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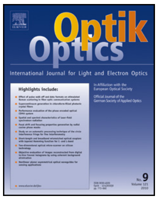

Original research article

Aberration influence and compensation on beam mode features for asymmetric folded laser resonators

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ABSTRACT

We demonstrate the influence on output coupling mode with introducing typical intracavity disturbation and results of aberrated mode compensation in a folded-type optical resonator used in high-energy lasers. The eigenmode profiles and relevant Zernike aberration with intracavity reflector misalignment are achieved by numerical calculation. Experimental result about the function of the reflector maladjustment and the mode features are described in terms of model reconstruction combined with Zernike annular polynomials. Results show that phase disturbation has significant influence on out-coupling beam property, and the uniform and symmetry of the mode are rapidly disrupted by a slight misalignment of the resonator reflectors. The influence on PSF profile in the far-field will be obviously different even if equivalent disturbation is inputted into the same cavity. The device of real-time controlling of the cavity reflector for compensating intracavity phase distortion is successfully constructed. In addition, Zernike defocus aberration is effectively controlled by precisely adjusting the resonator length. A high beam quality in the output coupling mode is realized, which is in good agreement with the analytical predictions.

1. Introduction

Excellent beam quality is an important prerequisite in present laser technique. The features of unstable oscillators with large and uniformly filled mode volume, uniform optical phase, good fundamental transverse mode selection and convenience of output coupling have made it a prime candidate for high-energy laser systems [1,2]. Such structure can also suppress the high-order mode to obtain high beam quality. Relative investigations indicate elsewhere that the laser brightness can be significantly improved by adopting an unstable cavity rather than a stable cavity structure in many situations [2–4]. However, high output power and high beam quality are two contrary characteristics for conventional lasers. The problems always affect the mode features and beam quality; mainly include the cavity geometry misalignment and thermal distortion, inhomogeneity and thermal aberrations of gain media, etc. [5–7]. So especially for a high-energy oscillator, the eigenmode features shall be degraded distinctly by such disturbations.

Under the premise of limited laser power, some suggestions are developed to improve mode distortion such as MEMS micromirrors [8], phase conjugation [9], temporal and spatial filtering [10], and so on [11] in recent years. However, these methods have the limitations by relatively more complex structures, higher cost or other disadvantages. For example, the

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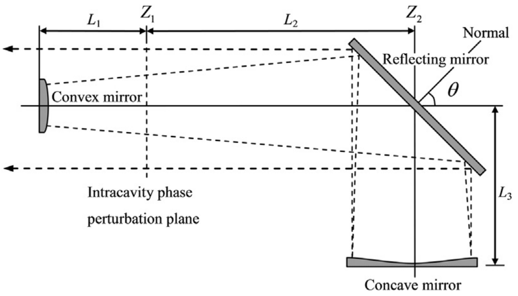

Fig. 1. Schematic diagram for passively asymmetric folded laser resonators with phase disturbation.

maximum correction stroke of MEMS mirrors is very small, usually only several microns. Moreover, the compensation capability of such method for lower order aberration e.g. Zernike phase tilt is very limited. It is very important to research the aberration of unstable resonators, and the effect on the beam quality and mode profiles with intracavity disturbation such as phase-tilted aberration, defocus, astigmatism and etc., which is the basis to further solve the problem of intracavity compensation and construct the aberration control device [12]. However, Experiment of unstable resonators with typical intracavity perturbation is few and fairly limited in scope. In addition, the impact of typical disturbation on the output wavefront distortion, and further the effect of low order aberration on higher order Zernike aberration has not been described [13,14].

We describe exactly the mode features disturbed by the intracavity aberration in a typical folded resonator with asymmetric circular reflectors by numerical calculation. In addition, the subtle wavefront distortion is achieved by polynomial fitting with first 64-order Zernike coefficients to improve reconstruction precision. The related device for compensating typical intracavity aberration by real-time control of laser oscillators is fabricated. We have succeeded in achieving effective elimination of laser aberration, and the mode wavefront is close to the ideal plane wave distribution. Finally, we demonstrate that the main phase distortion such as defocus, tilt, and astigmatism can be notably compensated by actively controlling the cavity reflectors and experimental results agree well with the numerical calculation. The results will be helpful in designing laser oscillators by optimizing the distribution parameters affecting the mode features and beam quality.

2. Numerical analysis

2.1. Mode features with phase disturbation

The application of Kirchhoff-Fresnel diffraction theory to an aligned optical resonator leads to the homogeneous integral for the resonator modes, e.g., for the cavity of symmetry rectangular plane mirror, the equation is given by

$$\varphi(x,y)=\gamma\frac{\mathrm{i}e^{-\mathrm{i}kL}}{\lambda L}\iint_S \exp\left\{\mathrm{i}k\left[\frac{(x-x')^2}{2L}+\frac{(y-y')^2}{2L}\right]\right\}\varphi(x',y')\mathrm{d}x'\mathrm{d}y' \tag{1}$$

Where L is the mirror separation, and the wavelength is λ, γ and φ is the eigen-value and eigen-function respectively, and ρ is the distance of the corresponding points on the two resonator cavity reflectors. The integral equation can be solved by related numerical algorithms [15]. The field characteristics with asymmetric circular resonator mirrors are further described as [16]

$$\begin{aligned}\gamma_1\varphi_1(x)&=\mathrm{i}^{l+1}(k/L)\int_0^{a_2} y\mathrm{J}_l(kxy/L)\exp[-\mathrm{i}(k/2L)\cdot(g_1x^2+g_2y^2)]\varphi_2(y)\mathrm{d}y\\ \gamma_2\varphi_2(y)&=\mathrm{i}^{l+1}(k/L)\int_0^{a_1} z\mathrm{J}_l(kyz/L)\exp[-\mathrm{i}(k/2L)\cdot(g_2y^2+g_1z^2)]\varphi_1(z)\mathrm{d}z\end{aligned} \tag{2}$$

where k is wave vector, R_i is the curve radius of reflectors, a_1 and a_2 are the half apertures of the two resonator reflectors respectively. The parameter $g_i=1\pm L/R_i(i=1,2)$, positive is defined only when the center of curvature lies toward the interior of the cavity. Schematic of the folded asymmetric unstable oscillator in confocal condition with disturbation is shown in