

Development of a $\Phi 150$ mm steering mirror for commercial laser fusion reactors

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One of the technical challenges in realizing commercial laser fusion reactors is continuously tracking moving fuel targets with intense laser beams at a high repetition rate (1–10 Hz) [1]. Although the recent breakeven achievement at the National Ignition Facility (NIF) demonstrated the fundamental scientific basis for inertial fusion energy (e.g., [2]), those experiments were conducted using single-shot lasers with indirect illumination on stationary targets. We, EX-Fusion Inc., a laser fusion startup established in Japan, have demonstrated laser pointing control for free-falling $\Phi 1$ mm pellets at 10 Hz by using a $\Phi 50.8$ mm, single axis steering mirror (STM), achieving a tracking accuracy of $86 \mu\text{m}$ (1σ) [3]. The next logical step is to improve accuracy while increasing the STM size to tolerate the high energy of fusion-driving lasers. One of the remaining issues is the resonance vibration of the STM in response to step inputs [4]. This considerably degrades the STM trackability of fuel targets because its resonance frequency decreases and becomes closer to or even below the operational frequency, as the mirror size increases. Therefore, damping such vibrations within the required settling time is a critical task.

Based on this background, we have developed a $\Phi 150$ mm, two-axes gimbal STM as an intermediate-size prototype. First, we adopted elastically deformable metal hinges for rotation axes to achieve higher resonance frequencies. In addition, the resonance frequency can be adjusted by changing the hinge diameter, allowing for optimization based on the operational frequency. Second, an optical lever is installed to precisely measure the mechanical deflection angle and enable closed-loop feedback control. The feedback signal comes from a position-sensitive detector, which precisely tracks the position of a ray emitted from a superluminescent diode and reflected off the back side of the STM. We set the STM specifications as follows [1,5]: (a) $\pm 10 \mu\text{m}$ accuracy at the reactor center located 30 m from the STM, (b) ± 10 mm mirror deflection range at the reactor center, and (c) settling time under 80 ms. The accuracy, in terms of repeatability, has been confirmed to be $0.12 \mu\text{rad}$ (rms, yaw axis) and $0.1 \mu\text{rad}$ (rms, pitch axis), which meets the specification (a). We have also confirmed the settling time of 66 ms (yaw axis) and 77 ms (pitch axis). Currently, the linearity in the range we confirmed is $< 0.18\%$. We are trying more to improve and validate our measurement condition, since the specification (b) means the linearity of 0.05%. The mirrors are now integrated into the EX-Fusion Hamamatsu facility (XF-COLR) to test the continuous laser-target engagement.

References

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