to the target face, and the interior lights will come along[4-5]. About the imaging pump cavity, there have lot of mature theories about the radiation energy distribution in the rod[6-9], but very little about non-imaging cavity because its research hot point mainly focus on the cavity design method[10], structural characteristics[11], maximum concentration ratio[12-13], etc. Therefore, for the non-imaging pump cavity of laser rod amplifier in this paper, we used the orthogonal test design method. The rod's absorption coefficient, distance between xenon lamp and rod, the proper number of xenon lamps and rod radius, all the four elements were set as orthogonal design factors, every factor have three sizes that make up a orthogonal array which contained nine sets of tests. The software of ASAP was used to simulated the tests, and the variance of energy density distribution in the rod cross section were calculated. The effect law of every element to the gain uniformity were obtained by comparing their variance.

2. NON-IMAGING PUMP CAVITY DESIGN

The edge-ray principle is that the lamp source's light at the maximum emission angle are transmitted by pump cavity with only one reflection to tangent to the tubular absorber, other lights that its emission angle less than maximum angle are transmitted by one reflection or multiple reflections to the absorber(see Figure 1(a)). The pump cavity configurations are calculated by constant string method. We loop the one end of a string to a edge ray wave front titled at angle θ to the aperture k_1k and tie the other end to the point D on tubular absorber. Holding the length fixed. We trace out a reflector profile as the string moves from k_1(the red one) to k(the blue one). The pump cavity's concentration ratio[14] is:

$$\text{Concentration ratio}={}^{k_1k}/_{2\pi r}={}^{1}/_{\sin\theta} \qquad (1)$$

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The laser amplifier with a single rod is pumped by multiple hollow cylinder xenon lamps, and the perimeter of lamp equal to one- n(n= number of lamps) of rod perimeter. Thus, a typical non-imaging pump cavity shape would be as in Figure 1(b).

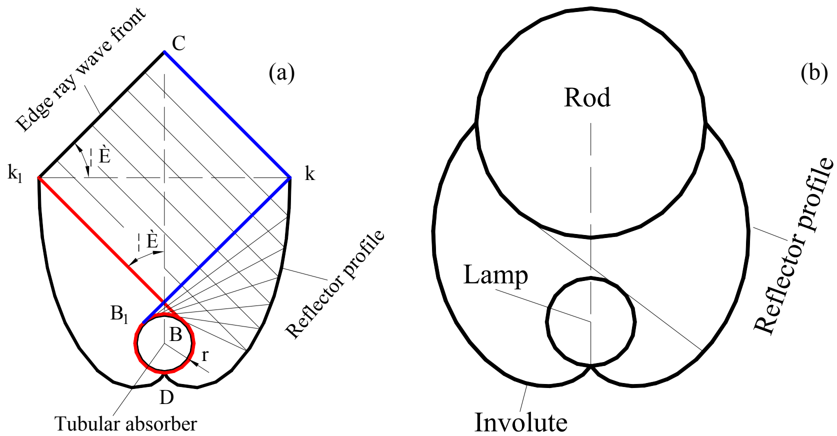


Figure 1. Edge-ray principle and non-imaging optics pump cavity

3. ORTHOGONAL TEST DESIGN METHOD

The four elements involved in the design of a non-imaging pump cavity are the absorber coefficient of rod, the number of lamps, the radius of rod and the separation of their centers. These elements cannot all be chosen separately. Separate choice of lamp and rod size results in a pump energy waste. We need to take several sizes for one element, then to understand the relationship between element and rod gain uniformity. In general, for the multi-element and multi-size simulation test, we use orthogonal test design method, the specific element sizes are shown in Table 1. The software of ASAP is used to simulated the energy density distribution on the cross section of the rod, and distribution variance are calculated, the results are shown in Table 2.

Table 1. Design element of pump cavities

Size	Element A	Element B	Element C	Element D
	Absorption coefficient/cm^{-1}	Radius/mm	Distance/mm	Num lamps/n
1	3.1	15	50	2
2	4.1	20	55	4
3	5.1	30	60	6

Table 2. Simulation results of Nd:glass rod cross section energy density

Test	A	B	C	D	Variance
1	1	1	1	1	1.7E-4
2	1	2	2	2	3.9E-5
3	1	3	3	3	1.8E-6
4	2	1	2	3	8.4E-5
5	2	2	3	1	3E-5
6	2	3	1	2	3.2E-6
7	3	1	3	2	8.2E-5
8	3	2	1	3	1.1E-5
9	3	3	2	1	2.8E-6
m_1	7.6E-5	11.2E-5	6.1E-5	6.8E-5	
m_2	3.9E-5	2.7E-5	4.2E-5	4.1E-5	
m_3	3.2E-5	0.3E-5	3.8E-5	3.2E-5	

Each element have three mean value of the set of variances(see Figure 2). We can draw the conclusions that, the variance of rod cross section energy density distribution decrease with the increasing element size, that is, the gain are more uniform. For the rod absorption coefficient, distance between xenon lamp and rod, number of xenon lamp, when their sizes increase to the certain degree, hardly affect the gain uniformity. To further verify the accuracy of the orthogonal test design method and the above conclusions, combining the Figure 2, a new pump cavity of that sort of is designed for a rod with a 60mm diameter, rod with 5.1cm^{-1} absorption coefficient, the distance between xenon lamp and rod equal to 60mm, number of lamps is six. As shown in Figure 3, the variance of energy density distribution is 0.6E-5, that means in the preceding definition, all is credible.

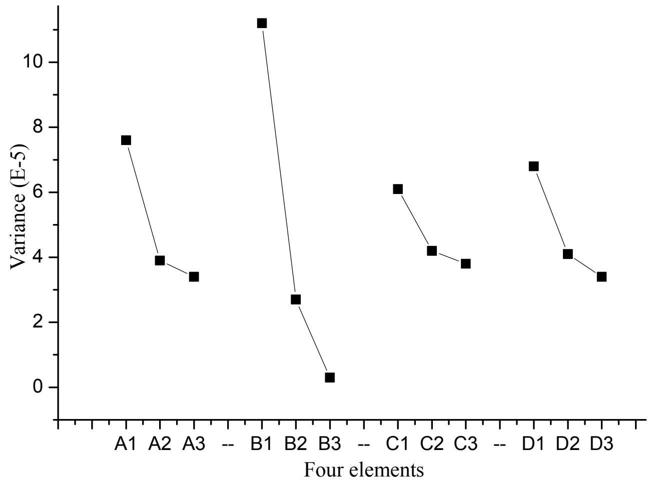


Figure 2. Relationship between gain uniformity and the four variances

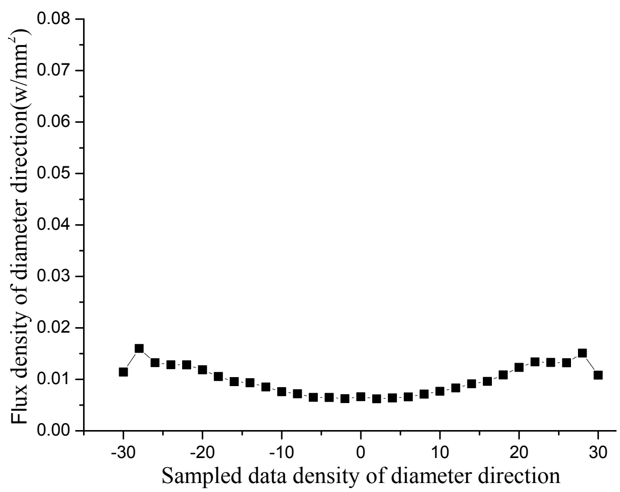


Figure 3. validate design results

4. ANALYSIS AND DISCUSSION

The energy density distribution on the rod cross section at the arbitrarily diameter direction are shown in Figure 4. According to the value of energy density, the nine sets of tests are divided into three groups. First group contains test one, four and seven. Second group contains test two, five and eight. Third group contains test three, six and nine. We discover that in the same group three values of rod radius are the same, they are 15mm, 20mm and 30mm, respectively, which means that the xenon lamp radius are also the same, they are about 2mm,4mm and 5mm, respectively. Among the four elements, the value of rod radius have the biggest effect on the energy density. Small rod radius produce a bigger energy density than the large rod radius do. The rod cross section energy density distribution of test one, two and three, which behalf of the three groups respectively, as shown in Figure 5. Comparing with the effect that rod radius size to the gain, it have the opposite function to the gain uniformity, that is the smaller rod radius, the more gain non-uniformity.

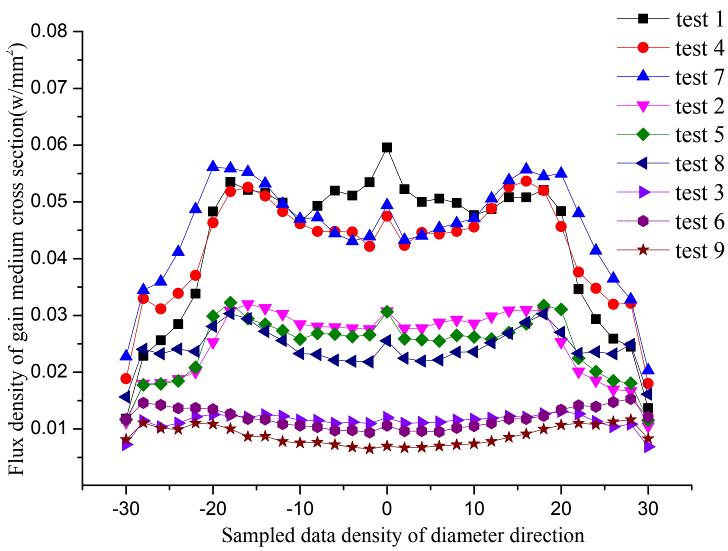
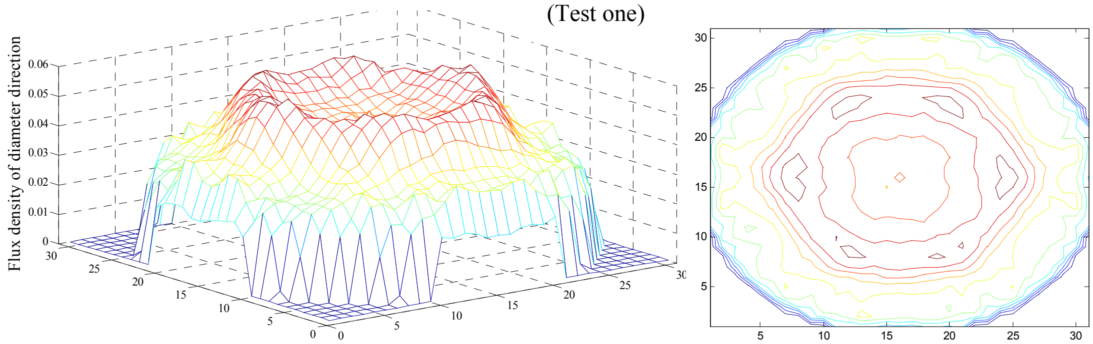
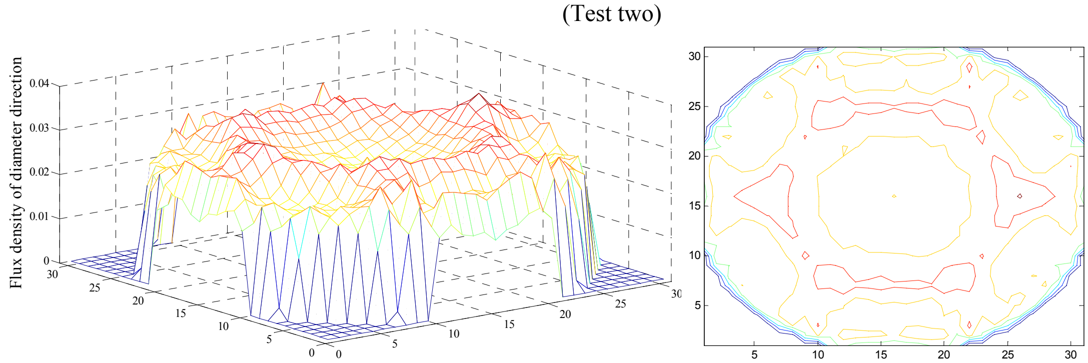


Figure 4. Energy density distribution on the cross section of Nd:glass rod

(Test one)



(Test two)



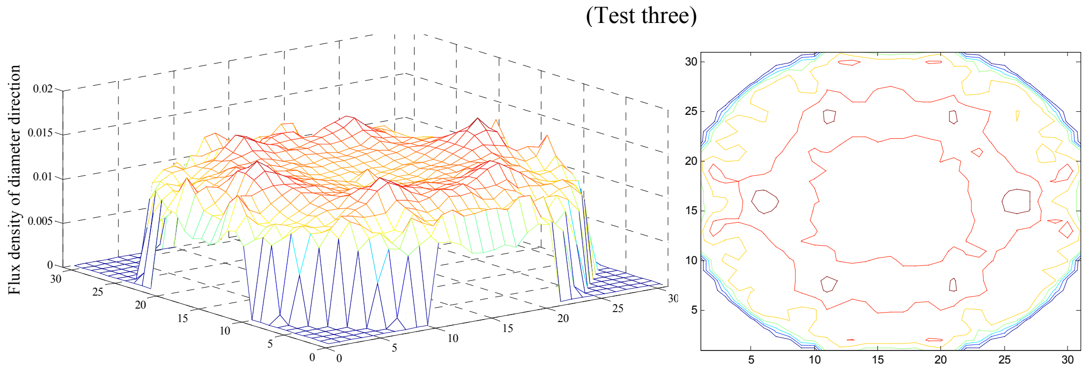


Figure 5. Simulation results of test one, two and three

We chose the second group as the research object to further study the energy density distribution under the condition that rod radius are the same. As shown in Figure 6, the changing trend on the sub surface of rod cross section is the exact opposite of rod centre, and also sub surface's energy density is bigger than rod center. In the rod sub surface, big rod absorber coefficient will absorber more energy than the small absorber coefficient do. Light enter into the rod and be absorbed in accordance with the beer's law[9]:

$$E(x)=E_{in}\exp(-ax) \tag{2}$$

E_{in} = the energy before enter the gain medium, x = transmission distance, a = the gain medium absorber coefficient. Light go through the rod from the outside surface to the center, its energy is exponentially absorbed, so the energy distribution like a parabola going upwards. In the rod center, all the lights are converging to it, so its energy density is bigger than both two sides that near the center. Whatever the gain ability or gain uniformity, the three test's results are very close, that means the absorber coefficient hardly affect the amplifier's gain property.

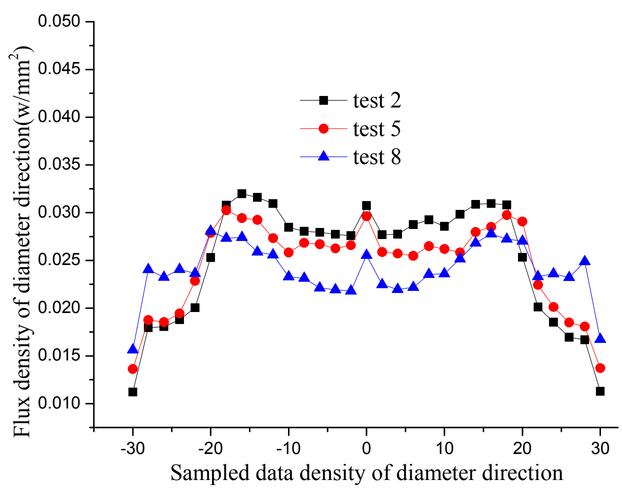


Figure 6. Energy density variation of diameter direction

When the rod radius = 15mm, 20mm and 30mm,respectively, the non-imaging optics pump cavity's curves are shown in Figure 7. We let the one-six of xenon lamps work to research the effect that pump cavity configuration to the gain uniformity, the energy density distribution are shown in Figure 8. When the rod radius = 20mm or 30mm, they have similar curves, that the lights enter to the rod surface have the same direction, and the pump energy distribute in the one-sixth of the rod cross section. When all lamps are working at once, the pump energy in the radial and circumference direction barely overlay each other, so the gain uniformity is very high. When the rod radius = 15mm, the angle between the normal of cavity curve and the positive direction of X-axis will become smaller, that the light incident angle will be big enough to emerge to the rod center, so the pump energy distribute larger area on the rod cross section than the amplifier that rod radius = 20mm or 30mm. The high pumping energy density corresponding to each lamp at the sub surface overlay each other on the circumference direction, that gain in sub surface is high and small in center, and make very bad gain uniformity.

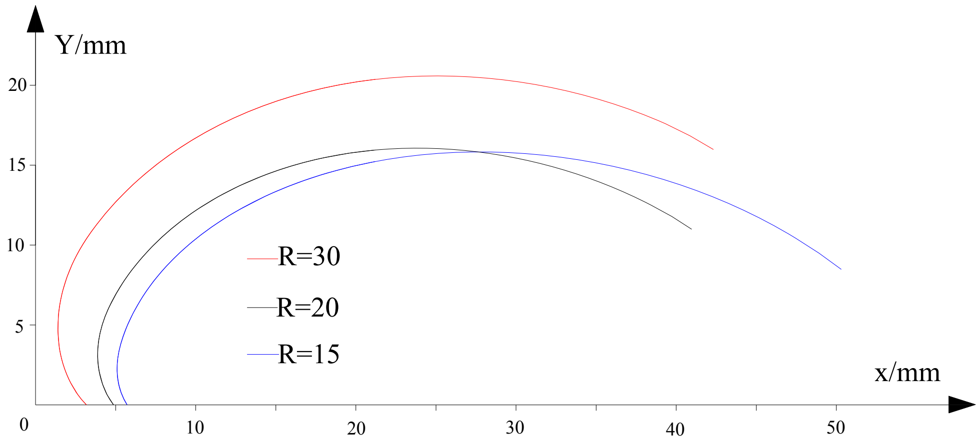


Figure 7. Reflector curves

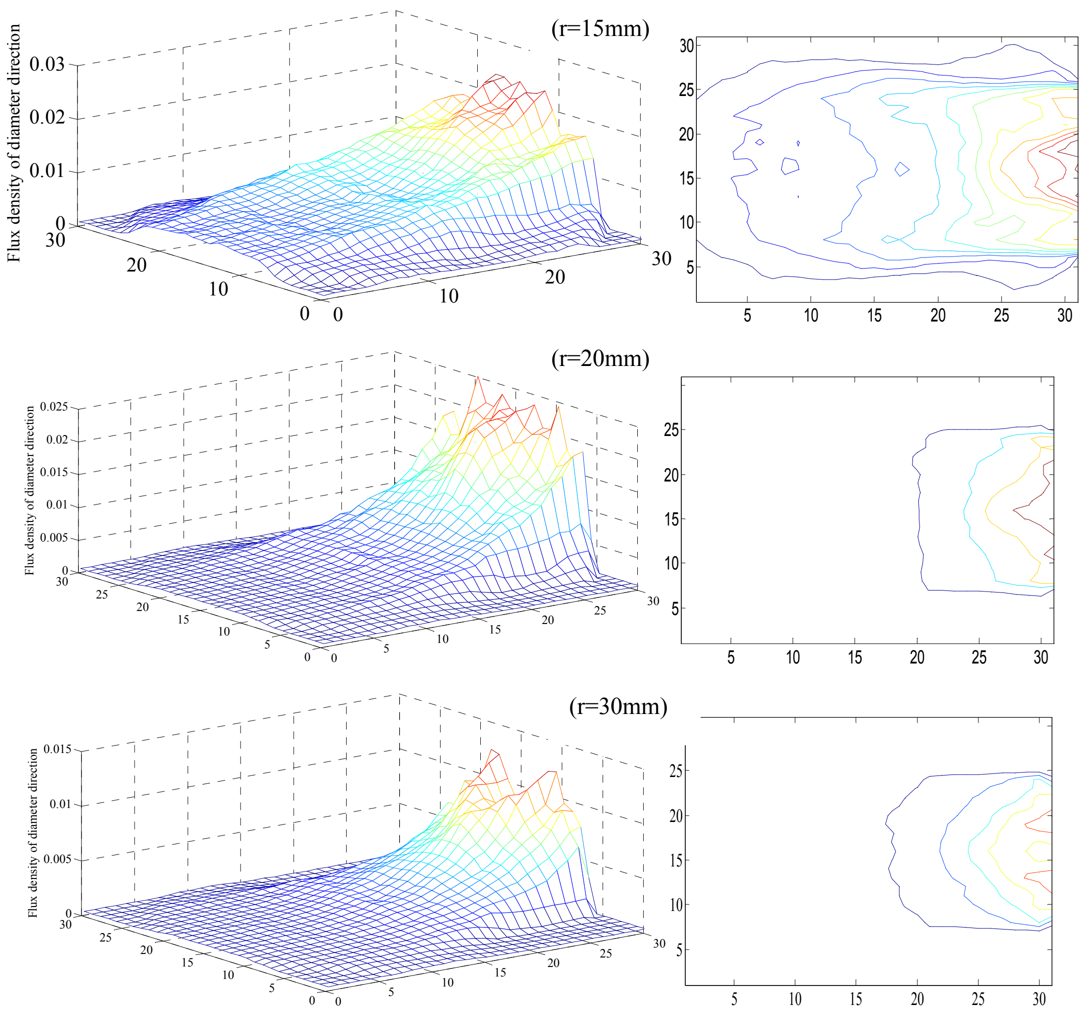


Figure 8. Energy density distribution of single lamp pump

5. CONCLUSION

The effect of laser rod amplifier system elements on the gain uniformity are simulated by orthogonal test design method. Gain uniformity improves and gain ability goes down as the increase of Nd:glass rod radius. Amplifier can obtain high gain and good uniformity by decreasing the rod radius and increasing pump cavity curve slope. The rod absorber coefficient, the number of xenon lamp and the separation of their centers have very little affect on the gain uniformity.

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