Portional coupling efficiencies in intersecting circular cavities

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Abstract: In this paper the contributions on the coupling efficiency from the various portions of intersecting circular pump cavity was investigated and the approaches to increase the coupling efficiency also was given. Theoretical calculations of the efficiencies of pump cavities are agreeable with experimental results.

Key words: pump cavity coupling efficiency intersecting circular cavity

相交圆聚光腔的分区聚光效率

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摘要： 研究了相交圆聚光腔中各反光部位对聚光的贡献，理论计算结果和实测数据基本相符，分析了提高聚光效率的途径。

关键词： 聚光腔 聚光效率 相交圆聚光腔

1. Introduction

One of the most important elements in solid-state lasers is cavity, which directly influences the laser coupling efficiency. The theoretical energy transfer effciency can be approximated by $\eta = \eta_{ge} \times \eta_{op}$, where η_{op} is the optical efficiency of the cavity and includes all the losses in the system, and η_{ge} is the geometrical cavity transfer coefficient[1]. The efficiency determines to a large extent the overall efficiency of the laser system.

The elliptical cavities have been most extensively discussed in the initial development of solid-state lasers. Many authors did researches on the geometrical cavity transfer coefficients in detail[2,3]. After the intersecting circular cavity was invented, many authors further studied the relationship between the geometrical dimensions of the intersecting circular cavity and coupling efficiency. At the same time, various cavities were investigated, too[4,5,6]. The aim of all the researches done here is to know the relationship among the geometrical dimensions, geometrical shapes and geometrical cavity transfer coefficients, and find the optimal cavity. It is found that the cavity was considered as an integer in all the researches mentioned above, and nobody investigated the geometrical coupling efficiencies of various portions of the cavities. But extensive researches on the coupling efficiencies of various portions of the cavity can make us better understand the energy transfer characteristics and obtain the new approaches to improve the cavity configuration.

2. Theoretical coupling efficiencies

Figure 1 illustrates the cross section of an intersecting circular cavity with one flashlamp and one rod in the laser, where D and d are the diameters of a flashlamp and a rod respectively, k is the centre-to-centre spacing between the lamp and the rod. If the origin of the co-ordinate system is defined at the axis of the lamp, the co-ordinates of the centre of the arc PP' are $x_Q = l$ and $y_Q = -h$.

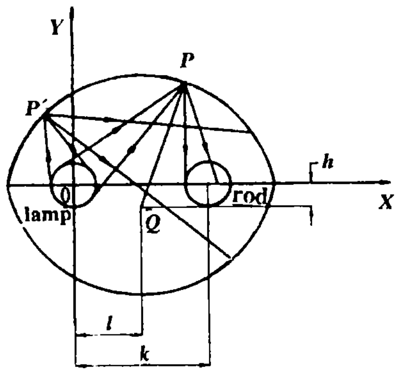

Fig. 1 Schematic of intersecting circular cavity

Suppose that the reflectivities on the two end surfaces of the cavity perpendicular to the longitudinal axes of the rod and the lamp are 100%, the reflectivities of all points on the surface of the cavity are the same, and the pump source with a Lambertian radiation pattern has constant brightness across its diameter when viewed from any point. It is also assumed that all the lamp radiation undergoes just one reflection and the laser rod absorbs the radiation which falls upon it. Therefore the geometrical coupling efficiency η is defined as following η = (Amount of energy trapped by the rod from direct radiation and one reflection)/(Amount of energy from the lamp).

As shown in Fig. 1, the rays from the lamp are reflected at the point P on the reflection surface but only partial reflected rays can illuminate the rod. The coupling efficiency can be calculated by considering what fraction of the energy radiated by the lamp is reflected into the rod. Integration over all points on the reflection walls leads to the total coupling efficiency.

In order to investigate the reflection contributions of various portions of the reflection wall, the reflection wall is divided into 12 portions shown in Fig. 2. The intersections of the radiation rays from the origin with the reflection surface are A, B, C, D, E, F, and G, with corresponding angles 0°, 30°, 60°, 90°, 120°, 150°, and 180° measured from the lamp and rod axis. Because the arcs AB, BC, ……, FG have equal angles relative to the lamp, they also are radiated equally by the lamp with equal energy.

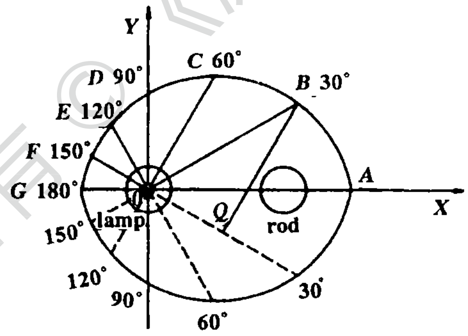

Fig. 2 Portional schematic of the cavity

The programs are written to calculate what fraction of the energy radiated by the lamp into an angle (for example, 1°) is trapped by the rod through direct radiation or one reflection. Integration over the angles of the portion leads to the coupling efficiency of the portion. Fig. 3 shows the calculated results for four cavities, where x axes indicate the angles from 0° to 180°, and y axes show the energy percentages of the total input energy into the rod. The coupling efficiencies of the upper semicavity can give us enough information on the whole cavity because of symmetry.

It is seen from Fig. 3 that much more rays are reflected into the rod from 0° to 60° (including the direct radiation) and the efficiency reduces with an increase in angles. After the angle reaches 150°, nearly no rays can be converged into the rod due to the blockage of the lamp itself. The fact that the coupling capability of the reflection walls for larger than 90° is smaller than that of the reflection walls for less than 90° is because of high imaging magnification of the lamp for the arc DEF. When the diameters of the lamp and the rod are equal, the rays radiated by the lamp can not be fully reflected into the rod. This problem also exists in an elliptical cavity and can be improved by increasing the diameter of the rod and reducing the diameter of the lamp.

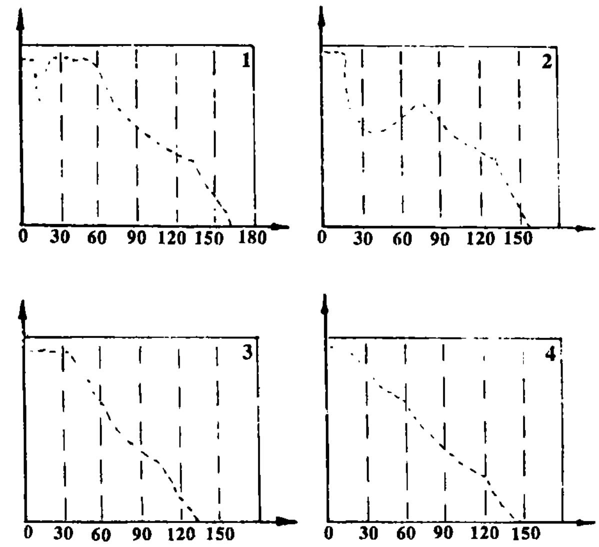

Fig. 3 Calculated coupling efficiencies

1, 2, 3, 4 – D = 19mm d = 8.4mm k = 18mm 1, 2, 4 – l = 8mm 3 – l = 10mm 1, 2, 3 – h = 4mm 4 – h = 2mm 1, 4 – R = 23mm 2 – R = 18mm 3 – R = 15mm

In Fig. 3 the areas enclosed by the curves, x axes and y axes indicate the overall coupling efficiencies of the cavities. It is obvious that the overall coupling efficiencies are different for different cavities. Therefore we can obtain an optimal intersecting circular cavity based on the calculations.

The calculations also show that the main limitation of the cavity with one rod and one lamp is that the coupling efficiencies for the arc from 90° to 180° are very low and especially the efficiency from 150° to 180° nearly reaches zero. The converged energy for the arc DEFG from 90° to 180° is only 24% of total converged energy.

3. Experiments

The experiments were done based on a typical intersecting circular cavity. Because it was difficult to directly measure the converged energy into the rod, we made one portion of the reflection walls shadowed each time. At first, we measured the output laser energy at the preset input energy of the lamp. Then, we plastered the fully absorptive material on the reflective portion (for example, from 0° to 30°) and measured the output laser energy at the same input energy of the lamp shown in Fig.4.

The portion coupling efficiency η_{ex} is defined below

$$\eta_{ex}(\Delta\theta) = 1 - (\text{Output laser energy with the shaded portion})/(\text{output laser energy without any shading}) = (E - E_{\Delta\theta})/E \quad (1)$$

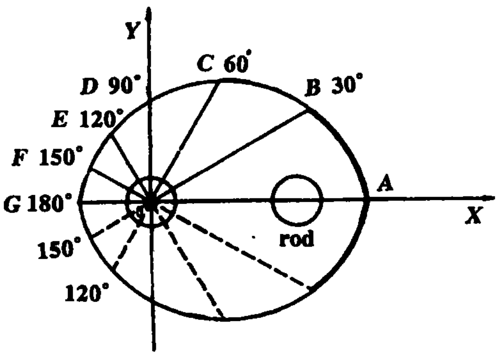

Fig.4 Experimental shading of the cavity

The measured $E_{\Delta\theta}$'s for 0°～30°, 30°～60°, 60°～90°, …, were substituted into the above equation and actual fractions of converged energy were obtained. The results were shown in Table, where D = 5mm, d = 4.19mm, L = 8mm, h = 4mm, R = 23mm, and k = 18mm.

It is seen from Table that the experimental coupling efficiencies of portions are agreeable with theoretical efficiencies very well. The differences of four portions from 0° to 120° between experiments and calculations are less than 5%, but the measured efficiencies are higher than the calculated efficiencies from 120° to 150°, that is because the multiple reflections are not included in our calculations although the rays in those two portions are partially converged into the rod by multiple reflection.

Table Experimental results of coupling efficiencies

	percentage of the energy converged into the rod			
	calculations(%)		experiments(%)	
		after deduction of direct radiation	$(E - E_{\Delta\theta})/E$	normalised
direct radiation	11.6			
0°～30°	14.8	17.8	17.8	16.49
30°～60°	28.2	31	31.3	28.98
60°～90°	20.8	23.5	25	23.15
90°～120°	14.6	16.4	18.6	17.22
120°～150°	8.8	9.8	11.9	11.02
150°～180°	0.5	0.55	3.4	3.15
total	99.3	100	108	100

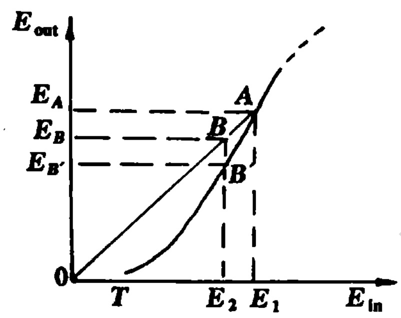

Fig.5 The working curve of the laser

It is also found that the sum of all portion coupling efficiencies is over 100% in the experiments, that is relative to the experimental methods. Suppose that the laser works at Point A, that is, input energy E_1 and output energy E_A without any shading, as shown in Fig.5. The ratio of output laser energy to input energy is E_A/E_1. Therefore, the output laser energy is $E_A - E_B$ corresponding to the input energy $E_1 - E_2$, where B is the point at Line OA. In the experiments, shading the portional wall of the cavity is equivalent to reducing the input energy to E_2. The laser works at point B' instead of point B due to shading the cavity, and output laser energy $E_{B'}$ is smaller than E_B. Therefore the contribution measured by $(E_A - E_{B'})/E_A$ for the portion is larger than $(E_A - E_B)/E_A$. Accumulation of this error makes the sum of all portion coupling efficiencies over 100%.

4. Conclusions

According to the above calculations and analyses, we can conclude that

(1) The fractions of total reflected energy from different reflection portions are not equal. The arcs corresponding to 0°~90° contribute 70% of total reflected energy, but the arcs corresponding to 120°~180° only contribute 15% of reflected energy although the latter receive 1/3 of total lihgt energy.

(2) The blockage of the lamp is the major factor influencing the coupling efficiencies. To reduce the diameter of the lamp can greatly increase the coupling efficiency.

(3) The coupling efficiency will greatly increase if the cavity with one lamp and two rods is used(namely, each rod of two sides of the lamp is placed). The calculation shows that 30%~50% will increase for the mentioned cavity comparing to the cavity with one rod and one lamp.

(4) The method used to value the various portional coupling efficiencies by means of portional shading is also suitable for other cavities.

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·产品简讯·

掺铒磷酸盐玻璃激光测距样机实现测距

西南技术物理所研制的铒玻璃激光测距实验样机于6月4日进行测距试验，测程达2.21km。该样机结构紧凑，国内公开文献中未见报道，进一步的改进工作在进行中。1.54μm铒玻璃激光测距机具有人眼安全，穿透烟雾较强，可室温下探测等优点，具有广泛的军事应用前景。

（张向阳　供稿）