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Simple method for eliminating the warming-up time of an Antares cw mode-locked Nd:YLF laser

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Mode locking of a cw Nd:YLF laser is sensitive to cavity-length mismatch. When a cw mode-locked Nd:YLF laser is turned on the power dissipation from the lamps causes a slow change in the cavity length because of heating of mechanical resonator parts. A method is presented to eliminate these warming-up effects.

Introduction

In our laboratory a cw mode-locked Nd:YLF laser (Coherent Antares 76 YLF)[1] with a lithium borate frequency doubler and a barium borate frequency tripler is used for the synchronous pumping of dye lasers. These lasers are used as excitation sources, together with a time-correlated photon counting detection setup, for time-resolved fluorescence studies. This technique is a research tool for the investigation of a variety of samples of biological or biochemical interest.[2–4] The equipment is placed in a room that is conditioned at 20 °C within 1 °C.

The Nd:YLF laser produces pulses of ~45 ps full width at half-maximum (FWHM) at a wavelength of 1053 nm and of ~30 ps FWHM after frequency doubling ($\lambda = 527$ nm) or tripling ($\lambda = 351$ nm). The pulses are approximately two times shorter than the comparable pulses of the YAG version of the Antares.

In the laser the Nd:YLF rod is excited by the light from two 4.5-kW lamps. The main power dissipation is drained away by the secondary cooling circuit, a deionized water flow that is conditioned at 35 °C by the primary cooling circuit. So the housing of the lamps and Nd:YLF rod is at ~35 °C after some time of equilibration.

That heat is transported, in part, to the 127 cm × 5.08-cm-diameter Invar rod that forms the backbone of the optomechanical construction. Because of the enormous heat capacitance of the solid Invar rod (~10^4 J/K) and the low heat conductance of Invar (~14 W/m K, ~30 times lower than copper), it takes more than 5 h before some equilibrium is reached. During this warming-up period the cavity length must be tuned continuously to have optimum mode locking and thus maximum peak power of the output pulses that are used for frequency doubling and tripling.

In Fig. 1 graphs are presented of the output power after the frequency doubler and tripler following cavity-length detuning. Of course, the temporal shape of the light pulses will also change following cavity-length detuning. Figure 2 depicts a typical curve of the cavity-length detuning during a warming-up period. In particular, during the first few hours after the laser system is switched on, the cavity length must be optimized every 15 min. After 24 h of warming up (by leaving the laser on overnight), a stability to within ±1 mm in an 8-h period was found. The horizontal scale in Fig. 1 and the vertical scale in Fig. 2 is in millimeters of turning at the circumference of the fine-tuning knob for the cavity length, whereas 10 mm of fine tuning corresponds to ~4.5 μm of cavity-length change.

Construction

The design of the Antares laser contains a compensation construction for the reduction of effects of the ambient temperature on the resonator length. The cavity is folded and the "turning mirrors are mounted on a special set of aluminum reflex action wings that maintain the cavity length in the presence of ambient temperature changes."[5] The amount of compensation of this construction can be varied by changing the active length of the aluminum push bars adapting

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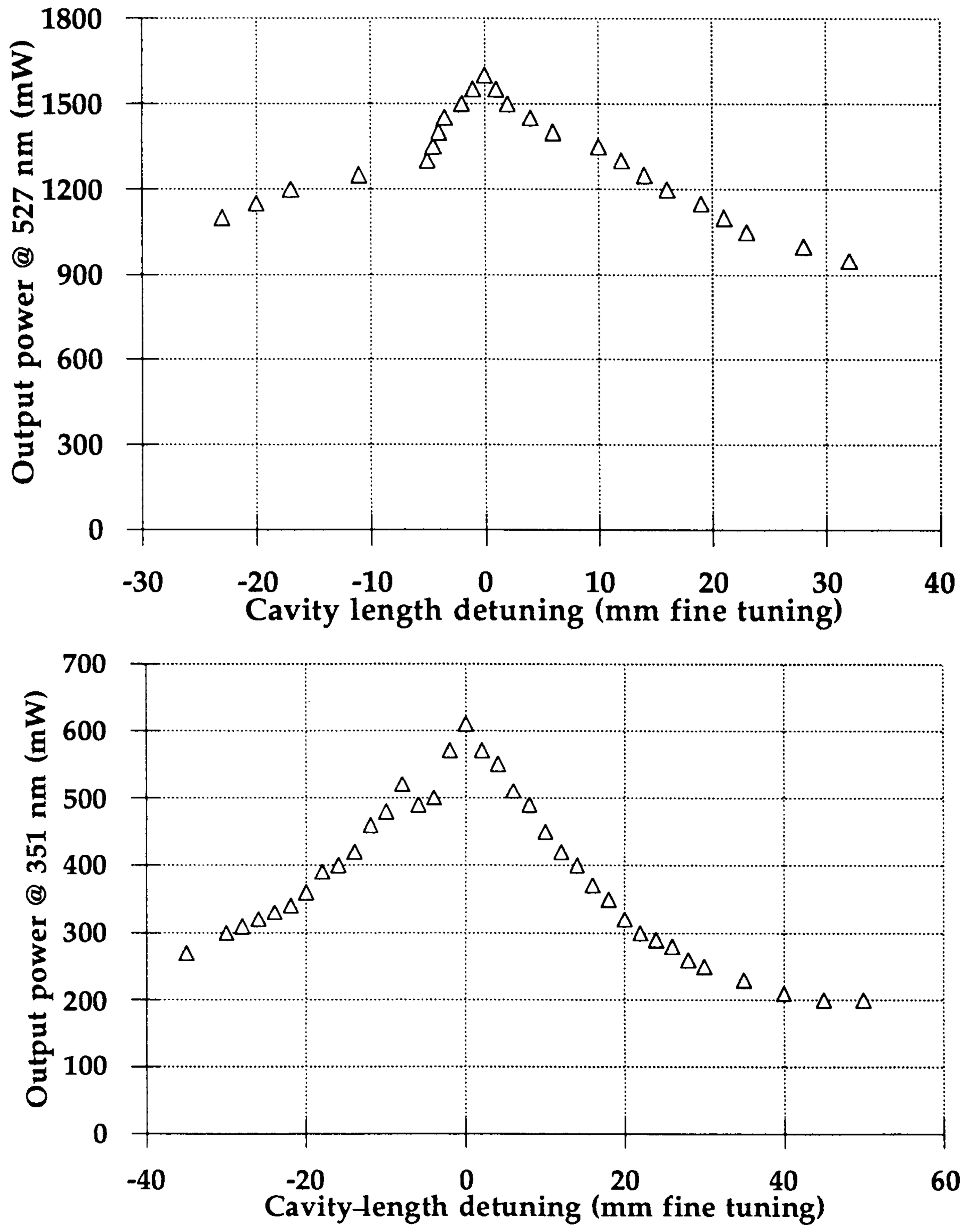

Fig. 1. Output power after frequency doubling and tripling following manual cavity-length detuning.

the compensation for the specific expansion coefficient of the particular Invar bar.

This design may work for the YAG version of the Antares; for the YLF version with its shorter pulses and, therefore, much greater sensitivity to cavity-length mismatch, it was found to be unsatisfactory.[6] The compensation was found to act for only a limited number of daily cycles (of warming up after the laser was switched on and cooling down to 20 °C at night), and then the changes in cavity length that were due to warming up appeared again. The reason for that is still unknown.

There is a temperature gradient of several degrees centigrade over the length of the Invar rod when the laser is on, and that makes a compensation construction critical. In the compensation construction a number of aluminum components are under (also thermally induced) mechanical stress. Because of the temperature differences caused by switching the laser on and off, this stress is not constant and may introduce artificial length changes.

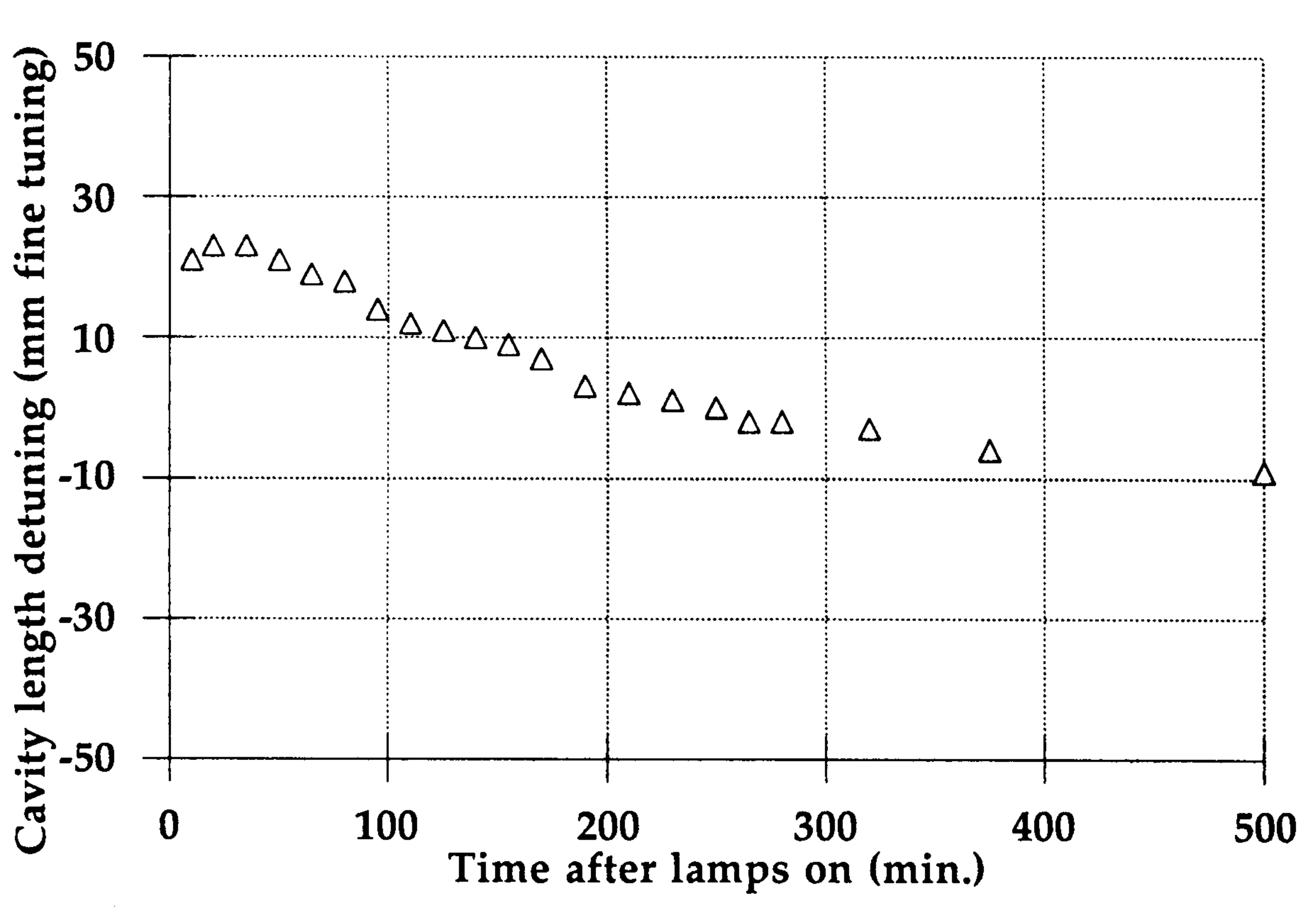

Fig. 2. Cavity-length detuning that is due to heating effects caused by dissipation after the lamps are switched on.

Invar 35 has an expansion coefficient[7] of 6.10^{-7}/°C. So without compensation the effect of thermal expansion of the bar on a 2-m cavity length would be 1.2 μm/°C. Next to thermal expansion the cavity length may also be influenced, on a time scale of longer than a day, by nonthermal dimensional instabilities such as microyield and microcreep properties, and mechanical hysteresis.[8,9]

Heat Sources

There are several heat sources in the laser head. The housing of the lamps is, by far, the most important one; there are also tubings of the secondary cooling circuit, the oven of the lithium borate frequency doubler, some electronics, and thin tubings for cooling the two beam dumps. After the tubings of the secondary cooling circuit are thermally isolated from the frame, the main heat flow to the Invar rod is from the lamp housing to the frame and then through the one fixed clamp, all by means of heat conduction, to the Invar rod. The other clamp holding the Invar rod is floating in the direction of the length of the Invar rod and shows little heat conduction to the rod.

From the Invar rod, the heat is transferred to the air in the laser head and to the laser head cover by radiation and convection from the many holders of optical components clamped to the Invar rod. Temperature differences of up to 5 °C at different places on the Invar rod are measured. The Invar rod is reflective in the range of visible wavelengths and probably is also reflective in the wavelength range of thermal radiation at 300 K, so the main heat transport from and to the rod is by means of conduction.

The (aluminum) holders of optical components make good thermal contact with the Invar rod and are black in the visible and in the IR. The final temperature distribution is a balance between the heat that leaks from the different sources and the heat that is drained to the 20 °C ambient. This also makes it clear that there is an important difference in temperatures in the head whether the cover of the head is opened or not.

Artificial Heat

To mimic the heat transport (when the laser is switched off) from the frame to the Invar rod via the one fixed clamp holding the Invar rod, we installed a heat source in the laser head. Two flexible heater elements (Watlow[10] silicone rubber rectangles, etched foil construction type F101000C7) were wrapped around the Invar rod (next to the one fixed clamp), fixed with a ty-wrap, and covered with aluminum foil. In these heaters, ~14.5 W of electric power were dissipated both when the laser was switched off and during the night (33 V × 440 mA from a laboratory power supply).

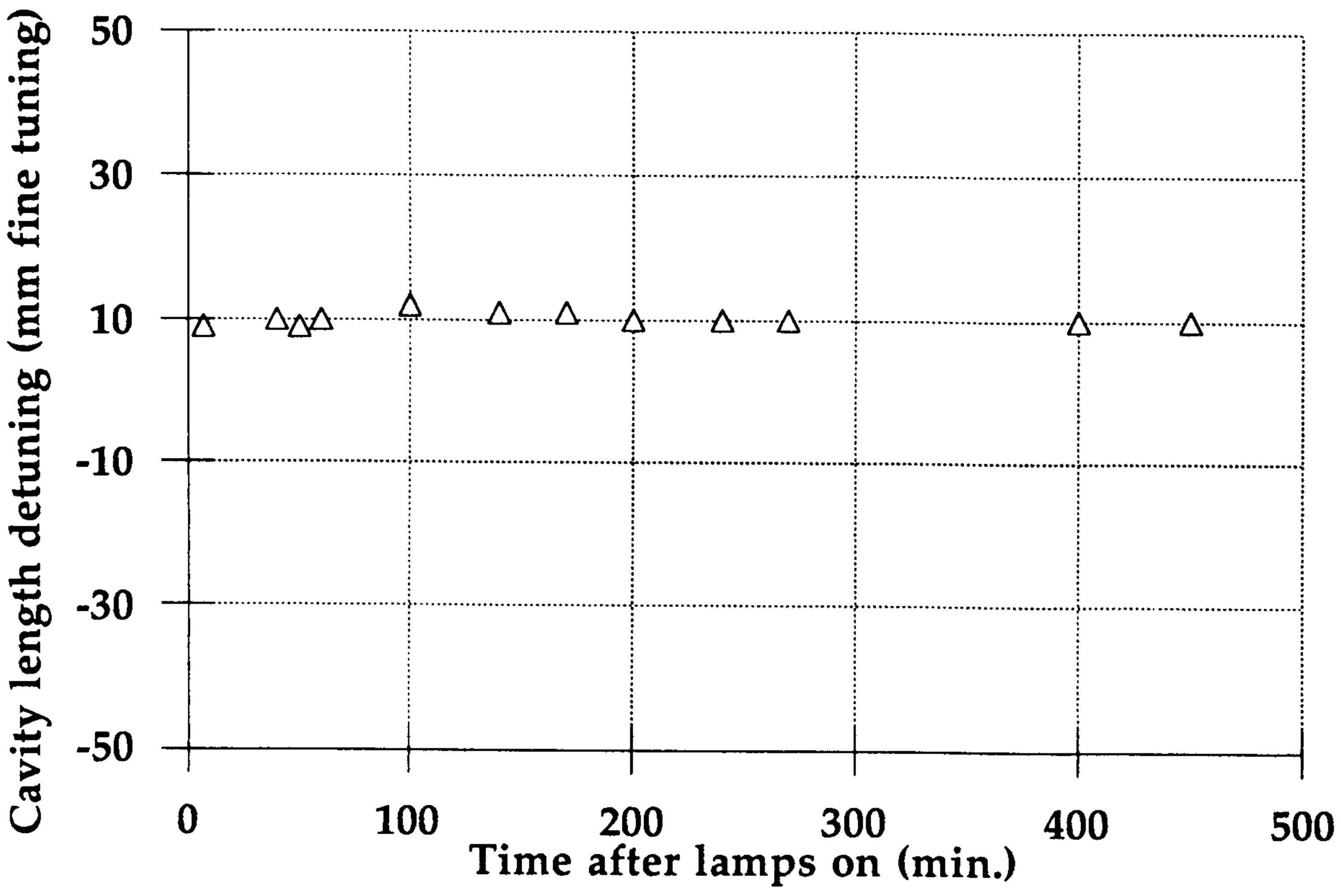

Fig. 3. Cavity-length detuning after the lamps are switched on and controlling the artificial heater, as described in the text.

The temperature distribution along the Invar rod appeared to be quite comparable with the steady-state situation with the laser switched on. After switching the laser on the next morning we could switch the heater off after some 50 min or the power dissipation can be gradually decreased, for instance, with a factor of 0.5 every 30 min. The exact method of switching off the heater is not critical. The values of artificial heat dissipation are an optimum for this situation; a higher or lower temperature of the secondary cooling circuit requires a higher or lower dissipation.

When switching off the laser, as mentioned in the operator's manual,[5] the main power must be switched off a few seconds after the lamps are switched off. This prevents the temperature in the laser head from decreasing quickly because of the flowing on of the cooling circuit and also supports the stabilization method, as described above. Of course, the simplest way to minimize warning-up effects would be to choose a temperature of the secondary cooling circuit that is close to room temperature but this was not possible in the current Coherent design.

Results

In Fig. 3 a typical example is shown of cavity-length detuning after the lamps were switched on. The laser was switched on in the morning; the artificial heater (14.5 W) was on during the previous night and switched off 50 min after the laser was switched on. As can be seen, the cavity-length offset during the warming-up period is within a few millimeters of fine tuning (less than 1-μm cavity-length detuning). When the method in this paper is used, the temperature of the Invar rod will be almost constant, so the forces that induce microinstabilities are always at some equilibrium.

Conclusion

Using an artificial heater to mimic the heating effects of the heat flow from the dissipation of the excitation lamps in the cw mode-locked Nd:YLF laser, we can reach an effective elimination of warming-up effects without using a complicated temperature regulation. This was made possible by the initially large heat capacitance of the solid Invar rod.

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