Piezo Flexure Mechanism for Extending Pulse Repetition Rate Control Range

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In this research, we aimed to improve the control range of pulse repetition in a femtosecond laser system by utilizing a piezo flexure mechanism. The mode-locked laser employed a nonlinear amplification loop mirror (NALM) cavity to ensure stable and reliable operation. However, by incorporating a piezo flexure, we were able to achieve a significantly broader control range over the pulse repetition frequency. The piezo flexure, which deforms in response to electrical signals, facilitated quick adjustment of the laser's pulse repetition frequency. Overall, the introduction of the piezo flexure in this study greatly contributes to enhancing the performance of a stable and reliable femtosecond laser pulse train

NOMENCLATURE

PMF = polarization maintain fiber
PZT = piezoelectric transducer
fs = femtosecond

1. Introduction

precision machining in mobile machining platforms, necessitating the use of a 3-dimensional absolute coordinate measurement technology. To enable precise location measurements using a laser tracker, we developed a Femtosecond laser[1-2]. The key to accurate distance measurements lies in stabilizing the pulse repetition rate frequency of the Femtosecond laser. In our research, we employed a flexure mechanism to effectively control the pulse repetition frequency. This mechanism allows for an increased stroke and a compact design, enhancing the overall performance of the laser system.

Through our study, we demonstrate that the Femtosecond laser with the Flexure mechanism enables long-term pulse repetition rate stabilization.

2. cavity design

In Fig.1 the laser cavity is constructed using a polarization-maintaining fiber (PMF) and follows the Nonlinear Amplifying Loop Mirror (NALM) configuration. In the cavity loop without gain fiber, light is guided to free space using a circulator and collimator, and then refocused back into the fiber using a retro-reflector.

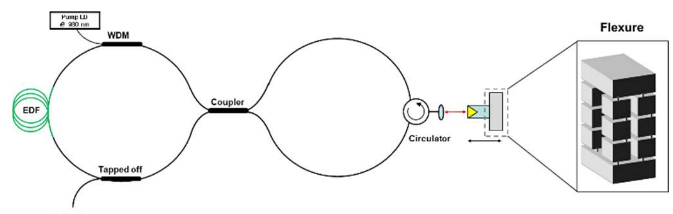

Fig.1 Nonlinear amplifying loop-mirror laser cavity with flexure mechanism[3]

The inclusion of a retro-reflector in the free-space section ensures the robustness of the cavity design, providing resistance against alignment disturbances. The retro-reflector is attached to a flexure mechanism, enabling precise adjustments to the length of the laser cavity, controlled by the movements of the internal Piezoelectric Transducer (PZT) within the flexure. The integration of the flexure mechanism with the retro-reflector extends the range of pulse repetition frequency control of the laser cavity, making it a critical element for achieving pulse repetition rate stabilization

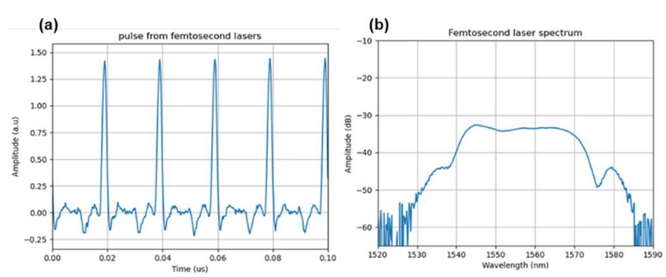

Fig.2 Pulse train and spectrum from femtosecond lasers, (a) pulse train of femtosecond lasers, (b) spectrum shape of femtosecond lasers.

3. simulation and result

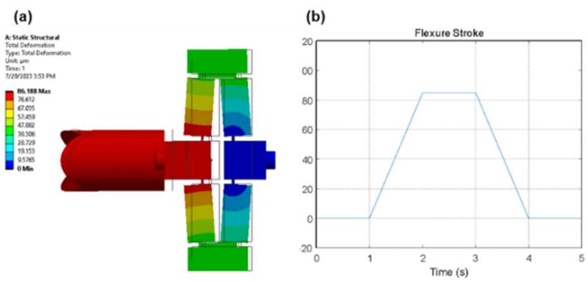

Fig.3 Analysis results of structure analysis software. (a) flexure maximum displacement shape by structure analysis software, (b) flexure stroke graph by structure analysis software.

For the analysis of the flexure mechanism, we employed AL6061 as the material, with a mesh size of 500 µm and a hinge size of 100 µm. The total number of nodes in the analysis amounted to 1,164,030.

Considering the stroke of the PZT, the analysis revealed that the maximum stroke shape, as shown in Fig. 3 (a), reached 86 µm as Fig. 3 (b). These simulation results were consistent with the measurements obtained from experiments.

By implementing the flexure mechanism into the laser cavity, the analysis demonstrated its capability to achieve pulse repetition frequency control of over 500 Hz. The experiment confirmed that the pulse repetition frequency of 500 Hz or more can be effectively controlled.

The Allan deviation measurement results revealed that the laser cavity exhibited an oscillation of 2.2x10^-12 per second compared to the Rb clock. This exceptional stability demonstrates the system's excellent performance, emphasizing its high precision and reliability for long-term frequency stabilization. The experimental verification confirms the laser cavity's capability to achieve prolonged and stable frequency stabilization.

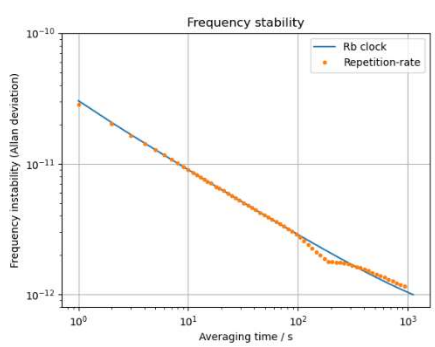

Fig.4 Femtosecond lasers relative intensity noise.

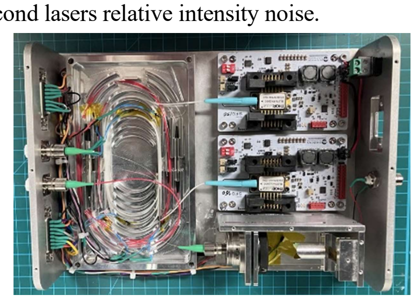

Fig.5 Femtosecond laser implemented using a flexure mechanism.

3. conclusion

Table. 1 Spec of femtosecond laser

Pulse repetition-rate	> 50 MHz
wavelength	1567.2 nm (peak)
Repetition-rate control range	< 500 Hz
Repetition-rate stability (Rb clock)	$< 2.2x10^{-12}$ @ 1 s
Output intensity	< 30 mW

This paper presented the development femtosecond laser for precise 3D coordinate measurements in mobile machining platforms. The laser cavity based on the NALM configuration and utilizing a polarization-maintaining fiber demonstrated stable pulse generation at 50 MHz. The inclusion of a retro-reflector in the free-space section provided robustness against alignment disturbances, while a flexure mechanism enabled long stroke control of the laser cavity's length.

The analysis of the flexure mechanism showed a maximum stroke of 86 µm and pulse repetition frequency control of over 500 Hz, successfully validating its effectiveness for precise pulse control and frequency stabilization. The experimental results confirmed the exceptional stability of the system, with an Allan deviation of 2.2x10^-12 per second compared to the Rb clock, showcasing its reliability for long-term frequency stabilization.

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