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SPIE—The International Society for Optical Engineering

Fifth International Conference on

Vibration Measurements by Laser Techniques: Advances and Applications

Enrico Primo Tomasini
Chair/Editor

18–21 June 2002
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Reducing the mechanical hysteresis problem in optically-addressed diaphragm pressure sensors

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ABSTRACT

Mechanical hysteresis problems associated with pressure sensors based on interferometric measurements of diaphragm deflection are discussed. The source and importance of each contribution to the net hysteresis is calculated and compared with experimental results. Possible methods to decrease hysteresis effects are presented. Based on these suggested methods, new sensors have been manufactured and their hysteresis evaluated. The results demonstrate that significant reductions in hysteresis can be achieved with minimum cost. Future sensor development will focus on materials selection and manufacturing methods to fully realize these improvements.

Keywords: Hysteresis, optically-addressed pressure sensor, temperature sensitivity, pressure transducer, Fabry-Perot interferometer

1. INTRODUCTION

Mechanical hysteresis exists in all materials and will therefore affect the performance of pressure sensors that utilize a diaphragm. An illustration of mechanical hysteresis can be seen in the stress-strain curves for most materials: usually the curves are not precisely aligned in the increasing and decreasing load directions. Mechanical hysteresis results from friction-like irreversibilities which are dissipated as heat. The mechanical hysteresis effects can be minimized through proper choice of material and working stress level. For example, crystalline materials yield low hysteresis errors and diaphragms made of monocrystalline silicon show minimal hysteresis effects.[1] However, other optically-addressed sensor construction issues such as: 1) price; 2) reflectivity; and 3) availability in foil or thin sheet form, could limit the use of low mechanical hysteresis materials in some cases.

The pressure sensor arrangement considered in the present work closely follows that of MacPherson et al.[2,3] in which copper diaphragms are bonded to zirconia ferrules (part of a standard fibre optic communications connector) using an epoxy. While results obtained with these devices have been very encouraging, the issue of mechanical hysteresis has not been addressed. In the present work, attempts are made to characterise and minimize the mechanical hysteresis effects associated with optically-addressed pressure sensors constructed from zirconia ferrules with bonded aluminium and copper diaphragms.

2. INTERFEROMETER AND CALIBRATION HARDWARE

The interferometer system used in the current work is illustrated in Figs. 1 and 2, and is very similar to the system used by MacPherson et al.[2,3] Light from a 20mW laser diode at 780nm is launched into a single mode fibre attached to a 50/50 bi-directional coupler. Light reflects off the cleaved end of the fibre, which is located about 10 μm from the diaphragm and propagates back towards the signal detector. Some of the light transmitted into the air cavity couples back into the fibre after it reflects off the diaphragm and also propagates back towards the signal detector. Deflection of the diaphragm due to changes in the external pressure alters the length of the air cavity and thus the relative phase of the two reflected signals. Changes in the relative phase of the two reflected waves are identified as changes in the intensity at the signal detector.

A tube was used for the pressure calibration of the optically-addressed sensors. The tube was approximately 2m long with an internal diameter of 27.5mm. The tube initially contained air from the laboratory environment at the local atmospheric pressure and ambient temperature. The laboratory ambient temperature was approximately 18°C, and the local atmospheric pressure was around 94kPa (Toowoomba is approximately 800m above sea level). The tube pressure was increased by adding compressed air from a regulated supply, and the subsequent decrease in pressure was achieved by venting the tube to the atmosphere. Each optically-addressed pressure sensor was mounted in a plate that was bolted

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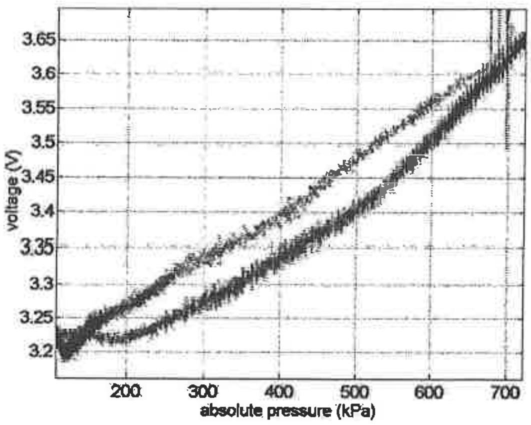

Figure 29: Calibration of a sensor made with 12.7μm thick copper (110) diaphragm after 500 pressure load cycles applied to the finished sensor

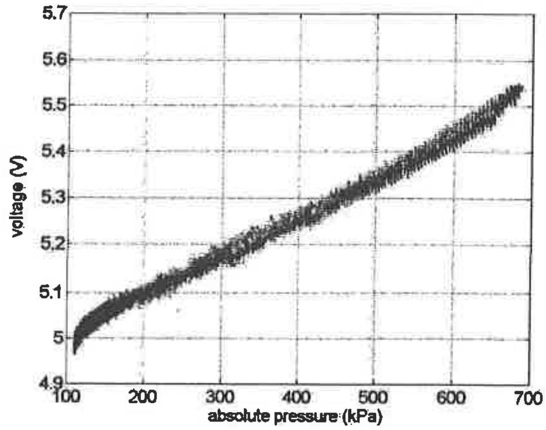

Figure 30: Calibration of the same sensor in Fig. 29 after 2000 pressure load cycles applied to the finished sensor

5. CONCLUSION

The hysteresis effects associated with fibre optically-addressed diaphragm pressure sensors have been investigated. It is demonstrated that without due attention to hysteresis issues, substantial problems are likely to be encountered. A number of techniques to reduce hysteresis effects have been proposed and investigated theoretically. Experimental results demonstrate the substantial reduction of hysteresis effects that can be achieved by: 1) tension load cycling the diaphragm material prior to bonding to the ferrule; and 2) pressure load cycling subsequent to sensor construction. Using the techniques outline in this publication, practical miniature pressure sensors with metallic diaphragms and a high measurement bandwidth can now be constructed at a low cost.

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