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Angle Measurement by Injection-Detection in a Laser Diode

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Introduction

Several sensing schemes based on laser diodes (LDs) have been proposed for different application fields (i.e., laboratory, industrial, medical, civil engineering). Advantages of these sensors are generally: compactness, accuracy, low cost and low invasivity. In this work we propose a new technique to measure the angle of a remote flat surface with respect to a laser beam based on injection-detection in a LD. The surface under test acts as the remote mirror of an external cavity laser (ECL), which is made to operate in the coherent collapse regime. The power emitted by the ECL depends on the alignment of the remote surface, and this allows to measure angles with a sensitivity of 0.1 arcsec (i.e., $5 \cdot 10^{-7}$ rad). The attained performances are comparable to those of existing autocollimators [1] with the advantage of compactness and low cost, that make the new technique interesting for the development of a measuring instrument.

Laser Diode in High-Feedback Regime

It is well known that a set-up similar to that shown in Fig. 1, in which a small fraction of the light emitted by a LD is reflected back by a remote target and allowed to re-enter the LD cavity, can be used for interferometric measurement of the target displacement [2]. This technique is called self-mixing or injection interferometry and works for moderate feedback levels (10^{-5} in power). In the high-feedback regime (i.e., 10^{-1} to 10^{-3} in power for a LD with an anti-reflection coating of a few percent on the output facet) interferometric signals are no longer observed, and the LD operates in the so-called coherence collapse regime [3]. In this case the remote reflector acts as the external mirror of an ECL, which is equivalent to a LD with an increased output reflectivity R_2. It turns out that both laser threshold and slope efficiency depend on the total round-trip attenuation in the external cavity. This is shown experimentally in Fig. 2 for a 825 nm Hitachi LD. Thus, the LD in the high-feedback regime allows us to detect variations of the round-trip attenuation in the external cavity path with high sensitivity by means of an injection-detection method.

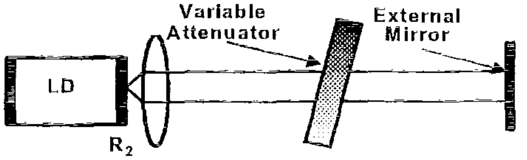

Fig. 1. Basic experimental set-up with LD, collimating lens, variable attenuator and remote reflector.

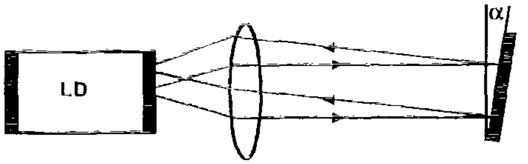

Fig. 3. A tilt angle α of the external mirror shifts the reflected spot. The equivalent effect is an increase of the round-trip attenuation in the external cavity .

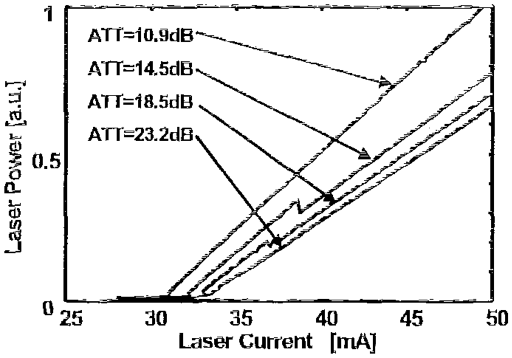

Fig. 2. Experimental P-I curves in the high-injection regime using the set-up of Fig. 1. Different values of total round-trip attenuation in the external cavity are reported on the graph.

Angle Measurement: Principle

In the high-feedback regime, a slight tilt of the external mirror is equivalent to an increase of the round-trip attenuation. This can be explained by Fig. 3, where it is shown that the reflected light is slightly offset with respect to the LD emission spot. Thus, a smaller fraction of the reflected light couples to the LD cavity mode, and this is equivalent to an increase of the round-trip attenuation. Fig. 4 reports the experimental plot of the power emitted by the ECL (collected by the monitor photodiode included in the LD package) for a fixed LD current as a function of the tilt angle of the remote mirror. The emitted power has a parabolic dependence on the tilt angle. If the external mirror is mounted on a loudspeaker, a very interesting effect can be observed. When the loudspeaker is actuated by a sine waveform, it not only moves parallel to the laser beam, but it also produces a small tilt of the mirror at the same frequency of the driving signal. The tilt generates a sinusoidal modulation of the power emitted by the ECL, due to the periodical variations in the external cavity round-trip loss. Interestingly, this modulation is in-phase or out-of-phase with respect to the driving signal depending on the DC offset tilt angle of the mirror. This is shown in Fig. 5. It is also noted that when the DC offset tilt angle is zero (i.e., optimal external mirror alignment) the power modulation

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only has the second harmonic component. The above results suggest that an accurate measurement of the DC offset tilt angle of the remote mirror can be performed by injection-detection in the high-feedback regime.

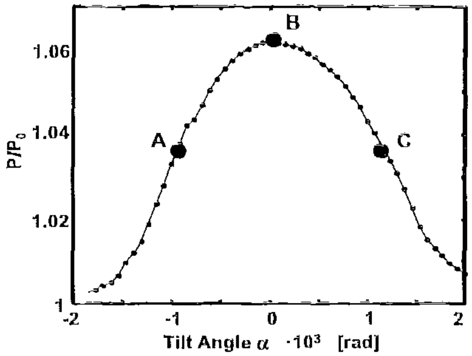

Fig. 4. Experimental measure of P/P_0 as a function of remote reflector tilt angle α. P: power emitted with remote reflector; P_0: power emitted by unperturbed LD. LD current: 60 mA.

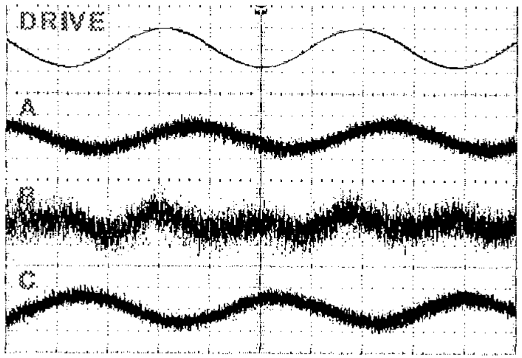

Fig. 5. Scope traces of power modulation occurring when the mirror is placed onto a loudspeaker, generating a sinusoidal tilt. Upper trace: loudspeaker drive. A, B and C traces refer to DC tilt points shown in Fig. 4 with corresponding label.

Angle Measurement: Experimental Results

The experimental set-up for angle measurement is shown in Fig. 6. A mirror is mounted on a bending PZT operating in flexure mode which is driven by a sinusoid at frequency f_d, thus generating a small dither Δθ (of the order of 10^{-5} rad) in the overall tilt angle α of the remote surface. Since the emitted power has a parabolic dependence on the DC offset tilt angle α (see Fig. 4), the amplitude of the power term modulated at frequency f_d is proportional to α. The amplitude of this sinusoidal signal is plotted in Fig. 7 as a function of α. The figure shows that the proposed scheme is actually capable of measuring the tilt angle of a remote surface. The measured sensitivity is 0.1 arcsec (i.e., $5\cdot10^{-7}$ rad) for a remote surface placed at 0.7 m from the LD, and the dynamics is $4\cdot10^{-4}$ rad. Common mode power variations are cancelled out by dividing the AC sinusoidal signal by the DC power term. The measurement can be performed on highly-reflecting surfaces as well as on glass plates, and the remote mirror can be up to 3 m apart from the LD. Angles in the two directions can be easily measured by adding another dither at a different frequency in the orthogonal direction. An additional interesting feature is that the information on the tilt angle can be retrieved anywhere along the beam path by using a beamsplitter, and hence also at the remote surface site.

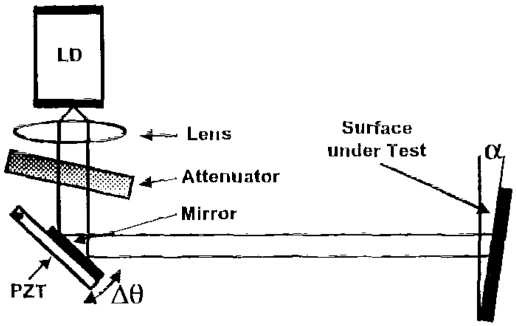

Fig. 6. Experimental set-up for angle measurement. A sinusoidal dither at frequency f_d is applied to the PZT.

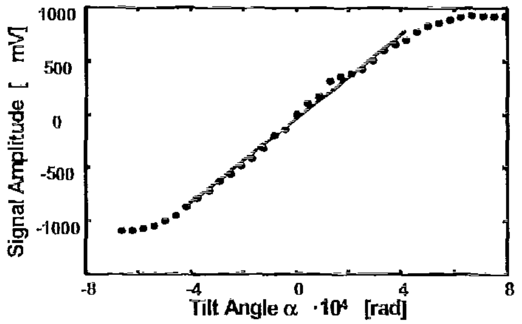

Fig. 7. Amplitude of sinusoidal signal at frequency f_d as a function of the tilt angle α of the surface under test.

Conclusions

We have demonstrated a new method for the measure of the angle of a remote flat surface based on injection-detection in a LD in the high-feedback regime. The simplicity of the approach, the high sensitivity comparable to that of existing autocollimators, and the low cost make the proposed scheme interesting for the development of a measuring instrument.

References

[1] D. Malacara, ed., "Optical shop testing", Wiley, New York, 1992.

[2] S. Donati, G. Giuliani, S. Merlo, "Laser diode feedback interferometer for measurement of displacements without ambiguity," *IEEE J. Quantum Electron.*, vol. 31, pp. 113-119, 1995.

[3] K. Petermann, "Laser diode modulation and noise", Kluwer, Dordrecht, The Netherlands, 1988.