Optical feedback interferometry for measuring dynamic stress deformation of beams

Reza Atashkhooei[1], Francisco Azcona[1] , Santiago Royo[1], Lluis Gil[2]
[1]Centre for Sensors, Instrumentation and Systems Development, Universidad Politecnica de Catalunya (UPC-CD6) Terrassa, Spain. reza.atashkhooei@cd6.upc.edu
[2]Laboratori per l'Innovació Tecnológica d'Estructures i Materials , Universitat Politècnica de Catalunya (UPC-LITEM), Terrassa, Spain.

Abstract

In this paper, we are proposing optical feedback interferometry (OFI) (also known as self-mixing interferometry) for tensile test and strain measurement of materials under dynamic loading. As an experimental example, deformation of a material in the form of a beam used in the construction industry for the bridge structure and building reinforcement will be used as the measurement subject.

The beams used in bridge structures suffer from different kinds of forces which affect their performance. Thus, the measurement and characterization of the elastic behaviour and deflection of beams under dynamic loading is a relevant topic of high interest in civil engineering. It typically is used in non-destructive testing, for conservation monitoring and maintenance purposes.

In OFI, the laser beam from the diode is partially back-reflected on the target, and enters back into the active laser cavity, interfering with the stationary wave present inside it. This interference inside the laser cavity yields a variation of the spectral properties of the laser beam and changes the emitted laser intensity. As the optical power of the laser may be monitored by the photodiode normally integrated in the same laser package, the arrangement gives rise to a type of interferometer extremely compact, cheap, self-aligned and robust. The basic resolution of the measurement is $\lambda/2$ (where λ is the laser wavelength) which can be improved and reach to the $\lambda/16$ by using signal processing methods [1].

On the civil engineering side, one of the most common sensors used for deflection measurement of the beam is the linear-variable-differential transformer (LVDT). The tip of the sensor is placed in contact with the beam and produces an induced voltage proportional to the sample displacement. LVDT has well-known disadvantages such as the limitation of the measurement range and the accuracy degradation outside the linear range. Besides, as the measurement of stress deformation may be a destructive procedure, the LVDT sensor can be damaged.

OFI obviously does not have the mentioned disadvantages of the LVDT sensor, mainly because it is a non-contact method and the measurement resolution is uniform in the whole measurement range. The only disadvantage of OFI is the speckle effect which appears in large displacements, which imposes amplitude modulation and amplitude fading. This modulation causes fading areas of the laser intensity which lead to lost information and accuracy degradation. A voltage programmable liquid lens has been shown an effective way to overcome speckle [2]. The liquid lens adaptively changes the focal length of the optical system to modify the speckle pattern, keeping the laser signal amplitude in the acceptable range of signal to noise ratio values for accurate signal processing.

As an example, deformation of a GFRP (Glass Fibre Reinforced Polymer) beam under dynamic loading will be measured. The measurement configuration is shown in fig.1. As shown in the figure, a GFRP beam was under loading at the middle with a controlled electro-mechanic machine, with both ends of the beam placed on fixed rounded metallic cylinders which acted as reliance points. At the loading point a displacement of roughly a millimetre is applied to the beam.

For proper comparison of the results, the OFI sensor and a LVDT sensor were placed together at about 155mm from the loading point to monitor the vertical displacement of the GFRP beam surface. Both sensing points are placed at the same distance from the loading point, and as close together as possible, for comparison purposes. The experimental arrangement is shown in Fig. 1, and a detail of the position of the sensors is observed at Fig.2.

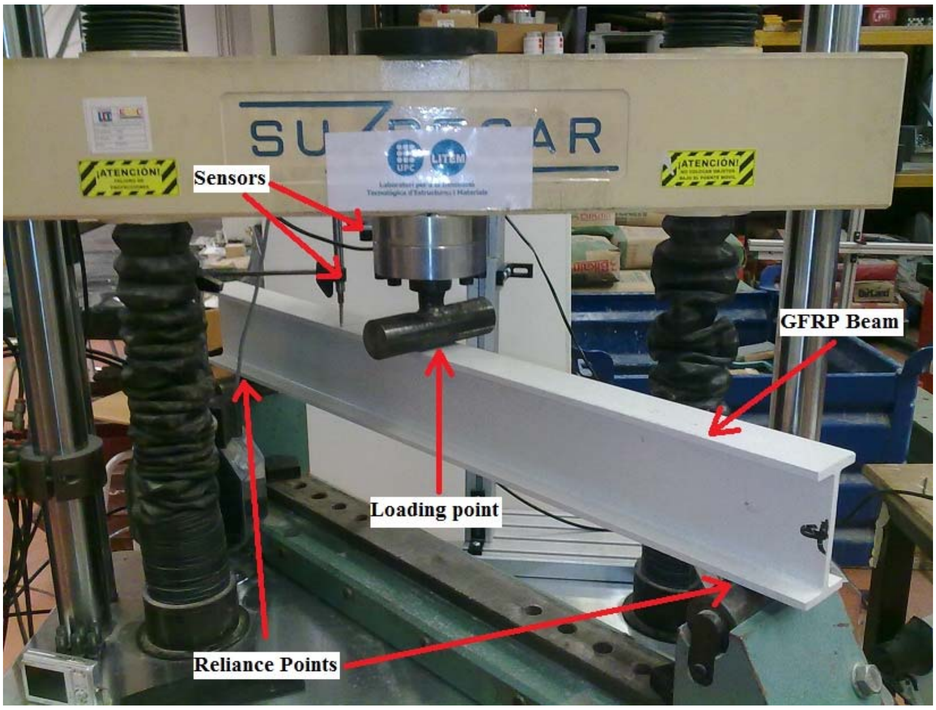

Fig. 1- Measurement configuration. See text.

The displacements measured by both sensors are depicted in Fig. 3. The measurement resolution by OFI was the basic resolution of the sensor (392nm). The LVDT signal had a high-frequency variation corresponding to about 40µm, so low-pass filtering techniques were applied to the LVDT signal. Fig.4 shows the difference of both signals showing the reconstructed displacements measured using SMI and LVDT sensors were below 20µm. The results prove the feasibility to use OFI for material deformation measurement of materials and elements in civil engineering.

References

[1] C. Bes, G. Plantier and T. Bosch, “Displacement measurements using a self-mixing laser diode under moderate feedback, “ IEEE Trans. Instrum. Meas. 55, nr. 4, pp. 1101-1105, 2006.

[2] R. Atashkhooei, S. Royo, F. Azcona, U. Zabit, “Analysis and control of speckle effects in self-mixing interferometry, “ Proc. IEEE sensors 2011, pp. 1390 – 1393.

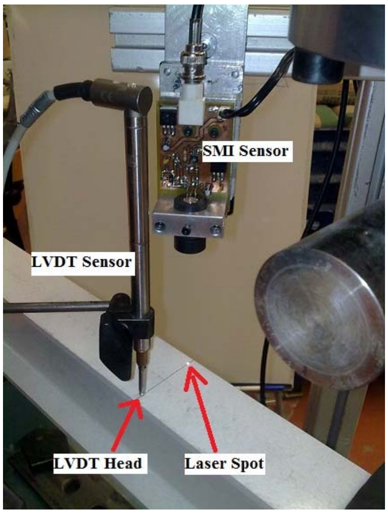

Fig. 2- Sensors configuration; OFI (SMI) sensor and commercial LVDT sensor as a reference.

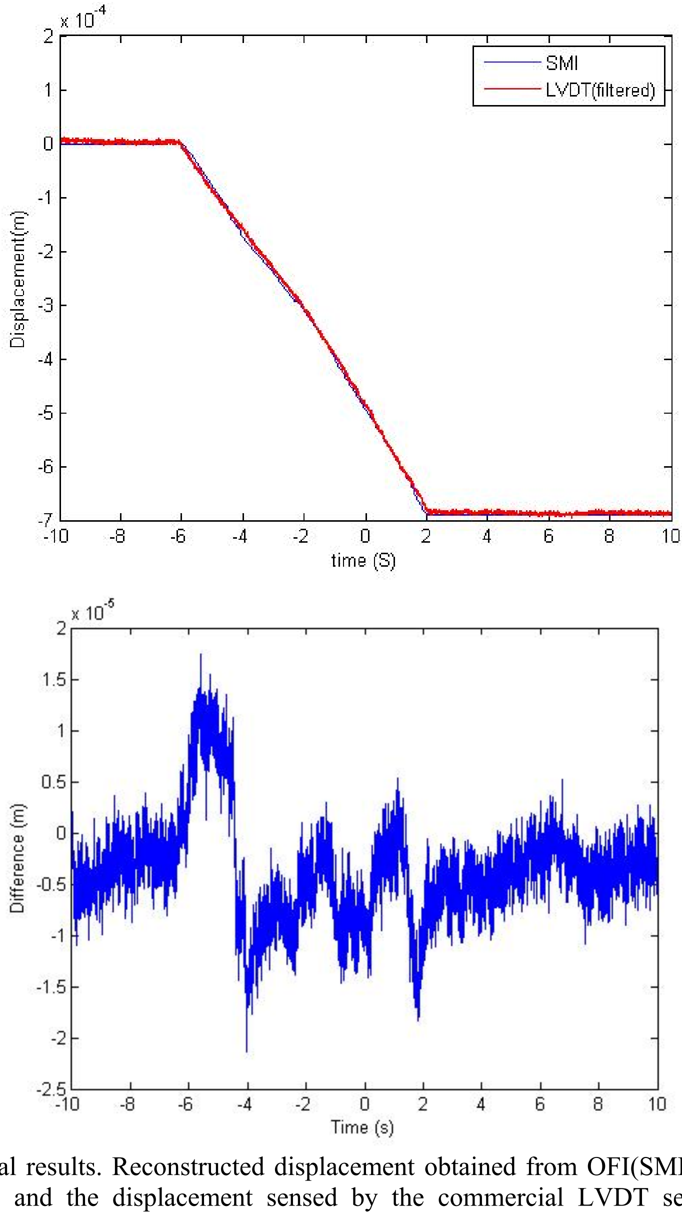

Fig. 3- Experimental results. Reconstructed displacement obtained from OFI(SMI) sensor using fringe counting technique and the displacement sensed by the commercial LVDT sensor (low-pass filter applied) (up), subtraction (difference) of the reconstructed displacements (down).