Adaptive feedback control in self-mixing interferometry using active optical elements

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Purpose

A voltage-controlled liquid lens has been used as an adaptive optical element integrated in a conventional self-mixing interferometry setup. The lens is used to control the optical feedback level and the focus position of the laser beam enabling the system to find automatically the good measurement condition for vibration measurements. The system has been set to work in closed loop having as input the coupling coefficient of the self-mixing signal, and as control parameter the voltage of the liquid lens, enabling to enhance the measurement capabilities of the technique.

Methods

The so-called self-mixing phenomenon in semiconductor lasers (also named optical feedback) has been widely studied during the last decade [1]. Interpreted initially as a disturbance, it was lately proven to become an extremely compact, self-aligned interferometric sensor with great potential for metrology applications such as displacement, vibration or velocity [2]. Self-mixing interference occurs when a part of the emitted laser beam leaving a laser diode (LD) is back-reflected from a moving object and partly re-enters into the active cavity of the laser diode. This reflected beam then interferes (becomes self-mixed) with the present standing waves inside the cavity, resulting in a variation in the spectral properties of the laser beam which yield changes in the emitted intensity of the laser beam. The Output Optical Power (OOP) of the laser is monitored by an integrated photodiode in the same laser package which makes the interferometer compact, cheap, self-aligned and robust.

In conventional self-mixing interferometry (SMI), a mechanically adjustable fixed focal lens is used to focus the beam on the target. Usually a skilled operator is required for the adjustment to bring the optical feedback level to desired regime for measurement, which normally involves working in the weak or low hysteresis moderate regime. Conventional signal processing [3] in other feedback regimes such as very weak, high-hysteresis moderate and strong regimes are unable to reconstruct the displacement even with the basic resolution of half wavelength of the beam. The feedback level is described by a parameter named the coupling coefficient of the signal.

In this paper we propose to change the fixed focal lens configuration by a combination of a fixed focal lens and a voltage controllable commercial liquid lens (LL) located in front of the LD. This enables to adaptively control the feedback level of the interferometer using the coupling coefficient of the signal as input of the loop, and the voltage of the liquid lens as the control parameter to be modified. Such an arrangement has allowed to maintain the proper feedback level at virtually any distance of the target, or working with cooperative and non-cooperative targets, by just changing the focus position and consequently modifying the beam spot size on the target surface, so we can control the amount of back-reflected light which gets back into the cavity [4].

Results

The proposed experimental setup has been designed and built in order to show the capabilities of the technique. Fig.1 shows a picture of the built setup, showing the mechanical support including the fixed focal lens, and the liquid lens. The laser diode is embedded within an aluminum area which becomes a heat sink. The setup is completed by the corresponding circuitry. The capability of the proposed LL configuration in finding the desired feedback regime under different experimental situations is presented in Fig. 2, showing that active control of the amount of laser light entering the cavity is achieved by adding or removing fringes (that is, adding hysteresis by changing the feedback level) in the signal. In a typical application, it can be shown how for a fixed-distance target, different focus positions of the liquid lens result in lost fringes, showing the mentioned changes in feedback level. Reliable vibration measurements at different distances from a few centimeters to more than 2.5m (limited by the optical table size) from the LD using the LL configuration have been demonstrated.

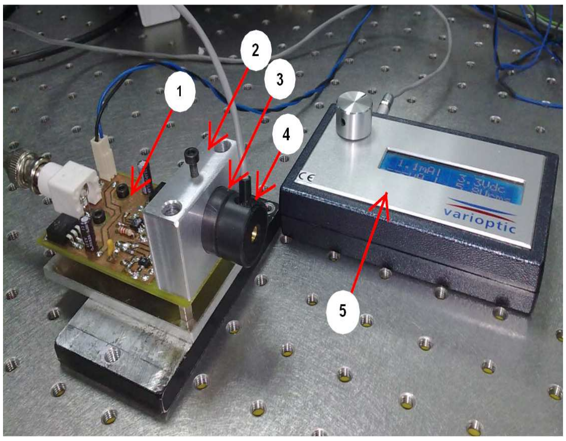

Fig.1: Experimental arrangement: (1) electronic signal acquisition board, (2) metallic heat sink containing LD package, (3) tube holding fixed focal length lens, (4) liquid lens, (5) liquid lens controller.

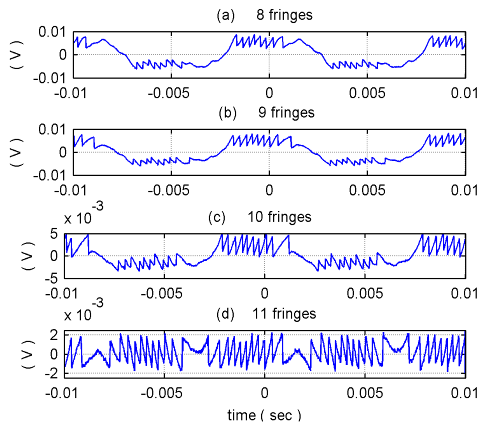

Fig.2: Experimental OOP of the LD for a fixed-distance sinusoidal-vibrating target at 78cm, at different focus positions. Changes in the shape of the signal correspond to changes in the feedback level

Conclusions

The interest of a configuration including a LL as a compact optical setup which can adaptively select the feedback level in a semiconductor laser has been presented. The adaptive element can be programmed to keep the self-mixing signal in the weak or moderate feedback regime under different situations, like important changes in the laser-target distance, by using the coupling coefficient of the signal as input value and the voltage of the liquid lens as control element. We have also shown that the optical feedback level can be modified by the proposed adaptive configuration in a fixed-distance target.

References

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