Automatic polarization compensation method for low-repetition frequency short optical pulse

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An automatic polarization compensation method for low-repetition frequency short optical pulse is proposed and successfully applied to the master oscillator room (MOR) in inertial confinement fusion (ICF) systems to maintain the MOR maximum output energy. After an average of 37 shots, the MOR output energy reaches maximum value with the sudden occurrence of polarization variation in the fibers. The peak-to-peak amplitude jitter of the MOR output is 9.52% at 4 h, which meets the requirement of the ICF system.

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Controlling the state of polarization (SOP) is important for fiber systems, such as communication systems[1], fiber sensors[2,3], fiber lasers[4], and pulse shaping system in inertial confinement fusion (ICF) systems[5]. A number of electrooptic polarization control methods and experiments have been reported, most of which have either been used for or focused on controlling the SOP of CW or high-repetition frequency pulse train[1,3,6−10]. For CW and high-repetition frequency pulse train, energy can be directly acquired by an A/D converter after energy is received by a photodetector (PD). However, in other fiber systems, such as Brillouin optical time domain reflectometry (BOTDR) sensors[2], Q-switched fiber lasers, and the ICF pulse shaping systems, propagation light is a low-repetition frequency short pulse train. Thus, energy acquisition of the pulse is difficult, which hinders the implementation of polarization control.

The master oscillator room (MOR) is one of the most important parts of an ICF system[5,11−14]. The MOR creates the temporal pulse shape specified by physical experiments. The pulse from the MOR is injected into a regenerative amplifier (RA). The MOR consists of lots of regular single-mode fibers and polarization sensitive devices, such as integrated waveguide electro-optic modulators (EOM). The control of SOP is particularly important because slow variations in the environment (temperature and pressure) can change the SOP of light in fibers and eventually reduce output energy of the MOR. After a long period of operation without polarization control, the output energy of the MOR will be reduced by more than 50%.

In this letter, an automatic polarization compensation method for low-repetition frequency short pulse is described. The repetition frequency of the pulse ranges from 1 Hz to 10 kHz, and the pulsewidth ranges from 100 ps to 1 μs. This method is successfully applied to the MOR. Through an integral circuit, the pulsewidth of the short electrical pulse converted from the optical pulse can be broadened to tens of microseconds. This allows acquisition of the energy of the optical pulse by a high speed acquisition card. Finally, by comparing the current pulse energy with the previous pulse energy, the pulse polarization is compensated and the stability of the MOR output is maintained.

Figure 1 shows the configuration of the MOR. The pulse begins in a CW Yb-doped fiber laser tuned to 1.064 μm. The CW signal from the output of the oscillator is chopped by an acousto-optic (AO) modulator to a 200 ns pulse at 1 Hz. The pulse is amplified by an Yb-doped fiber amplifier, and subsequently goes into a two-stage amplitude modulator, which shortens the pulsewidth to 8 ns. Finally, the pulse is amplified by another Yb-doped fiber amplifier. After passing through a 90/10 coupler, the pulse is injected into a RA through the 90% port. The MOR output energy is 2 nJ.

The oscillator, amplifiers, transmission fibers, and fiber optic jumpers between devices are made up of single-mode fibers. The SOP of the pulse in the MOR gradually varies with the environment. The amplitude modulator in the MOR contains a polarizer. Therefore, the variation of SOP will lead to a fluctuation in the MOR output and will eventually reduce the output energy of the RA.

Figure 2 shows the normalized amplitude of the MOR output without polarization control as a function of time at 3 h. The amplitude has dropped by more than 70% at 1.5 h. The periodic fluctuation of the output curve is caused by the inherent periodic fluctuation of the fiber laser output. The ICF system requires that the long-time peak-to-peak variation of the MOR output energy should be less than 20%, which can lead to an amplitude variation of less than 3% in the RA output.

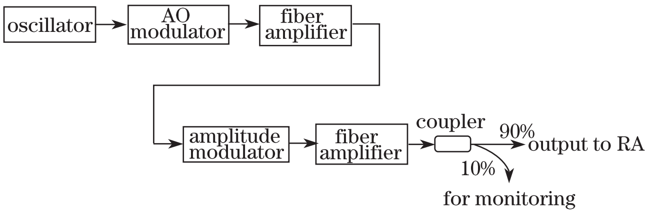

Fig. 1. MOR configuration in an ICF system.

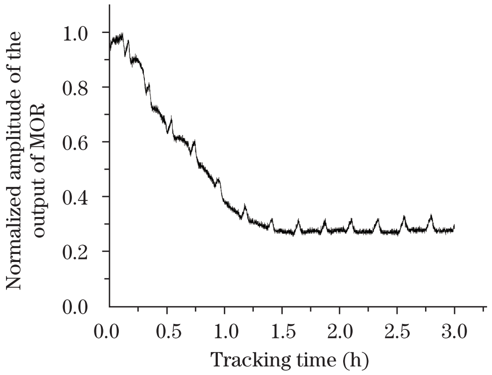

Fig. 2. Normalized amplitude curve of the MOR output without polarization control at 3 h.

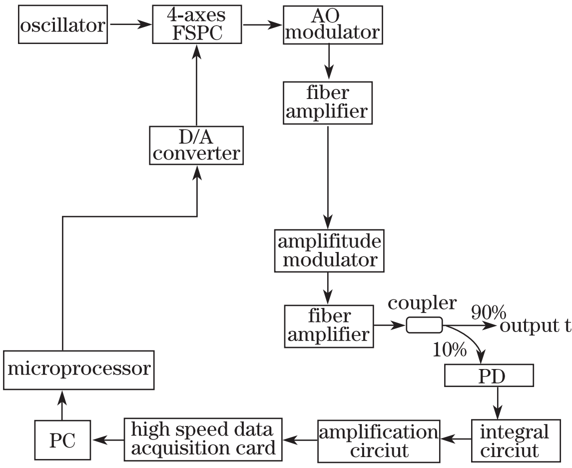

Fig. 3. Configuration of the MOR with the automatic polarization compensation system.

The proposed automatic polarization compensationl configuration for low-repetition frequency short pulse is shown in Fig. 3. The pulse that comes out of the 10% port is received by a PD and used for polarization control.

The four-axis fiber squeezer PC (FSPC), which consists of four fiber squeezers (X1, X2, X3, and X4) oriented at 45° from each other, is used as the polarization controller (PC) in this technology. Polarization control is achieved by applying radical stress to the optical fiber using a piezoelectric actuator, the electrically driven PC (EPC-400, OZ Optics Corp.)[15]. The phase retardation of four fiber squeezers can be expressed as follows:

$$\varphi_1 = \pi \cdot (V_1/V_{\pi,1}) + \varphi_{0,1}, \quad (1)$$

$$\varphi_2 = \pi \cdot (V_2/V_{\pi,2}) + \varphi_{0,2}, \quad (2)$$

$$\varphi_3 = \pi \cdot (V_3/V_{\pi,3}) + \varphi_{0,3}, \quad (3)$$

$$\varphi_4 = \pi \cdot (V_4/V_{\pi,4}) + \varphi_{0,4}, \quad (4)$$

where $V_{\pi,1}$, $V_{\pi,2}$,$V_{\pi,3}$, and $V_{\pi,4}$ are the half-wave voltages and $\varphi_{0,1}$, $\varphi_{0,2}$, $\varphi_{0,3}$, and $\varphi_{0,4}$ are the initial phase bias retardations, respectively.

The Poincare sphere can illustrate the performance of the four-axis FSPC[3]. The fiber squeezers X1 and X3 cause the SOP to rotate around the *OH* axis, and X2 and X4 initiate the SOP rotation around the *OQ* axis, as shown in Fig. 4. In principle, the orderly fiber squeezers are capable of transferring the SOP of light before it enters the amplitude modulator P1 toward the polarization direction of the polarizer contained in the modulator P0. Each fiber squeezer control voltage changes to facilitate the rotation of the SOP of light before it enters the modulator to decrease the arc length *d* between P1 and P0 on the Poincare sphere surface. The shorter the arc length *d*, the larger the pulse energy output of the modulator. When *d* reaches a comparative minimum (i.e., when the pulse energy reaches a comparative maximum), the controlled voltage will remain constant, and the next fiber squeezer functions in the same way. The SOP changes because of environmental variation, thus the P1 on the Poincare sphere surface varies dynamically. Therefore, the controlling process must be continually repeated to ensure maximum MOR output energy.

The PD converts the light pulse that comes out of the 10% port into an electrical signal with the same pulsewidth. The electric signal goes into an integral circuit, as shown in Fig. 5. This is the key device in the polarization control method because of its capability to broaden the pulsewidth of the electrical signal from 8 ns to tens of microseconds, as shown in Fig. 6. Consequently, the electrical signal is amplified by an amplification circuit, which ensures that the waveform of the broadened pulse can be collected by a high speed acquisition card at a 100 MHz/s sampling rate.

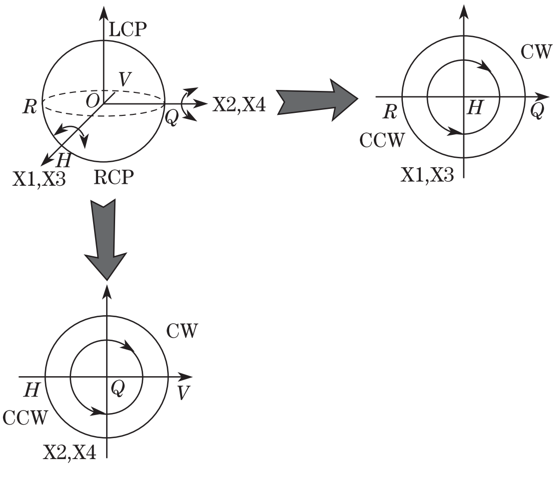

Fig. 4. Fiber squeezer principle described in the Poincare sphere. *H* represents horizontal linear polarization, *V* represents vertical linear polarization, and *Q* and *R* represent the linear polarizations inclined by +45° and –45° to the horizontal. LCP: left circular polarization, RCP: right circular polarization, CW: clockwise, CCW: counter-clockwise.

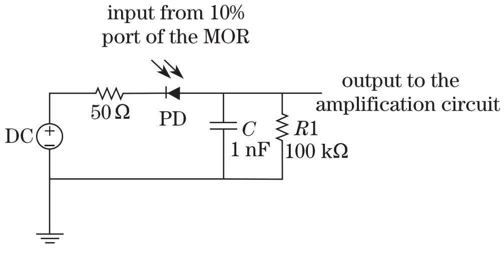

Fig. 5. Configuration of the integral circuit.

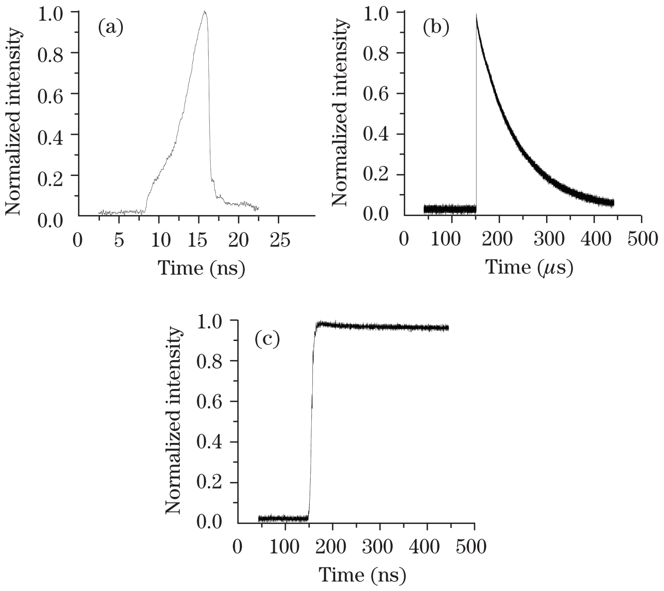

Fig. 6. Integral circuit broadening the pulsewidth of the signal. (a) Optical pulse out of the MOR; (b) and (c) broadened pulse out of the integral and amplification circuit displayed in scale of 100 μs/div and 100 ns/div.

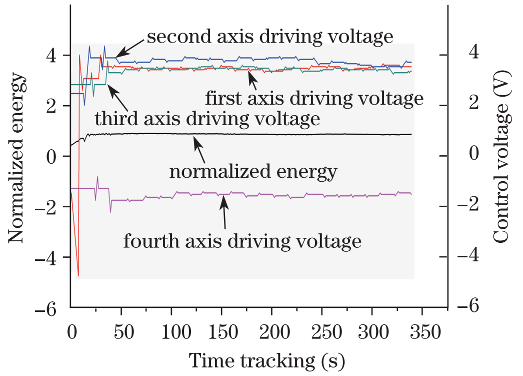

Fig. 7. Curves of the four driving voltages of the FSPC and normalized MOR output energy.

After sampling the waveform of electrical pulse, the waveform data is transmitted to a PC. The PC regards the sum of the first 100 data points as the MOR output energy. By comparing the present energy with the previous energy, the PC generates optimal data to control the microprocessor through the RS232 interface. Finally, the microprocessor transforms the control data into a format that can be received by the D/A converter, the output of which drives the four-axis FSPC to obtain and maintain the maximum MOR output energy.

Step voltage is a key parameter in the determination of tracking rate and control resolution. When step voltage increases, recovery time for obtaining maximum MOR output energy decreases, although control resolution deteriorates. To achieve a trade-off between recovery time and control resolution, the step voltage is set at different values. When the polarization control system begins operation, the energy of the MOR output is low. Thus, a larger step voltage, which is set to 0.47 V, is adopted. After the controlling process is performed twice, a small step voltage, which is set to 0.06 V, is adopted. Four driving voltage curves of the four-axis FSPC and the normalized MOR output energy are drawn as functions of time in Fig. 7.

In Fig. 7, the MOR output reaches the maximum energy after the controlling process is performed twice in large step and thrice in small step.

To ensure that the polarization control system works more efficiently, the maximum energy should be recorded and four fiber squeezer voltages should be held constant after the controlling process is performed twice in large step and thrice in small step. Simultaneously, the current MOR output energy should monitored and compared with the maximum energy recorded. If current output energy is less than 90% but more than 80% of the recorded maximum energy, the controlling process should be performed thrice in small step using the method mentioned previously. On the other hand, if current output energy is less than 80% of the recorded maximum energy, the controlling process should be performed twice in large step and thrice in small step. Consequently, the voltages will be held constant again. The process should be repeated continuously.

Recovery time for the return to the maximum energy when a sudden polarization variation occurs is verified in the experiment. A manual PC (MPC), which is placed between the CW fiber laser and the FSPC, is used to simulate a sudden polarization variation. The FSPC executes active polarization compensation. Using the algorithm mentioned above, the output energy of MOR reaches maximum value. Subsequently, the MPC creates a sudden polarization variation, which immediately reduces the normalized MOR output energy to less than 0.5. Subsequently, the tracking system recovers the maximum output energy. The experiments are repeated 13 times. On the average, the output energy of MOR returns to the maximum value after 37 shots.

Long-duration tracking performance is verified using the configuration shown in Fig. 3. A PD with a bandwidth of 14 GHz is used to acquire the energy of the pulse from the 90% port. Figure 8 shows the experiment results for 4 h. Compared with the results in Fig. 2, the slow variation of SOP caused by the environment has been compensated. The amplitude jitter of the MOR output is 1.66% (root mean square (RMS)), and the peak-to-peak value is 9.52%. These values are generally caused by the inherent periodic variation of the CW

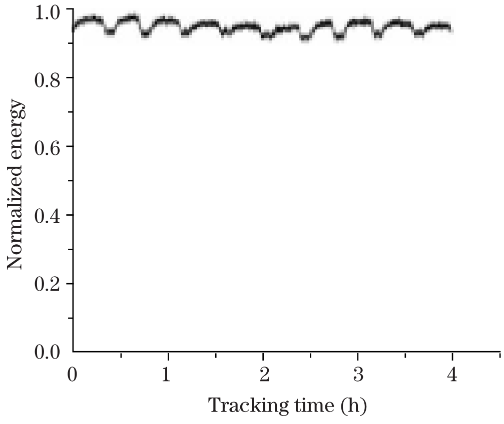

Fig. 8. Experiment al result of the MOR output energy at 4 h with polarization control.

fiber laser output. This result will produce peak-to-peak amplitude variation of the RA output with a value of less than 1%, which meets the requirement of ICF systems.

In conclusion, polarization fading is a critical problem in fiber systems. Thus, an automatic polarization compensation method for low-repetition frequency short optical pulse is proposed and applied to the MOR in ICF systems to obtain and maintain maximum output energy. Use of an integral circuit and a high-speed acquisition card facilitates acquisition of the MOR output energy. The experiments verify the effectiveness of the proposed method. After an average of 37 shots, the MOR output energy reaches the maximum value when there is a sudden polarization variation in fibers. Using this method, the amplitude jitter of the MOR output is 1.66% RMS, and the peak-to-peak value of the amplitude jitter is 9.52%. These values meet the requirement of ICF systems.

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