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Adaptive mode optimization of a continuous-wave solid-state laser using an intracavity piezoelectric deformable mirror

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Abstract

A 19-element piezoelectric deformable mirror has been used as a rear intracavity mirror to adaptively optimize the mode of a flash lamp-pumped continuous-wave solid-state laser. A closed-loop adaptive global genetic algorithm is adopted to search the optimum voltages which are used to control the deformable mirror. A series of experiments have been accomplished and results showed that it is efficient to use such a piezoelectric deformable mirror to compensate the thermal effects in the laser resonators and can successfully change TEM_{11}, TEM_{10}, TEM_{20} transverse modes into fundamental TEM_{00} mode. Further more, the output laser powers can also be optimized automatically.

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Keywords: Adaptive optics; Deformable mirror; Genetic algorithm; Solid-state laser

1. Introduction

In recent years, more and more industrial applications fields need solid-state lasers to work on a high power level while simultaneously keep a relatively high beam quality. Unfortunately, although solid-state lasers can generate multimode output with powers at the order of several kilowatts, however, the thermal effects in the laser resonators limit the laser output with high beam quality to a very narrow power range and make the beam diameter, beam divergence and beam quality change greatly with varying power [1]. We have known that thermal lens and thermally induced birefringence are the main thermal effects in solid-state laser resonators. Through carefully selecting a natural birefringent crystal, thermally induced birefringence can be eliminated successfully, the spherical component of the thermal lens can also be compensated by designing the resonator cavity well [2]. However, the non-spherical aberrations (such as the coma aberrations, astigmatism aberrations and the other higher order aberrations) can not be corrected in the same manner [3]. In general, the conventional way for a solid-state laser to generate high beam quality TEM_{00} mode output is to insert a pinhole in the laser resonators. However, this way will reduce output power greatly and may cause the resonator to be misaligned as well.

Although excellent laser crystals may be used to obtain the higher power in the TEM_{00} mode, whereas it is difficult to develop those crystals and the prices may be too expensive to afford. Since the thermal effects in the resonators change with varying power, the promising ways to compensate the thermally induced phase aberrations and thermally lenses are to apply adaptive methods.

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Adaptive optics (AO) is a technique that allows dynamic correction of aberrations. It was firstly developed for astronomy [4] but it can also be used in the laser fields. As the key element of AO system, a kind of deformable mirror (DM) has been successfully used intracavity to select the laser modes [2,5]. However, the DM applied is a membrane DM and not used as the rear intracavity mirror of the resonator. In this paper, we investigate the possibility of using a 19-element piezoelectric deformable mirror (DM) in conjunction with a closed-loop global genetic algorithm (GA) to compensate the intracavity aberrations and control the beam mode of a flash lamp-pumped solid-state continuous-wave (CW) laser [6].

2. Method and experimental setup

Fig. 1 schematically shows the experimental setup of the solid-state laser intracavity mode control system. The laser which is used to mode optimization is a flash lamp-pumped Nd:YAG laser with a maximum output power of 30 W. A 19-element piezoelectric DM is used as the rear mirror of the laser resonator. The surface deformation of this DM is driven by applying voltages on the actuators of the DM. The configuration of DM is shown in Fig. 2. Each dot stands for an actuator. The DM which is fabricated in our laboratory is coated high reflectivity (HR) at 1064 nm ($R > 99.5\%$) and with an available diameter of 32 mm. The output coupler (OC) is a plane mirror with a 10% transmission at 1064 nm. A 5X telescope is introduced to enlarge the laser beam (about 5 mm) near the crystal to about 25 mm onto the DM so as to cover as many actuators as possible. A power meter which is put behind a beam splitter (BS) is used to detect the output laser power in real time. The beam which is reflected by BS is focused by a lens onto an infrared CCD camera. The intensity information of the focus spot is acquired with a frequency of 25 Hz by a frame grabber. Using the intensity information as the object function to maximize, the computer calculates the voltages that needed to control the DM to select the TEM_{00} laser mode, and then these voltages are amplified by a high voltage amplifier (HVA) before applied on the DM.

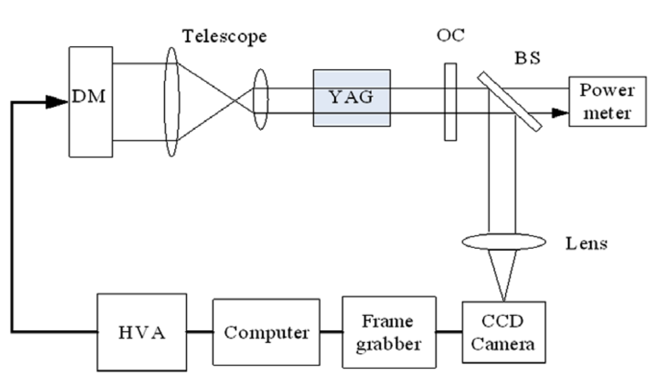

Fig. 1. Experimental setup of an adaptive intracavity mode control system.

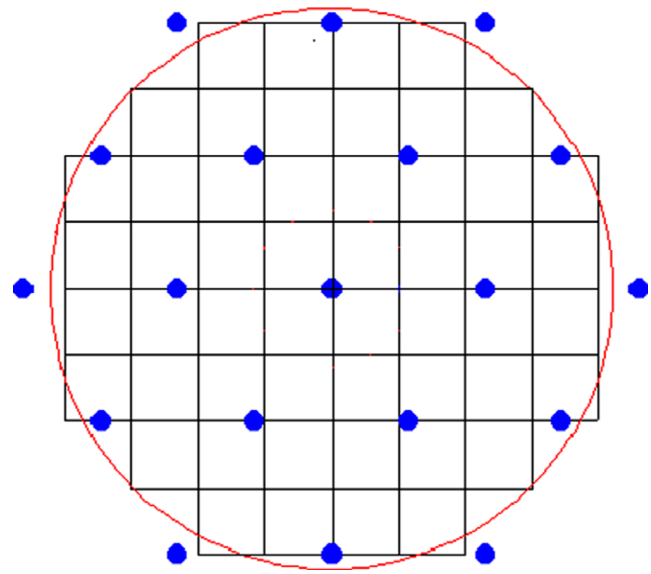

Fig. 2. The configuration of the 19-element DM.

In order to find the optimum DM voltages that maximize the light intensity, a global GA is used to control the DM [6]. As a very robust optimization algorithm, GA can operate on a population of potential solutions through applying the principle of survival of the fittest to produce more and more closer solution to the optimum solution. GA is often used to solve the non-linear problem with a large number of variables. In recent years, GA has been successfully used to solve some optimization problems of laser application field and adaptive optics systems [7–9].

The main steps of the basic GA are selection, crossover and mutation. Fig. 3 is the flowchart of the basic GA. GA proceeds by generating a population of individuals randomly represented by genes, in this paper, each individual corresponds to a surface shape of the DM [10], and each individual has 19 genes which correspond to the voltages on the 19 actuators of the DM, all the individuals are tested based on their fitness parameter. The fitness parameter here is the light intensity information within a specified aperture of the CCD array on the focus plane of the lens, and size of the aperture can be set by software. After the fitness parameter is obtained, GA will proceed selection operation, crossover operation and mutation operation respectively. By executing these steps iteratively, GA will gradually find the globally optimum DM shape that yields the largest light intensity.

3. Experimental results

We firstly examined the optimization performance of the solid-state laser at a pump current of 15 A. Before optimization, the output power was 3.4 W, the transverse mode which is shown in Fig. 4 is a TEM_{10} mode. During the course of optimization, we found that the transverse mode on the CCD camera was changed into the TEM_{00} mode gradually, after about 3 min, the TEM_{10} mode converged