Study on Dynamic Alignment Technology of COIL Resonator

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Abstract. The performance of great power chemical oxygen-iodine laser (COIL) beam is decided mostly by resonator mirror maladjustment and environment vibration. To improve the performance of light beam, an auto-alignment device is used in COIL resonator, the device can keep COIL resonator collimating by adjusting the optical components of resonator. So the coupling model of COIL resonator is present. The multivariable self study fuzzy uncoupling arithmetic and six-dimensional micro drive technology are used to design a six-input—three-output uncoupling controller, resulting in the realization of the high precision dynamic alignment. The experiments indicate that the collimating range of this system is 8 mrad, precision is 5 urad and frequency response is 20Hz, which meet the demand of resonator alignment system.

1. Introduction

Along with the application field of big power COIL expanding, high quality light beam is much more required. Such factors will destroy the COIL laser beam quality: unevenness of gain medium, surface error of optical components, maladjustment error of the optical system, mechanical vibration, thermal distortion of mirror plane and so on. Among them, resonator mirror maladjustment is the one of the important factors that affect the resonator system [1].

Figure 1 shows the structure of high energy COIL resonator. The scraper reappears by the reflecting of the resonator reflector, so the outlight is alignment parallel light. To overcome the resonator mirror maladjustment and environment vibration, The optical module of the resonator is fixed on a firm optical platform. Vibration distortion, maladjustment and etc, which will affect the - of the output of the light beam, then lower the light beam quality [2]. At the same time because of the external vibration, the output beam appear to quiver, it will cause COIL to work abnormal. So an auto-alignment device is imported, which will keep COIL resonator collimating by adjusting the optical components of resonator.

As to gain medium only appear during the light output process, then auto- device must process auxiliary lightline outside the gain area. Such is the method: we fix the secondary mirror on a low power lasing device, the light beam from the lasing device arrive to the primary mirror and reflector through an additional channel which is different with the resonator, we can get the driving signal according to the variety position of resonator mirror, then fulfill the alignment of resonator. The alignment beam is also split at the scraper mirror forming a surrogate beam which may be used to simulate the extracted high power laser beam, that is to adjust high energy resonator lasing device in closed loop by targeting low power lasing generator.
This article adopts the detection lightline parallelled with the resonator optical axis, the lightline check the maladjustment signal, takes Position Sensitive Detector(PSD) as position detective components, takes three symmetric groups Piezoelectric(PZT) as actuators ,adopts blurring parameters adaptive PID combined with three dimensional uncoupled control to solve dynamic alignment of resonator.

2. Principle of resonator auto-alignment

Figure 2. the structure of COIL resonator auto-alignment system.

Figure 2 shows the resonator auto lightline, Alignment instrument 7 transmits laser beam, which passes through reflector 3 and reflector 4 and irradiate the center of orientation mirror 5, and goes back over the course. The maladjustment signal is detected by position sensitive device, Alignment instrument 7. Three groups PZT 6 driven by the maladjustment signal which has been processed are used to bring the system to return to the ideal appearance, then convex mirror 1 and concave mirror 2 are coaxal. Figure 3 shows the principle of the alignment instrument, semiconducting lasing device transmits the alignment beam, after being back from the lightline, the beam reversed after going through beam splitter 8, then goes through condenser lens 9 and arrives to PSD 10, data processing and controlling module 11 gets maladjustment information about position from PSD 10. After processing the data, the controller sends signals to three groups PZT to translate the resonator into alignment.
Figure 3. The principle of alignment.

Figure 4 shows the driving way adopted by PZT, concave 2 turning in any two-dimensional direction and move along the direction of the light axis are all completed by adjusting three groups PZT. The motion along the direction of the light axis can convert to rotate at the vertical direction of beam axis in spherical system. So the driving instrument can adjust the maladjusted resonator mirror which is inclined, abaxial, or noconfocal. Alignment instrument 7 and convex mirror 1 are fixed on as a whole, and the laser from instrument 7 must be delivered parallel to the system axis. The curvature of orientation mirror 5 and concave mirror 2 must be equal in detecting lightline, the beam axis distance between them is equal to what between instrument 7 and convex mirror 1.

Figure 4. The driving principle of Alignment system.

The accuracy of laser alignment servo system is mostly decided by the dynamic detecting accuracy about position maladjustment information of resonator mirror. Wide detecting region, detecting in concave surface, high precision, and excellent dynamic characteristic, being able to detect slight signals, being freedom from interaction are needed by this system. So it uses PSD as optoelectronic converting components, the subsequent circuit is made up of preamplifier, differential amplifier, summation circuit and normalization circuit.

The preamplifier provides low input bias current, low input impedance and high quality feedback impedance. The differential amplifier circuit provides excellent common-mode rejection and credible symmetry, so it overcomes the variational symmetry faults that ordinary amplifier is provided with. The summation circuit is used to amplify and sum the signals from PSD, and prepare for the succeeding normalization circuit. The normalization circuit is to normalize the maladjustment signals, to eliminate the influence of the detection result caused by light intensity fluctuation. These fluctuation are mainly from the power offset of laser pipe and surface reflectivity variety of different optical components.

3. Blurring uncoupled control
In this collimating system, we use three PZT actuators which have the same performance. First, in the alignment beam path we chose three symmetric points (which were named A, B and C respectively)
from the pedestal of concave mirror as the place where to install PZT and its micro-displacement device. We have installed corresponding displacement sensor on the micro-displacement device, and the corresponding coordinate are \(A(x_1, y_1, z_1)\), \(B(x_2, y_2, z_2)\), \(C(x_3, y_3, z_3)\). In order to get the mathematical model of the control system, we set up such coordinate system as figure 4. In the system, we chose the center of controller pedestal as the coordinate origin. We can get the expressions of vertical height \(Z_H\) and slant angle of the concave mirror’s \(X\) and \(Y\) direction, as follows [3,4]:

\[
\sin \phi_x = \phi_x = \frac{\Delta Z_x}{d_x} = \frac{Z_1 - Z_3}{x_3 - x_1},
\]

\[
\sin \phi_y = \phi_y = \frac{\Delta Z_y}{d_y} = \frac{2Z_1 - Z_2 - Z_3}{2y_1 - y_2 - y_3},
\]

\[
Z_H = \frac{Z_1 + Z_2 + Z_3}{3}.
\]

Thereinto, \(Z_i\) as mean value of the displacement of PZT.

In the resonator auto-alignment system, the three PZT are controlled respectively in three control loops. The corresponding control variable of PZT1, PZT2 and PZT3 are \(V_1\), \(V_2\) and \(V_3\) respectively. Because there are interaction among PZT1, PZT2 and PZT3, uncoupled control method must be adopted to eliminate this interaction. Suppose the controller is \(G_c(s)\), \(H(s)\) is controlled, then this system is simplified as what is shown in Figure 5.

To uncouple the system, \(G(s)\) must be diagonal matrix [3], that is to say:

\[
G(s) = \begin{bmatrix}
G_{11}(s) & 0 & 0 \\
0 & G_{22}(s) & 0 \\
0 & 0 & G_{33}(s)
\end{bmatrix}
\]

\[
G(s) = [I + H(s)G_c(s)]^{-1}H(s)G_c(s)\]

\[
H(s)G_c(s) = G(s)[I - G(s)]^{-1}
\]

Then

\[
G_c(s) = H^{-1}(s)G(s)[I - G(s)]^{-1}
\]

If \(G(s)\) is confirmed, the uncoupled control matrix \(G_c(s)\) will be certain, as is shown in Figure 6.

Figure 5. The structure of uncoupling control system.
Uncoupled model must be set up to fulfill the above uncoupled control. PID control of blurring parameter is added to this system to overcome the magnetic hysteresis nonlinear characteristic of PZT. PID parameter is adjusted by the real-time status of the alignment system, it is to say that PID parameter is adjusted by the difference between the input signal and the feedback signal, at the same time, it is confirmed by the blurring control rules [5], the system structure is shown in Figure 7.

Because of the nonlinear characteristic of detection circuit and actuator component, and asymmetric characteristic of installation error, machining error, disturbance and circuit, the performance of the alignment system is deeply decreased. In order to increase the performance, the nonlinear characteristic must be corrected automatically. The step is as follows: first, we mark on the actuator, detection device and adjusting circuit by experiment to get aligning curve. The data where is marked is:

\[
x_j : x_1, x_2, x_3, x_4, \cdots, x_N
\]

\[
u_i : u_1, u_2, u_3, u_4, \cdots, u_N
\]

In the above \(x\) is input, \(u\) is output, \(i=1,2,3,\ldots,N\).

Suppose the anti-nonlinear equation is:

\[
x_j(u_i) = a_0 + a_1u_i + a_2u_i^2 + a_3u_i^3 + \cdots + a_nu_i^n
\]

\(n\) is decided by the precision that is required by the system, if \(n=3\), then

\[
x_j(u_i) = a_0 + a_1u_i + a_2u_i^2 + a_3u_i^3
\]

\(a_0, a_1, a_2, a_3\) are constants to be confirmed.

4. Description of experiments and results

In the COIL resonator alignment system, to fulfill rapid deflection in any spacial angle, fuzzy uncoupling is adopted to get the driving voltage to actuate PZT, the data deprived from PSD is shown in Figure 8(a), the track of light in resonator is a circle, as is shown in Figure 8(b), that illustrate this system can complish turning in in any spacial angle. The experiments indicate that the collimating range of this system is 8 mrad, precision is 5 urad and frequency response is 20Hz, which can meet the demand of resonator alignment system. The auto-alignment system have a broad application future, and it afford technical reference to the utility of laser.
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