MULTICHANNEL OPTICAL SENSOR FOR OIL FILM PRESSURE MEASUREMENT IN ENGINE MAIN BEARING

H. RONKAINEN, A. HOKKANEN, M. KAPULAINEN, I. STUNS, S. VARJUS, R. TURUNEN, S. NYYSSÖNEN, J. HALME

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland, helena.ronkainen@vtt.fi

ABSTRACT

An optical sensor has been developed for experimental determination of oil film pressure in journal bearings. The non-intrusive fibre optic sensor is integrated in the sliding surface of the bearing to measure the actual oil film pressure under load without disturbing the actual tribological contact conditions. The sensors with a multichannel system also allowed the use of several optical sensors simultaneously.

Four optical sensors were integrated in a hydrodynamic journal bearing of a large scale diesel engine and the engine tests were carried out with different loads to study the sensor operation in demanding operating conditions. The oil film pressure was successfully measured and the results showed differences in bearing pressure depending on the position of the sensor and on the operating cycle of the cylinders. The optical sensor was capable to measure the oil film pressure in journal bearing with a good sensitivity and repeatability during the tests.

INTRODUCTION

Journal bearings are used in various applications, such as combustion engines, compressors, turbo-machines, power generating units and gear boxes. The operation of the journal bearings is dependent on the load-carrying hydrodynamic film generated in the bearing and the oil film pressure is one of the functional parameters in journal bearing operation [1, 2]. The determination of the oil film pressure in the journal bearing is typically carried out with numerical calculations based on Reynolds equations [3, 4, 5] and several commercial computer programs have been generated to simulate the operational conditions in the bearings in order to assist the design of the bearing systems for practical applications.

The experimental determination of the hydrodynamic pressure in journal bearings has been typically based on the use of intrusive pressure sensors. The piezoresistive and capacitive sensors are typically mounted in a hole drilled through the journal bearing surface. This approach was adopted for example by Kawase et al. [6] and Natsumeda et al. [7] that used the semiconductor pressure transducers for oil film pressure measurements in a bearing test rig. Since it is difficult to level the sensor with the surface, a cavity is easily created in the bearing surface that can change the oil flow and disturb the contact conditions. The use of intrusive sensors in practical applications is difficult also because of the reliability aspects of pressure sensors.

In order to measure the oil film pressure in the sliding contact, Mihara et al [8, 9, 10] have developed thin films sensors. The sensors consist of a layered structure with insulating layers covering the pressure sensitive material. The sensors have been used successfully for oil film pressure measurements in engine tests to verify the evolution of lubricant film pressure during engine operation.

An optical method for determination of oil film pressure in a journal bearing was developed at VTT. The basic principle of the sensor has been described in earlier publications [11, 12, 13]. In this study the operation of the optical sensor has been verified for oil film pressure measurement in diesel engine tests. The optical fibre technique provides benefits, such as insensitivity to electromagnetic disturbances and capability to transmit the information long distances even from difficult operational circumstances without electrical wiring.

EXPERIMENTAL

The optical sensor system consisted of a fibre optic sensor and a specific non-intrusive cavity structure machined in the bearing. The fibre optic sensor was mounted in the cavity. The cavity formed a measurement membrane that was deflected under the oil film pressure. The fibre optic sensor itself consisted of two optical fibres, one to illuminate the measurement membrane and the other to collect the reflected light. The intensity of the reflected light was changed according to the deflection of the measurement membrane and was detected and converted to pressure data by using the calibration data acquired by a specific calibration procedure. More detailed description of the sensor can be found in earlier publications [12, 13].

Four fibre optic sensors were integrated in a main bearing of the crankshaft in VTT's diesel engine (W32). The bearing diameter was 300 mm, width 124 mm and thickness 7.4 mm. The bearing was a tri-metal bearing consisting of lead bronze (0.4 mm), tin alloy overlay (0.045 mm) and a tin flash (0.008 mm) on a steel shell. The cavity structure was designed by using 3D FE modelling. Abaqus 6.8-2 software with parabolic elements (C3D19) was used to generate a symmetric 3D model of the cavity system. Simulations were carried out in order to study the stresses and strains generated in the structure and in order to determine the optimum operational dimensions for the sensor.

The cavity structures were machined in the bearing and the dimensions were checked by microscopy and by replica analyses. Four sensors were mounted in the bearing and fastened with riveting joints. After mounting the sensors the calibration was carried out with a specific calibration unit in the pressure range of 0 to 500 bar (0 to 50 MPa). The calibration showed linear behaviour of the sensors with good sensitivity. The sensors were mounted in the main bearing between the cylinders 1 and 2. They were positioned 23 mm aside from the center line of the bearing, two sensors on the area of high load and two sensors on the area of lower load behind the loaded area. Figure 1(a) shows the positions of the four sensors in the main bearing and Figure 1(b) presents the sensors mounted in the bearing as the bearing was assembled in the bearing.

The test engine was a large scale diesel engine Wärtsilä Vasa 4R32 LN E with four cylinders, maximum power of 1640 kW and rotating speed on 750 rpm. The cylinder diameter was 320 mm and the piston stroke 350 mm. During the tests a light fuel oil was used as fuel and the engine was lubricated with marine diesel oil. In the beginning of the test the engine was run with the full load to warm up the engine and to stabilize the temperatures. The measurement were carried out in stabilized conditions with load of 100 %, 75 %, 50 %, 25 %, 10 % and 0 %.

RESULTS AND DISCUSSION

The motor tests were carried out with different loads from 0 to 100 % of the maximum engine load which was 1640 W to study the sensor operation in real operating conditions. The oil film pressure was successfully measured and the results showed differences in bearing pressure depending on the position of the sensor and on the operating cycle of the cylinders. The pressure peaks of all four cylinder work cycles could be identified in the measured pressure curves and the pressure variations within the pressure curves fit well to the diesel engine’s work cycle.

The oil film pressure was measured with all four sensors. The pressure values are presented as mean values of 100 cam shaft angle rotations. Figure 2 presents the oil film pressure measured with sensors S1 and S2 that are situated on the area of higher contact load. The work cycles of the four cylinders are also marked in the Figure. As can be seen the highest pressure was measured during the work cycle of cylinders 1 and 2 since they are the closest ones. The highest pressure values were in the range of 550 to 600 bar (55 to 60 MPa). The position of the sensors had an effect of the pressure level, since the sensor located closer to the cylinder under work cycle experienced higher load as can be noticed for sensor S1 during the work cycle of cylinder 1 and for the sensor S2 during the work cycle of cylinder 2.

Figure 3 presents the pressure values measured by sensors S3 and S4. These sensors were mounted in the area of lower load and the oil film pressure measured with these sensors was thus lower compared to the previous ones showing maximum values in the range 300 to 400 bar (30 to 40 MPa). Also in this case the pressure was higher during the work cycle of cylinder 1 for the sensor S3 positioned near cylinder 1 and in a similar way during the work cycled of cylinder 2 for the sensor S4 positioned near the cylinder 2.

The oil film pressure fluctuation with different loads is presented in Figure 4 for sensor S1. The pressure increased as the engine load was increased but even in 0% load conditions oil film pressure was generated in the bearing.

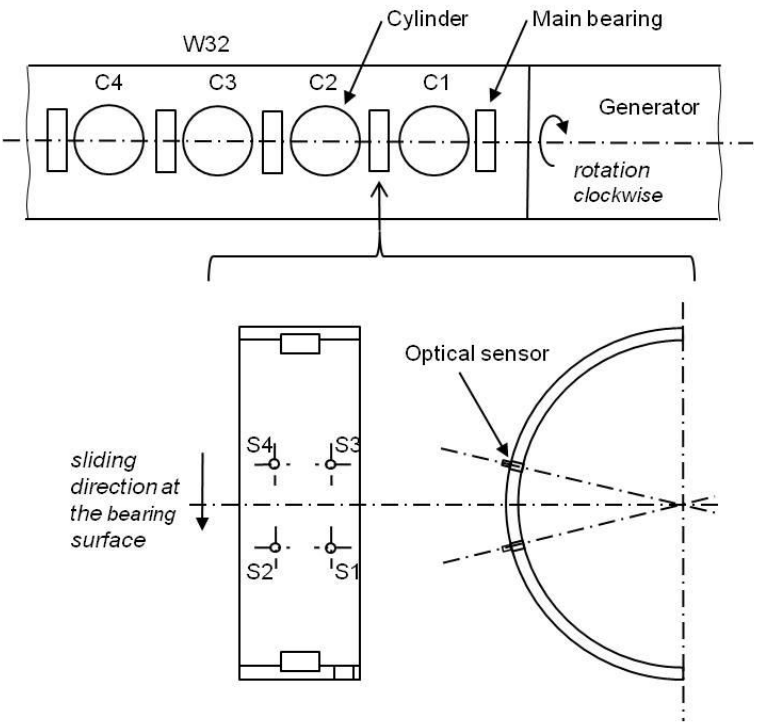
The optical sensors were capable to measure the oil film pressure in journal bearing with a good repeatability during the tests which could be observed by comparing the results from repeated measurements and by studying the scatter of the results. The dynamic measurement accuracy was in one bar range and the absolute pressure accuracy was in the tens of bars range. In the future studies the repeatability of the sensors will be further evaluated by carrying out repeatability tests after several month of engine operation.

The valid sensitivity of the optical sensor was more difficult to evaluate due to the lack of reference measurements. The static calculation models available were used for the rough estimation of the oil film pressure. The comparisons between responses from these models and the optical sensors gave results having resemblance, but the calculated values presented clearly higher maximum values compared to measured ones. The difference between calculated and measured values was expected to be arising from the dynamics of the system, which the static models were not valid to estimate.

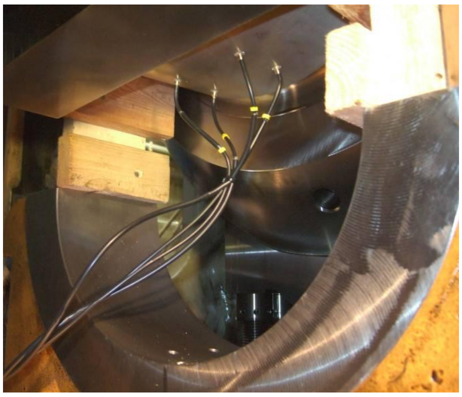
The present design of the optical sensor is suitable for laboratory use, since the integration of the sensor into the component structure requires accurate machining and installation work to be carried out. Therefore the design needs to be modified to facilitate easy assembly and calibration of the sensor in order to use the sensor widely in industrial applications for monitoring purposes.

CONCLUSION

Four optical sensors were integrated in the main bearing of a diesel engine and the engine tests were carried out with different loads to study the sensor operation in real operating conditions. The results showed that the optical fiber sensors were successfully integrated with riveting joints and they had sufficient sensitivity to measure the oil film pressure in main bearing of a large scale diesel engine. The dynamic measurement accuracy was in one bar range and the absolute pressure accuracy was in the tens of bars range. The oil film pressure measured showed that the pressure peaks identified all four cylinder work cycles and the pressure variations within the pressure curves fit well to the diesel engine's work cycle. The highest pressure values were in the range of 550 to 600 bar (55 to 60 MPa). This fiber optic pressure measurement system for journal bearings fits very well for laboratory use and can be used e.g. in the engine development work.



(a)



(b)

Figure 1. (a) The positions of the four fibre optic sensors in the engine main bearing. (b) Four sensors mounted in the main bearing.

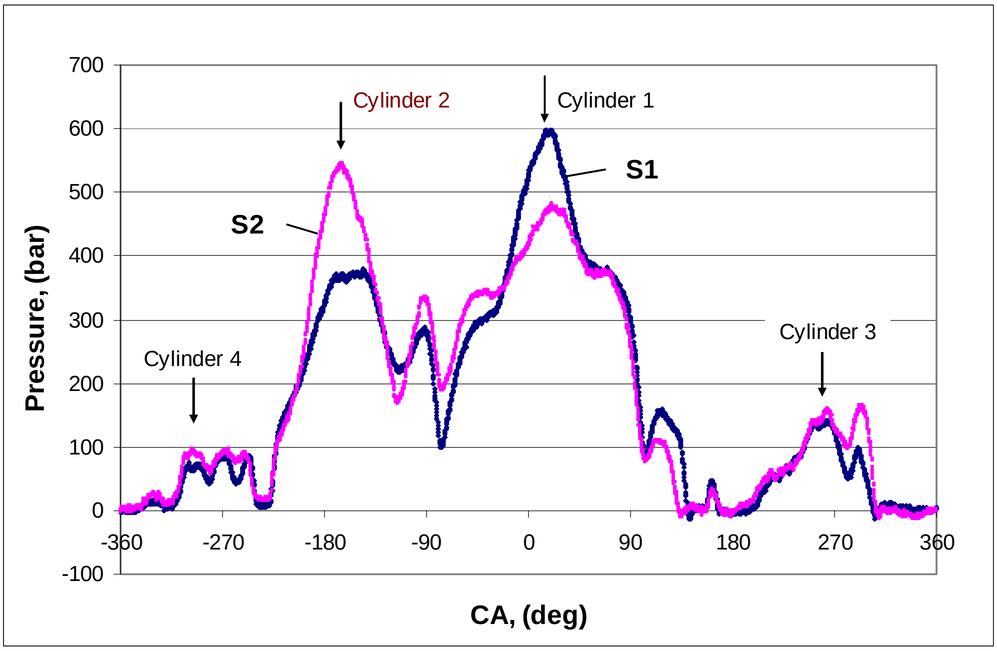


Figure 2. The oil film pressure in a diesel engine main bearing measured with integrated fibre optic sensors S1 and S2. The values are presented as average values of 100 CA´s. The tests were carried out with 100 % load and cylinder work cycles are marked in the picture. The main bearing temperature during the measurements was 80.7 °C and the lubricant oil temperature before the engine 65 °C.

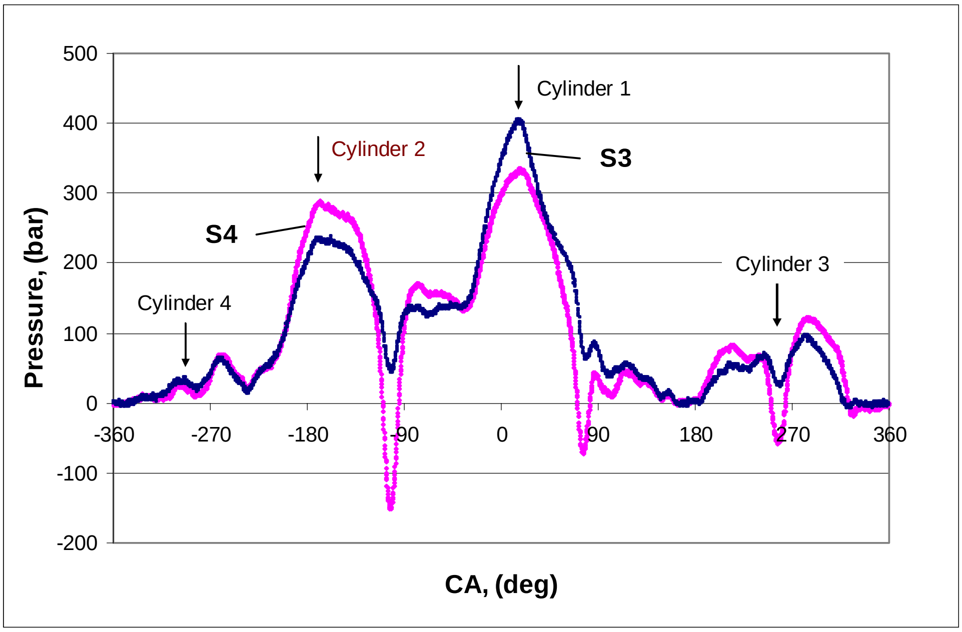


Figure 3. The oil film pressure in a diesel engine main bearing measured with integrated fibre optic sensors S3 and S4. The values are presented as average values of 100 CA´s. The tests were carried out with 100 % load and cylinder work cycles are marked in the picture. The main bearing temperature during the measurements was 78.5 °C and the lubricant oil temperature before the engine 63 °C.

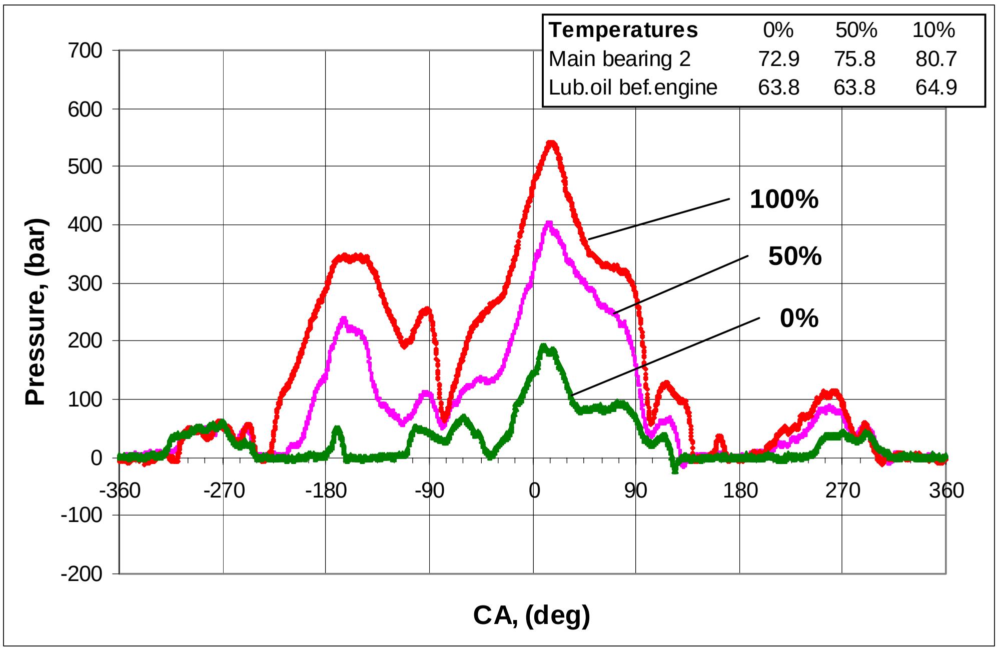


Figure 4. The oil film pressure in a diesel engine main bearing measured with integrated fibre optic sensor S1with loads 0, 50 and 100% of the maximum load. The values are presented as average values of 100 CA´s. The main bearing temperatures and the lubricant oil temperature before the engine are shown in the picture.

REFERENCES

1. B. Bhushan, Introduction to Tribology. USA: John Wiley & Sons, Inc., 2002.

2. D.E. Brewe, Slider Bearings. In: B. Bhushan (Ed.). Modern Tribology Handbook, Vol 2. USA: CRC Press, 2001. p. 969-1039.

3. J. Frêne, D. Nicolas, B. Degueurce, D. Berthe, M. Godet. Hydrodynamic Lubrication, Bearings and Thrust Bearings. Amsterdam, Elsevier, 2005.

4. S. Bukovnik, N. Dörr, V. Caika, W. Bartz, B. Loibnegger. Analysis of diverse simulation models for combustion engine journal bearings and the influence of oil condition, Tribology International, 39 (2006) 820-826.

5. N.J.A. Moreno, H.F.C. Gomez de Leon, F. Alhama. Solution of temperature fields in hydrodynamic bearings by the numerical network method. Tribology International 40 (2007) 139-145.

6. T. Kawase, T. Someya. An investigation into the oil film pressure distribution in dynamically loaded journal bearings. Proc. 4th European Trib. Cong, 2, pp. 1-10.

7. T. Natsumeda, T. Someya. Negative pressure in statically and dynamically loaded journal bearings. Proc. of 13th Leeds-Lyon Symposium on Tribology, pp. 65-72.

8. Y. Mihara, T. Hayashi, M. Nakamura, T. Someya. Development of maesuring method for oil film pressure of engine main bearing by thin fil sensor. JSAE Review 1995; 16: 125-130.

9. Y. Mihara, M. Kajiwara, T. Fukamatsu, T. Someya. Study on the measurement of oil-film pressure of engine main bearing by thin-film sensor – The influence of bearing deformation on pressure sensor output under engine operation. JSAE Review 1996; 17: 281-286.

10. T. Someya, Y. Mihara. New thin-film sensors for engine bearings. Proceedings of the CIMAC Congress, 2004. Paper no. 91.

11. H. Ronkainen, A. Hokkanen, M. Kapulainen, A. Lehto, J. Martikainen, I. Stuns, A. Valkonen, S. Varjus, J. Virtanen. Optical sensor for oil film pressure measurement in journal bearings. In the Proceedings of NordTrib 2008. 13th Nordic Symposium on Tribology. 10-13.6.2008 Tampere, Finland. 12 p.

12. H. Ronkainen, A. Valkonen, M. Kapulainen, S. Varjus, A. Hokkanen, I. Stuns, J. Virtanen, J. Martikainen. Embedded optical sensor for oil film pressure measurements in journal bearings. Proceedings of the ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, SMASIS2008, 1, 607-613.

13. H. Ronkainen, A. Valkonen, S. Varjus,, M. Kapulainen, I. Stuns, A. Hokkanen, J. Virtanen, A. Lehto, J. Martikainen. Optical sensor for journal bearing oil film pressure measurements. Tribologia 28 no 3-4 (2009) 3-15.