# Dynamic strain measurement in a ball bearing

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**Abstract** Knowledge of the remaining life of gearbox bearings, allows the operator to schedule the maintenance cost of machinery effectively. It is therefore essential to equip bearings with quantitative health monitoring systems, which to-date has not been possible due to the absence of a cheap and readily available technique. The aim of this research was to measure the dynamic contact strain in a bearing by stroboscopic energy dispersive X-ray diffraction (EDXD) to independently validate a recently developed acousto-elastic strain measurement technique. To this end a narrow ball bearing (approximately 13 mm thick) was mounted in a bearing test and stroboscopic energy dispersive X-ray diffraction was used to measure the contact strain between the outer race and the balls while the bearing was rotating at 150RPM. The work was done at the I12 Beamline, Diamond light source.

**Introduction** Machines that transmit load and power require tribological machine elements such as rolling element bearings, which have two bodies that transmit load and motion through contact. Bearings typically fail by rolling contact fatigue, with factors such as overload in the form of plastic deformation, impact damage or buckling acting as accelerants. One particular example is the shaft bearings in a wind turbine. The load path, from the blades through the gearbox to the shaft, is complex and highly transient. Simple measurements of torque on the rotor shafts cannot effectively be used to determine the load history in the bearings. This makes it difficult to determine the load on the bearings, and to identify whether overload, which governs the residual life of the rolling bearing [1], has occurred. Further, the load applied to the bearing is not uniformly distributed on each of the rolling elements. The load applied to the whole bearing therefore does not indicate a priori the stress exhibited on the individual rolling elements or raceways. A novel characterisation method, based on the acousto-elastic properties of the rotating machinery, has recently been developed that allows the load on the contact in a tribological machine element to be determined. The method comprises the generation of an ultrasonic pulse or wave in the machine element, and propagation of that wave or pulse through the element to the contact. By measuring the change in acoustic wave or pulse time of flight, the dynamic deflection of the bearing's outer ring (i.e. its average strain) is measured.

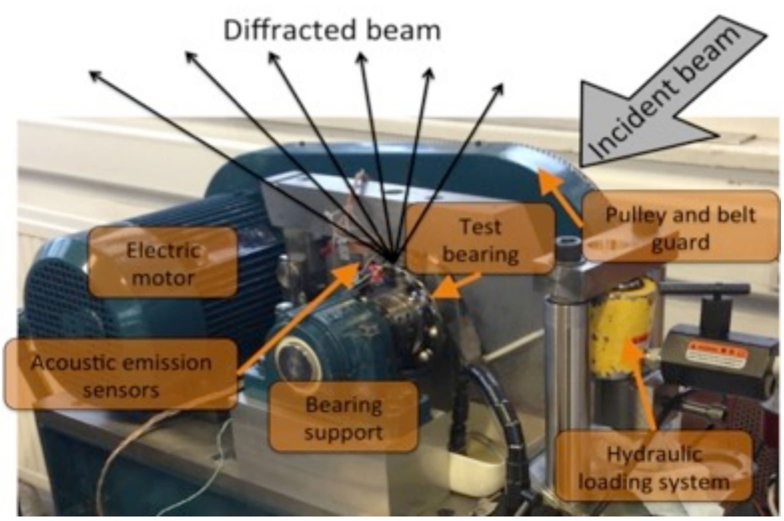
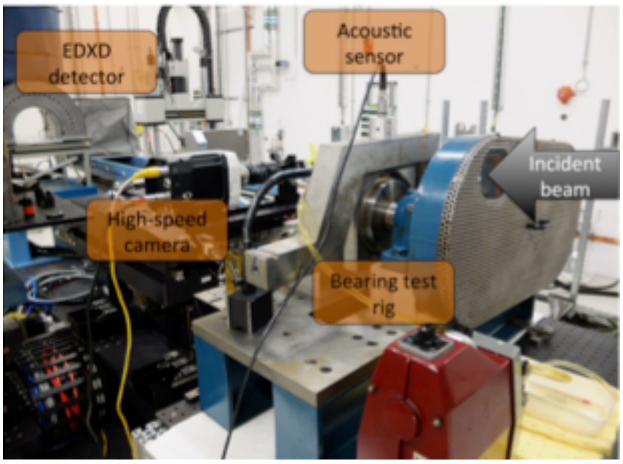


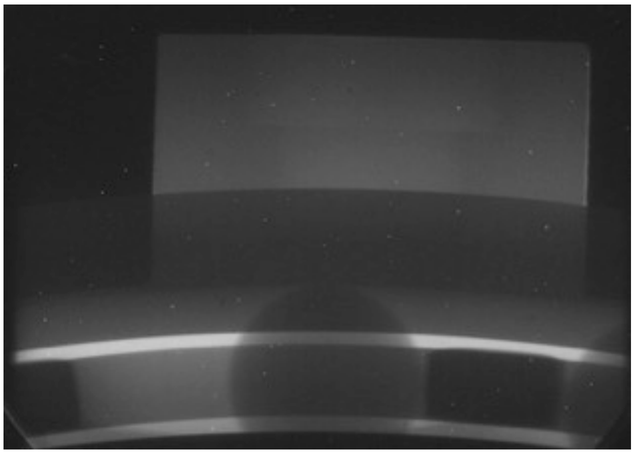
Figure 1 – Bearing test rig

Recent developments in synchrotron X-ray instruments, such as Beamline I12 at Diamond Light Source, offer high energy and flux X-ray diffraction data and imaging of engineering components and materials under realistic conditions. The beamline's X-ray detectors permit fast, time resolved acquisition of polycrystalline diffraction patterns along different diffraction vectors, enabling the measurement of dynamic elastic strains within bearing raceways while the bearing is rotating. Stroboscopic Energy Dispersive X-ray Diffraction (EDXD) was used in this research to validate the acousto-elastic measurement. The key objective of the experiment was to measure the average dynamic strain field in the outer ring of a bearing with both techniques, while rotating the bearing at 150 RPM. The University of Sheffield's bearing test rig (see Fig. 1) was installed onto the Experiment Hutch 2 of the I12 Beamline. It should be noted that although the two techniques are used together in this work, they are complimentary and one cannot replace the other. The acousto-elastic technique is cheap, practical and can provide the engineers with an overall level of strain in the raceway while the EDXD method is highly accurate with high spatial resolution that is more appropriate for fundamental studies.

**Methodology** The experimental setup can be seen in Fig. 2a. As shown, an ultra-slim ball bearing with 0.5 inch thickness raceway (REALI-SLIM, KD047CP0) was used to allow for approximately 10% X-ray transmission. The axis of bearing rotation was aligned parallel to the direction of the incident X-ray beam.




(a)



(b)

Figure 2 – (a) Experimental setup in the I12 beamline, DLS. (b) Single frame from high-speed x-ray radiography, part of the ball in the outer raceway can be seen

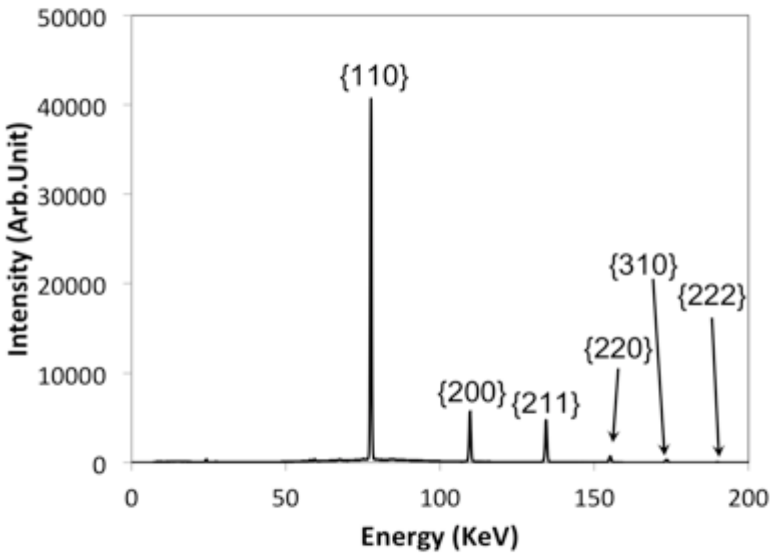



Figure 3 –Example of diffraction data

Precise alignment of the bearing with the X-ray beam was confirmed using a high-speed X-ray imaging camera (See Fig 2b). Strain measurements in the outer ring of the bearing were performed using energy dispersive X-ray diffraction (EDXD) in stroboscopic mode [2]. In stroboscopic mode, the X-ray data acquisition is gated, so that data is only collected in a time interval determined by a trigger signal from the experimental equipment. In our case, a Hall sensor on the bearing rig was used to generate the gating signal, so that X-ray data was collected only when one ball of the bearing was directly below the X-ray measurement point, and hence at the position of peak strain. The beamline signal processing equipment was used to specify the gate pulse width and phase lag. Correct setting of the lag was determined by high speed X-ray imaging, which was subsequently used to optimise the precise position of the diffraction information. X-ray collimators were used to define a gauge volume within the sample. For an incident beam size of 0.25 x 0.25 mm$^2$, 150 μm collimator and 200 μm detector entrance window slits were used, giving a gauge volume length along the beam was 6.4 mm [3]. Four different loading conditions were considered and diffraction patters were collected (see Fig. 3) as well as acousto-elastic measurement. The strains measured by the two techniques will be compared to estimate the accuracy of the acousto-elastic measurements. An example of the radial X-ray diffraction data is given in Fig. 3 which can be used to measure the strain.

**Conclusion** Stroboscopic Energy Dispersive X-ray Diffraction was successfully used at Diamond Light Source's I12 beamline to measure dynamic elastic strains within the outer raceway of a ball bearing, in-situ, rotating at 150 RPM. The data will be used to validate a novel acousto-elastic technique.

**References**

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