The power stability of a fiber amplifier based on a multifunction card and PID control program

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Abstract
The power stability of a fiber amplifier was significantly improved by means of simultaneously controlling the current of a fiber amplifier and the diffraction efficiency of an acousto-optical modulator. The real-time fluctuation of laser power was recorded by a multifunction card and processed by a proportional–integral–derivative (PID) control program. The feedback loop voltage was introduced to the fiber laser amplifier and acoustic-optic modulator through the analog output of the multifunction card. The control method based on a multifunction card and PID program has good scalability, flexibility and reliability for the complex system on the condition in which the frequency and power of the laser need to be precisely stabilized.

Keywords: fiber amplifier, power stability, PID control

(Some figures may appear in colour only in the online journal)
2. Experimental approach

Figure 1 is a schematic figure of the power stability system. In the experiment, the output of the fiber laser (RFLM-25-1-1064.46-1-S-0 NP Photonics) with fiber amplifier (NUA-1064-PC-0010-B2, Nufern) was controlled. The maximum power of the fiber laser is 25 mW and the wavelength is 1064 nm. The output beam of the fiber amplifier is linearly polarized. The maximum output power is about 10 W. The frequency and amplitude of the laser beam from the fiber amplifier was modulated by an AOM (MT200-B100A0, 5-1064, AA Opto Electronic). The first-order diffraction beam was divided into the reference beam and experimental beam with a glass with reflectivity 5%. The reference beam was detected by a fast photo-detector (FDS100, Thorlabs) and acquired by a high-speed data acquisition card (PCI-1742U, Advantech). The sampling rate is about 1 KHz. The data was processed by the PID control program [11]. The feedback voltage was introduced to the AOM and the fiber amplifier through the DAQ output port.

A flow chart of the PID controlling program is shown in figure 2. The reference light was detected by a fast photodetector. The conversion voltage is fed into the DAQ card and compared with the ‘set-point’ in the PID control program. The ‘set-point’ is a relative value of the voltage corresponding to the light power that we expected. The deviation between the ‘set-point’ and real-time measured value was calculated firstly in the controlling program. According to the adjustable range of the AOM, a threshold value will be generated in the program. If the calculated deviation is greater than the threshold value, the control program will execute the PID program branch I for the current control of laser amplifier. Otherwise, it will execute the branch II for the modulation control of the AOM. The feedback signals were produced by the processing of the PID control program and translated into the suitable voltage value, which was then introduced into the mod-in port of the AOM and the modulation port of current of the fiber amplifier.

The control curve of fiber amplifier output is shown in figure 3(a). Taking account of the large control range and moderate output power of the fiber amplifier, the control voltage range of the fiber amplifier that we choose is from 0.5 V to 3.5 V. The nonlinear control curve is processed in the program. The control of the fiber amplifier would feedback the fast and wide-range variation of power from several milliwatts to a few watts output. The diffraction efficiency of the AOM is measured with different modulation voltage, as shown in figure 3(b). The AOM would bring the precise and finite range feedback. In order to obtain high diffraction efficiency and intended control range, the range of the AOM control voltage is from 2.5 to 5 V in the program. The control accuracy of the AOM is up to 0.05 mW mV$^{-1}$ compared with the 0.3 mW mV$^{-1}$ of the fiber amplifier.

3. Results and discussion

To check this method, we theoretically simulate the dual-path feedback loop control of both the AOM and fiber amplifier through the program, and the derived formulas of the control program are as follows:

$$P_{\text{amp}}(t_n) = \alpha(t_n) \times \left\{ C_1 + K_P \times [P_{\text{amp}}(t_{n-1}) - SP_1] + K_I \times \int [P_{\text{amp}}(t_{n-1}) - SP_1] \, dt \right\}$$  (1)
where the $P_{\text{amp}}$ and $P_{\text{aom}}$ correspond to the output power of the fiber amplifier and the AOM, respectively. $K_P$, $K_I$, $K_P'$ and $K_I'$ are PID parameters. $\alpha(t_n)$ corresponds to man-made noise. $C_1$, $C_2$, $C_3$ and $C_4$ are constants. $SP_1$ and $SP_2$ are the value of power we expect.
The numerical simulation was applied to evaluate the dual-path feedback loop control of both the AOM and fiber amplifier. The stochastic noise of 1% was modulated into the controlled value in the program. We use the Allan variance to analyze the results of simulation. As shown in figure 4, the Allan variance of laser power decreases significantly under the feedback loop control.

We experimentally perform three steps mentioned above using the dual-path stability system: (1) we detect the power variation with the PID control program of the AOM turning on while a constant voltage was sent to the fiber amplifier. (2) Then we detect the power variation with the PID control program of the active fiber amplifier while a fixed voltage was sent to the mod-in port of the AOM. (3) Finally, PID control programs of both the AOM and amplifier are used to observe the power dithering. Meanwhile, the three results are compared with the power changes when the fiber laser was running freely, as shown in figure 4. When only the PID control program of the amplifier or AOM is active, the RSD is 0.84% and 0.05%, respectively. But the RSD rises up to 1.04% when the fiber laser is running freely. The RSD of the error signals reaches about 0.03% with the PID control programs of the fiber amplifier and AOM simultaneously turning on. The stability of laser power was improved significantly when the PID control programs of both the fiber amplifier and AOM were turned on.

Moreover, the long-term stability of the fiber amplifier output was evaluated through analyzing the Allan variance when the fiber amplifier operated under the PID control of the dual-path feedback loops. The results were compared with those of when one of the PID control programs of the fiber amplifier or AOM was turned on. The results in figure 6 shows that the Allan variance significantly decreased when the fiber laser was controlled by a PID program in the period of experimental measurement. In comparison, an obvious increment of the Allan variance appeared when the control loop was switched off.

4. Conclusion

By means of a dual-path feedback loop accomplished by the PID program and a multifunction card, both the AOM and the fiber laser amplifier can be controlled by a computer program. The power stability of the fiber amplifier is significantly improved. The stability system is robust and highly scalable. It can be extended easily to control more devices for the complex systems.

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