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EXPERIMENTAL INVESTIGATION OF MICRON LEVEL CLEARANCES BY FIBRE OPTIC INTERFEROMETRY

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Abstract: *In this study a fiber optic interferometer (FOI) was designed and constructed to measure micron level clearances occurring in piston cylinder arrangements. A Cartesian model of the piston cylinder assembly is manufactured and lateral motion and vertical displacement are generated via a step motor, and micrometers, respectively. Clearance measurements were conducted in air and also in a lubricant. The range of vertical displacements is kept between 10-50 micrometers, and the lateral motion is 13.5mm. The results show that the surface profile becomes dominant when vertical displacement values are lower than 10 micrometers.*

Keywords: *fiber optic interferometry, lubrication, Fourier transforms, parallelism of surfaces, clearance*

1. INTRODUCTION

Clearances in piston cylinder arrangements range between 1–7 micrometers in hermetically sealed compressors to hundreds of micrometers in internal combustion engines. The static and dynamic measurements of clearances are difficult due to the intricate geometry and the inherent complexity of introducing measuring instruments into the tight space. The current study involves the development of the first phase of an experimental setup, which is capable of measuring clearances larger than 10 micrometers. In smaller clearances the effect of surface profile on the measurement of clearances needs special attention.

Different types of lubricant fluids are used to reduce friction, wear, deformation of the piston cylinder mechanism and the power consumption. Due to small clearances, estimation or measurement of lubricant thickness is a challenging problem, with the main goal of reduction of friction and wear.

Initial studies to measure clearances used electrical contact resistance and voltage discharge methods [1]. Capacitance measurement and optical interferometry became popular in the study of elastohydrodynamic lubrication films [2]. Johnston *et al.* used a method of spacer layer to detect the lubricant thickness in nanometer scale [3]. Luo *et al.* used optical interferometry to measure film thickness with a resolution of 0.5 nm [4]. Hartl and co-workers achieved the measurement of 5 nm film thickness using colorimetric interferometry technique [5].

Fiber optic interferometry is also used to determine different physical parameters. Sathitanon used it to build up a displacement sensor [6]. Djinovic *et al.* tried to find wear rate and vibrations by using fiber optic interferometry in nanometer scale [7]. Zeeland et al. used fiber optic interferometry for plasma density measurements [8].

2. FIBER OPTIC INTERFEROMETRY

Fiber optic interferometry is widely used in numerous applications, such as, distance measurements, telecommunications, and medical endoscopy. Advantages of fiber optics are their low power loss, safety, low cost, accessibility to small spaces and flexibility of the equipment. A fiber optic interferometer is a typical multiple beam interferometer. It consists of a laser, a single mode fiber optic cable, a beam splitter or a coupler, a target and a photo detector. A classical configuration of a fiber optic interferometer is shown in Figure 1.

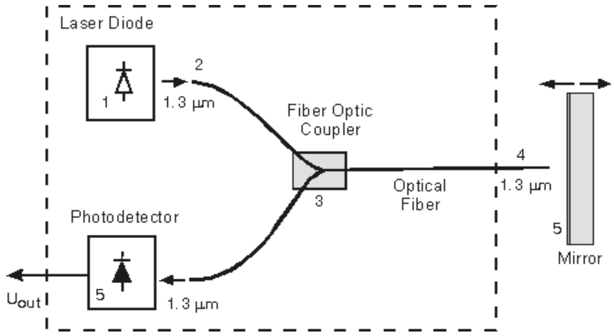


Figure 1. Classical configuration of Fiber optic interferometry

In Figure 1, the infrared laser beam emitted from the laser source (1) is directed into the fiber cable (2) and propagates through the coupler (3) to fiber (4). Laser radiation reflected from the end face of the fiber (4) interferes with the laser beam reflected from the mirror. The resulting intensity detected by the photo detector is given by [9]

$$I = I_1 + I_2 + 2 * \sqrt{I_1 * I_2} * \cos(\Delta\phi) \quad (1)$$

where, I_1 and I_2 are the reference and sensing signals, ϕ is the total phase difference. Phase difference can be determined by

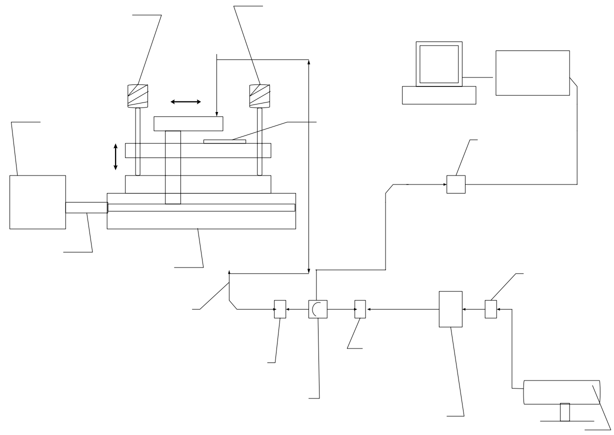
$$\Delta\phi = \frac{4 * \pi * n * \Delta L}{\lambda} \quad (2)$$

where, n is the refractive index of the cavity, λ is the laser wavelength, ΔL is the twice the distance between end face of fiber (2) and the mirror. Equation 2 gives the distance between successive maximum and minimum intensities detected by the photo detector. Total distance, d , is calculated by

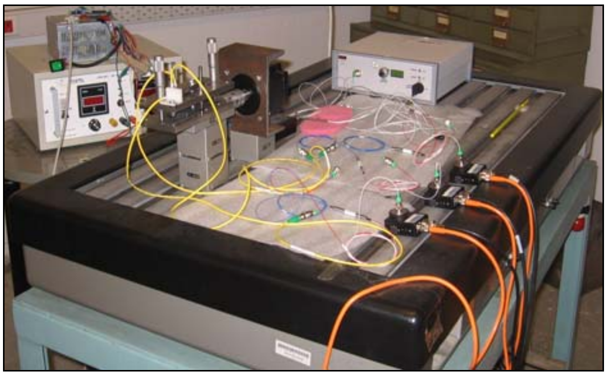
$$d = \frac{N * \lambda}{2 * n} \quad (3)$$

2.1 Experiments and Results

In the experimental setup, a laser with a wavelength of 1550 nm is used as the monochromatic light source. The radiation emitted from the laser source is coupled into the fiber optic cable and directed to the isolator. Laser radiation propagates through the circulator, which has one input and two output ports. Initially, the laser radiation is directed to the simulated piston-cylinder assembly in which the optical beam reflected from the end face of the fiber interferes with the beam reflected from the gold-coated reflective surface. The interfering beams propagate back through the circulator and are directed to the photo detector. In the photo detector, the optical output is converted into electric signals, which are transmitted to the computer through a data acquisition card. The lower plate which has a gold coating to reflect the infrared light efficiently is fixed, and the upper plate, which holds the fiber optic cables, is movable relative to the lower plate in the horizontal direction. The lower plate is fixed to the optical table. The schematic view and photo of the experimental setup is given in Figures 2a and 2b, respectively.



(a)



(b)

Figure 2. Experimental setup (a) schematic view, (b) photograph

In the simulated piston-cylinder assembly the rotary motion of the step motor is converted into a linear motion by a coupling. Two micrometers are used to adjust the vertical relative displacement between the plate on which fiber optic cables are located and the gold-coated reflective surface. When the step motor operates, the upper plate moves in the forward or backward direction and the fiber optic interferometer detects the vertical displacements at different horizontal locations of the gold-coated reflective surface. The micrometers are used to set the relative vertical clearance between the two surfaces. The horizontal motion of the simulated piston is given schematically in Figure 3.

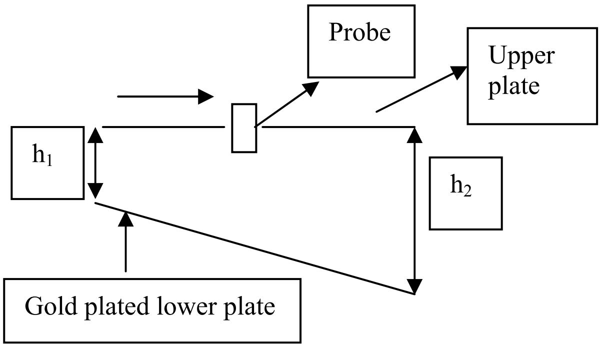
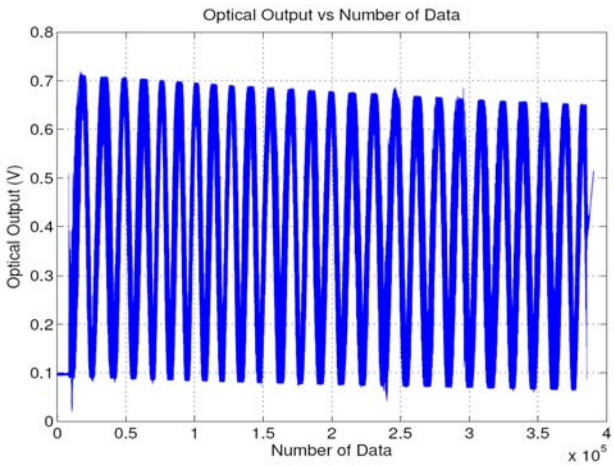
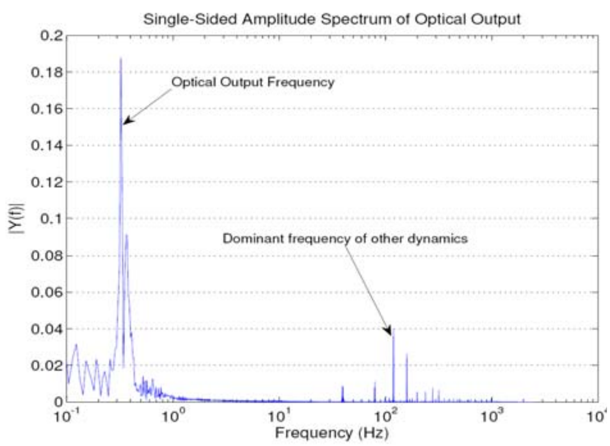


Figure 3. Horizontal motion of the upper plate

Data acquisition process is performed using Matlab and after acquiring data, the optical output is processed. Due to various dynamics of the lateral motion of the experimental setup, the acquired rough data contains noise. After acquiring the rough data, a Fourier transformation (FT) of the rough data is taken and a filtering is applied in time domain. The rough data, FT of the rough data and filtered data are given in Figures 4a, 4b and 4c respectively.



(a)



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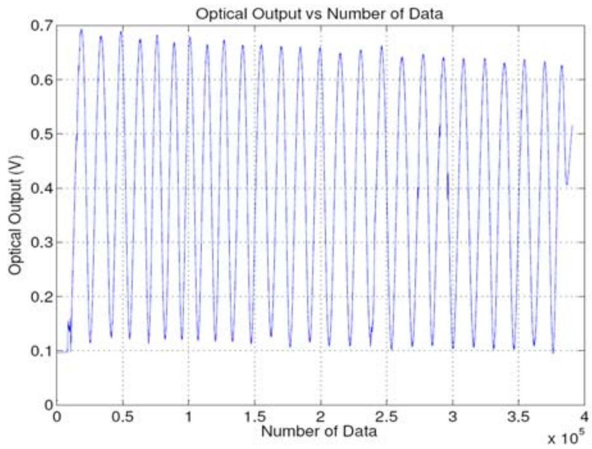


(c)

Figure 4. (a) Rough data, (b) FT of rough data, (c) Filtered Data

After filtering the data, the optical output is processed using a numerical code, to convert the optical output into vertical displacement. The code counts the interference fringes and the fractions thereof, to calculate the relative vertical motion. A vertical displacement (i.e. clearance) is given as a function of relative horizontal displacement in Figure 5.

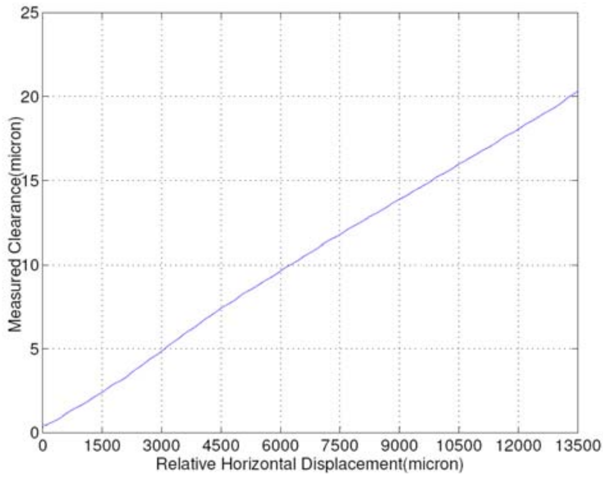


Figure 5. Measured vertical displacement for 13.5 mm of horizontal motion

The reference micrometer settings should be determined to guarantee that a reference setting is found in which the two plates are parallel. In order to achieve this, one of the micrometers is fixed and the other one is displaced, and the relative vertical displacement of the two surfaces is measured *via* the interferometer. This procedure results in a "V" shaped curve, the minimum of which indicates the setting where the two plates are parallel. By determining the reference micrometer settings, the desired slope between the two plates can be implemented. The "V" shaped curve used in obtaining a parallel configuration of the two surfaces is shown in Figure 6.

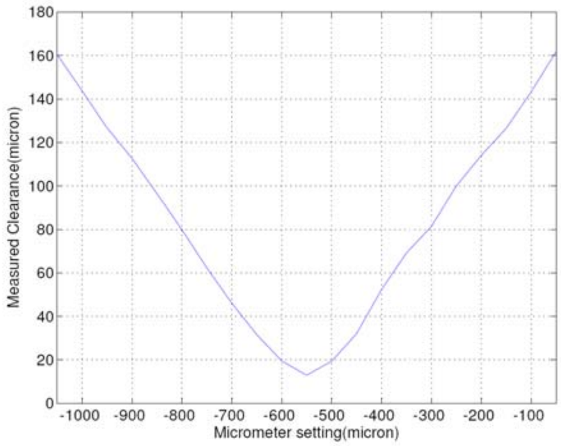
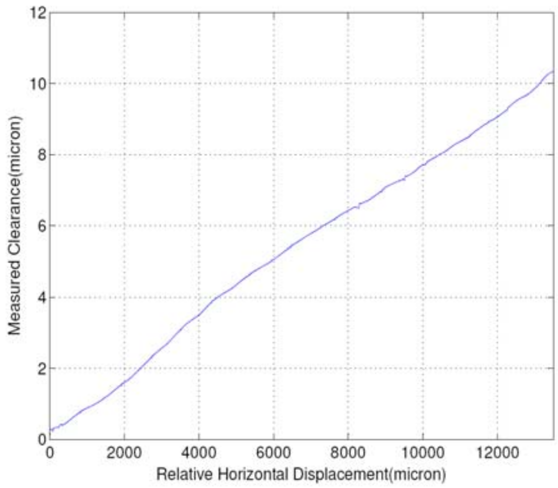
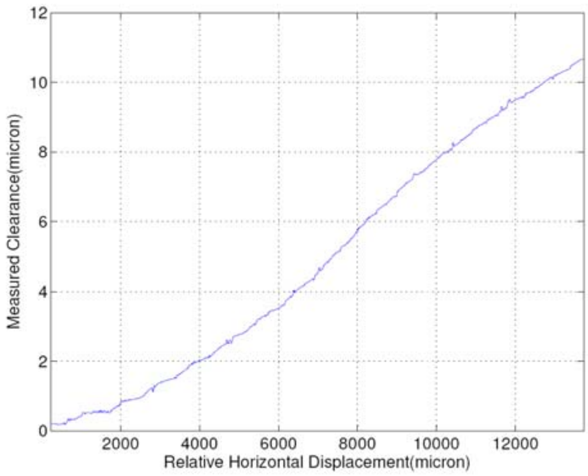


Figure 6. Parallelism of the two surfaces

In this case the parallelism of the two surfaces is achieved by setting the micrometer at –550 micrometers.



(a)



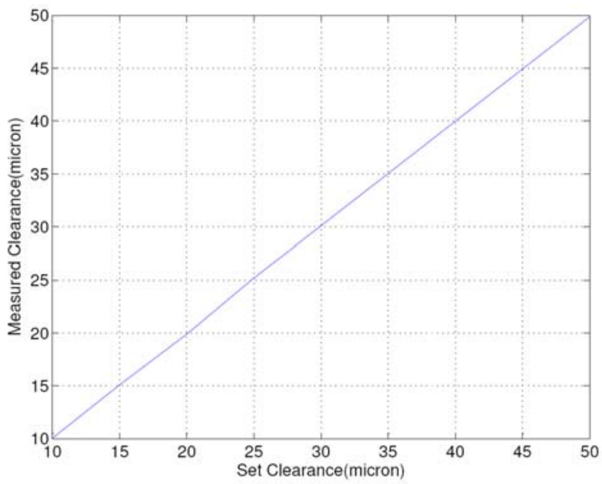
(b)

Figure 7. Measured clearance in (a) air, (b) lubricant

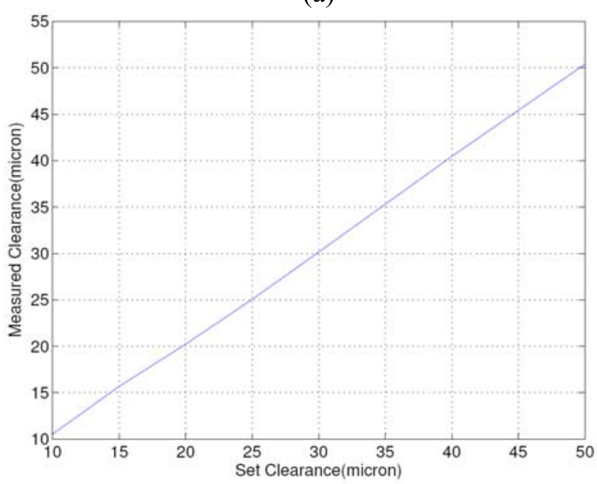
A set of experiments were conducted with air and a lubricant whose refractive index is 1.484764 at 25°C with different height differences between the two ends of the reflective surface. The measured clearance vs. relative horizontal displacement graphs for air and lubricant are shown in Figures 7a, 7b, respectively, when height difference between the two ends of gold coated reflective surface (h2-h1) is 10 micrometers and the horizontal motion 13.5 mm.

In this experiment, a clearance difference of approximately 10 micrometers was set between a 13.5 mm span of the gold plated lower surface using the micrometers. Figures 7a and 7b show that the results obtained both in air and oil accurately measure this clearance difference as 10.1 to 10.2 micrometers, in air and in oil, respectively. The variation of the surface along the 13.5 mm surface, however, differs in the two cases, since different sections of the surface are traced in oil and air. The figures, therefore, depict the surface profile, and the effect of the mechanism used in moving the plate, as well as the clearance.

These experiments are repeated for a clearance difference (Δh) of 10, 15, 20, 25, 30, 40 and 50 micrometers and the results for set and the measured clearance differences between the two ends of reflective surface for air and lubricant are shown in Figure 8a and 8b, respectively.



(a)



(b)

Figure 8. (a) Air, (b) Lubricant

3. CONCLUSION

In this study the feasibility of using a fiber optic interferometer to measure the clearance in a simulated piston-cylinder assembly is assessed. It is concluded that set values of clearances can be accurately measured in the 10-50 micron range for in horizontal displacement of 13.5 mm. In the current study when the difference in clearance over a horizontal displacement of 13.5 mm is 10 micrometers, the effect of the surface profile and imperfections of the motion mechanism reflect in the measurements.

4. ACKNOWLEDGEMENTS

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