Guidance - Crankcase Bearing Testing

Plain journal bearings cover a wide variety of different devices, ranging from standard dry and lubricated bulk material bearings, to dynamically loaded coated bearings, as used in engine crank cases. It is sensible to treat the latter as a special case.

Crankcase bearings operate lubricated with oil and are invariably subjected to high-speed dynamic loading. Further to this, during stop/start cycles the bearings are subjected to a range of different lubrication regimes, ranging from boundary, at start up, to (hopefully) fully hydrodynamic during steady state operation. Protection under boundary lubrication must be provided by a combination of materials and lubricant additives, but during hydrodynamic lubrication, through lubricant bulk properties (viscosity).

Current key issues with crankcase bearings are associated with:

1. The move from softer coatings (lead) to harder materials (tin).
2. The on-going reduction in lubricant viscosity, hence hydrodynamic film thickness.

The kinds of wear and failure mechanisms endured by crankcase bearings include:

Adhesive Wear

This occurs under boundary lubrication, in other words, during stop/start cycles. Journal bearing tests, involving stop/start cycles, thus make sense.

Scuffing Resistance

This is essentially failure, following the onset of adhesive wear. It is caused by thermal or mechanical overload during stop/start cycles.

Conformability

This is a measure of the ability of the bearing shell to conform to the housing and shaft.

Embeddability

This is a measure of the ability of the bearing to resist damage from entrained particles in the lubricant. These particles can either be those generated within the engine (from ingested hard particles) or, more seriously, residual particles generated during the manufacturing process.

Fatigue Strength

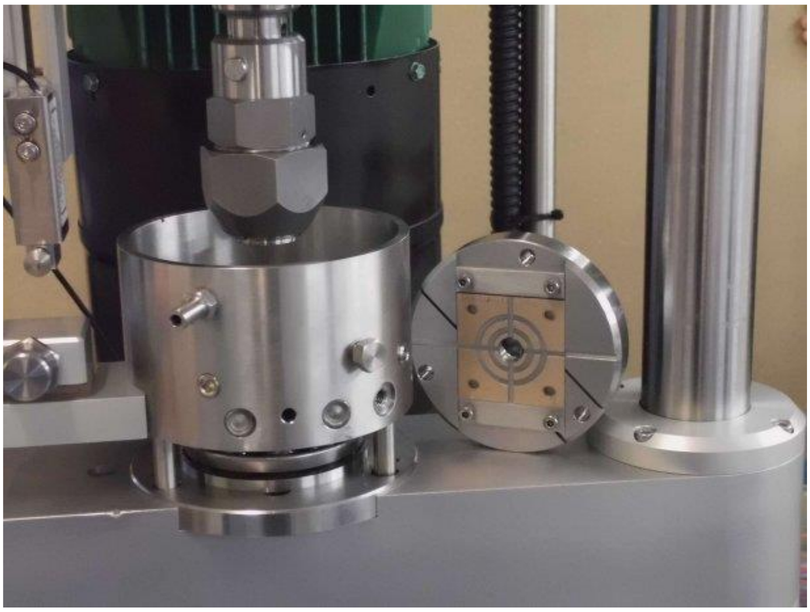
This is a measure of the de-lamination life of the soft metal coating, caused by cyclic loading.

Adhesive Friction, Wear and Scuffing Tests

Suzuki Test

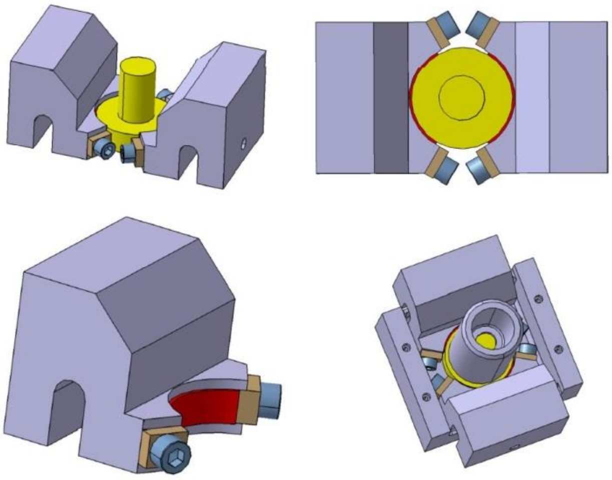
The Suzuki test is a modified version of the standard thrust washer test geometry, using a coated plate as the candidate sample. It is used for friction, wear and scuffing tests.

The plate is machined with radial grooves, to facilitate lubricant entrainment. The lubricant is fed to the centre of the assembly and flows radially outwards. In addition to measuring friction and sometimes wear, the difference in lubricant inlet and outlet temperature is a useful measure.



Half-Journal Test Geometry

This is a more complicated arrangement than the Suzuki thrust washer set-up and can be used for experiments using samples manufactured from actual bearing shells.



This arrangement can be used for:

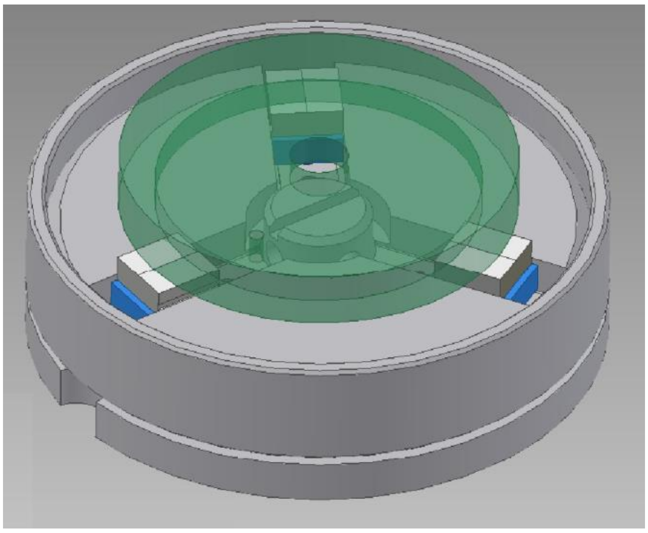
Friction running under boundary and mixed lubrication

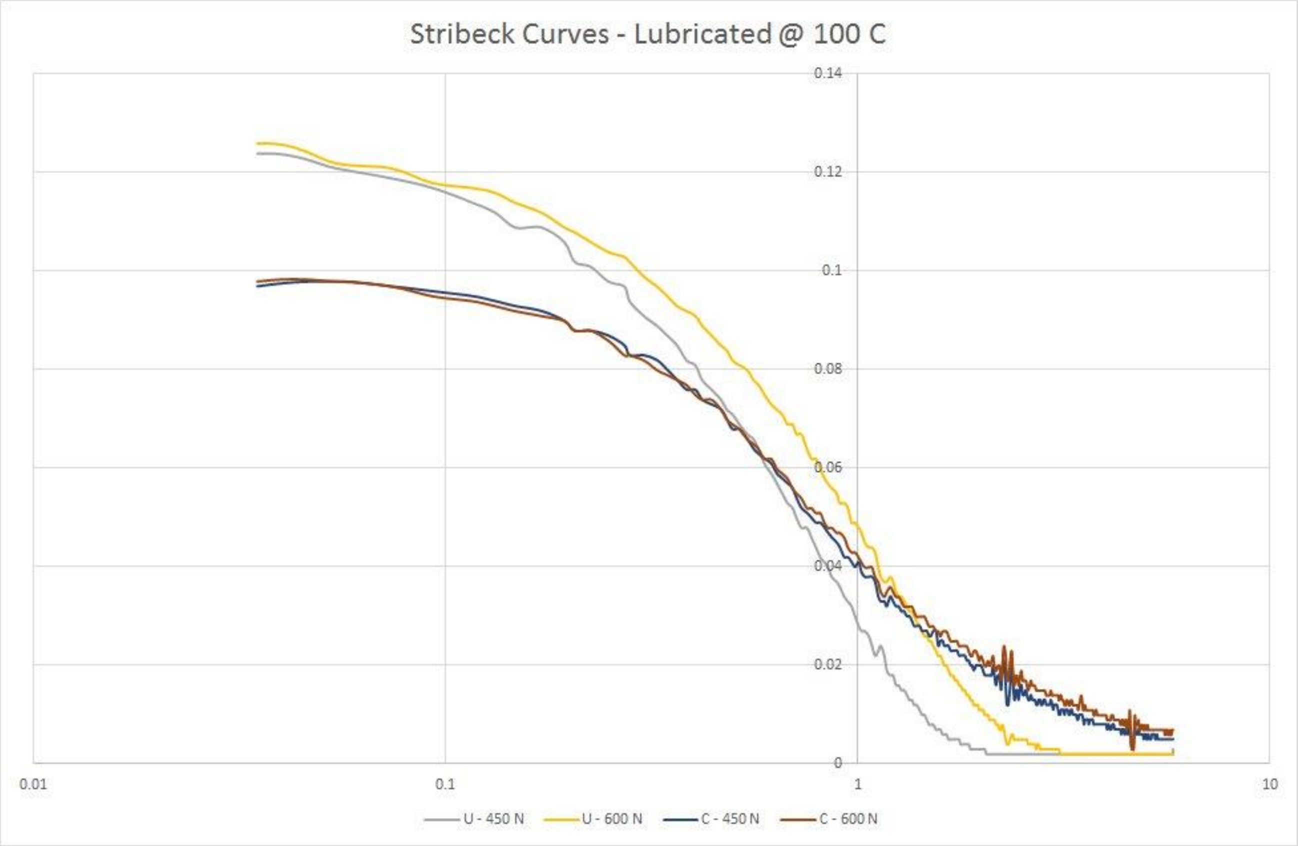
Adhesive wear

Scuffing tests

Despite the potential for rotating at high speeds, **this geometry cannot be used for tests under hydrodynamic regimes**, because it is not possible to duplicate the necessary lubricant entrainment conditions associated with a full journal bearing. The bearing inlet tends to close over resulting in starved lubrication.

Boundary to Hydrodynamic - Taper/Flat Pad Bearing

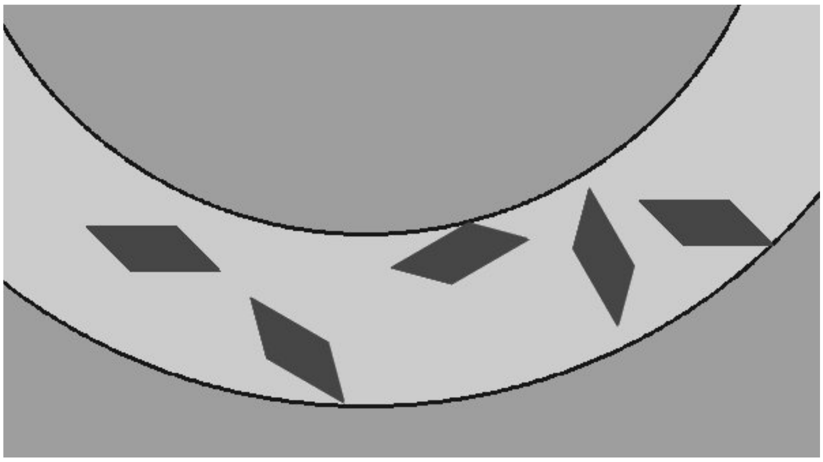




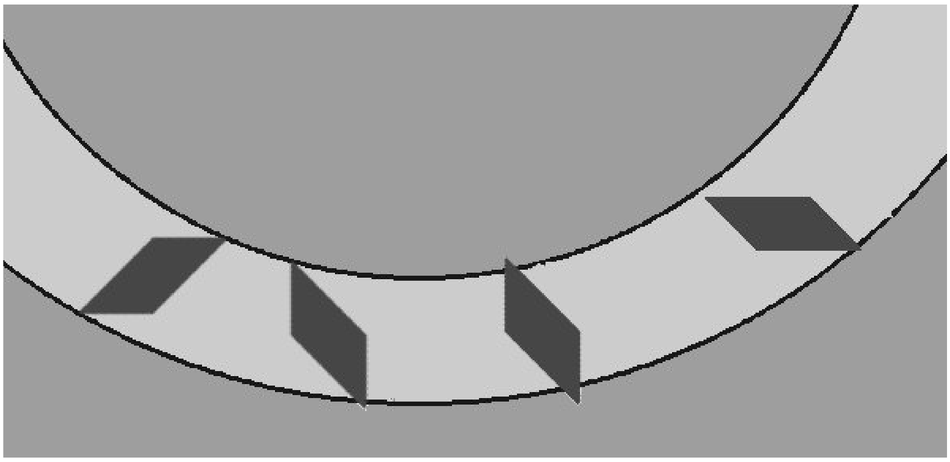
Embeddability

Journal bearings, except during start up, are essentially designed to operate with comparatively thick lubricant films between the loaded surfaces. Transit of particulate contaminants through the bearing gap can give rise to different wear mechanisms, each producing different wear rates.

When the size/gap ratio is small, worn surfaces may consist of a large number of small pits and indentations, usually with no obvious orientation in the direction of relative sliding, indicating either free movement of the particles through the fluid film and subsequent impact with the surfaces or the rolling of the lightly loaded particles through the contact. In both cases, the actual load on the bearing is of no relevance other than as a mechanism for setting the bearing gap. This mechanism, perhaps similar in nature to conventional polishing wear, has been termed “tumbling” wear. With polishing wear, we would expect the free particles to roll through the tribo-contact in continuous contact with both sides. The term tumbling is used to describe the situation in which particles are not in continuous contact with both surfaces but are free to tumble through the bearing gap.



Above a certain size/gap ratio, the particles are no longer free to roll through the contact, instead being dragged through, generating grooving wear. As with the pitting wear mechanism, the actual load on the bearing is of no relevance other than as a mechanism for setting the bearing gap. It will be apparent that the load on a particle will be a function of the size/gap ratio, the relative hardness of the particle and the bearing surfaces and the number of particles sharing the load. It is not a function of the load on the bearing itself.



For surfaces of similar hardness, grooving wear may occur on both surfaces of the tribo-contact. For surfaces of different hardness, there are two possible mechanisms that may not be mutually exclusive. If the surface roughness of the harder surface is sufficiently large, particles may become trapped by asperities and be dragged through the contact producing grooving or micro-machining wear of the softer surface. However, increasing the hardness ratio between the two surfaces may cause hard particle to become embedded in the softer surface, resulting in more severe grooving wear on the hard surface.

The critical parameters for an adequate test model are therefore:

- A test configuration that allows precise control of the bearing gap
- A means of introducing abradant particles of carefully controlled shape and size into the contact

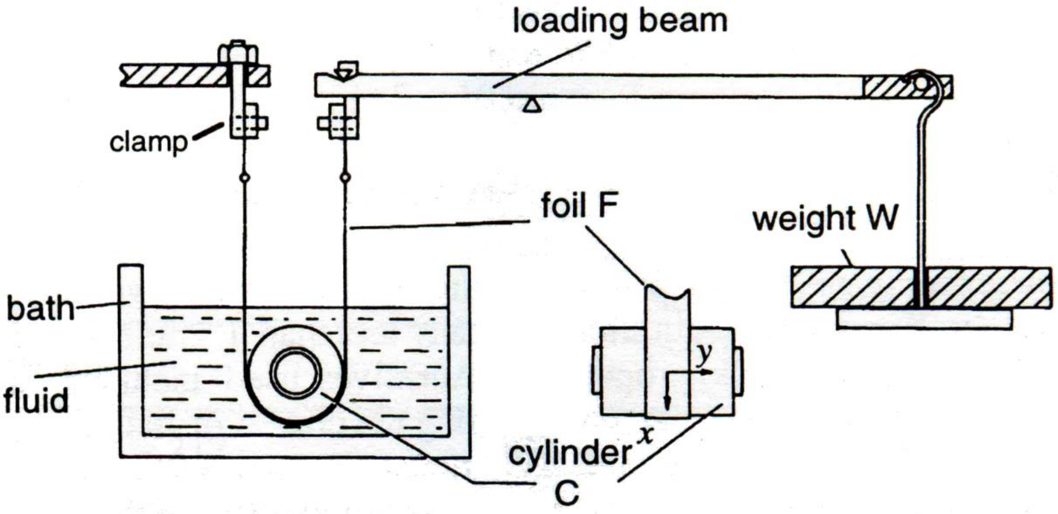
It will be noted that load (either static or dynamic) is not considered of importance except in as much as it may provide a mechanism for setting the bearing gap.

Possible Test Systems

The key challenge is the injection of particles in a controlled fashion into the test bearing. As with any tests involving abrasive particles, there are uncertainties associated with how long the particles remain in the contact and avoid comminution.

Ideally, one would like to control the total mass, size and angularity of the particles passing through the contact. One way of achieving this is to machine a small pocket into the in-running side of the loaded bearing shell and insert a known quantity of well calibrated abrasive particles, held in place with a suitable wax.

As the bearing runs and heats up, the wax melts, releasing the particle into the contact.



The foil bearing arrangement provides easy control of the lubricant film thickness and a ready mechanism for introducing abradant into the lubricant.

A major advantage of this arrangement, other than its simplicity, is that the film thickness, a key parameter in the experiment, is not affected by wear during the experiment or, unlike all other types of journal bearing rig, minor changes in diameter of the journal sample as manufactured.

By standardizing the film thickness and abrasive conditions, the rig can be used to compare abrasion resistance of different tribological pairs under both “tumbling” and “grooving” wear processes, or a combination of both.

By standardizing tribological pairs, the rig can be used to rank the abrasiveness of different of different particle contaminants.

Typical foil samples are made of steel foil typically no more than 50 microns thick and 10 mm wide, wrapped around a 25 mm journal. This could of course be scaled up with ease to match more closely the diameter of a crank-case bearing, but the affect of this increase in size is likely to be purely cosmetic.

This is of course not a classical journal bearing rig in the engineering sense but is a tribologist’s model system.

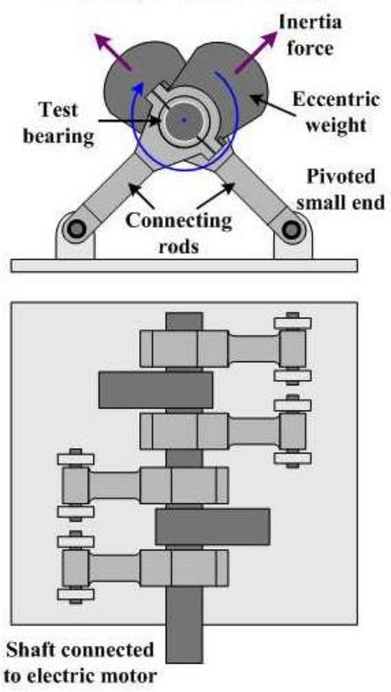
Fatigue Strength - Cyclic Load Test Rigs

These rigs can be divided into two basic categories:

- Machines Applying Pulsating Alternating Loads - Full Wave Load Cycle
- Machines Applying Pulsating Loads Between Zero and Maximum in one direction - Half Wave Load Cycle

Dynamic loads can be generated mechanically, hydraulically, servo-hydraulically and by resonance pulsator.

Underwood Machine



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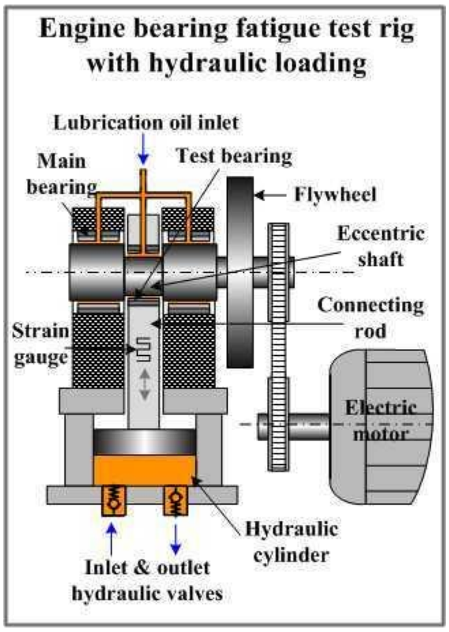
This machine, which is still used in various guises, involves out-of-balance masses generating a cyclic pulse on a test bearing. The bearing is loaded in both directions.

Sapphire Machine

1958 – “Sapphire” Machine (Glacier Metals – now Mahle):

This is a half-wave actuator machine. A journal bearing sample is mounted on an eccentric shaft with a connecting rod attached to the equivalent of a dashpot, making the equivalent of a badly pulsing pump. This is however an ideal and simple method of generating a pulsating load.



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Sapphire machines remain in service to this day with Mahle.

Pulsator Rigs

Puslator rigs are resonant frequency devices. An electromagnetic drive is used to excite a specimen assembly at its natural frequency, which, for a given system stiffness, is adjusted by varying the mass of the assembly. Although the dynamic load cannot be directly controlled in real-time, pulsators are a very reliable, energy efficient, but less flexible alternative to a servo-hydraulic actuator-based test system. Furthermore, pulsators tend to operate at much higher frequencies than servo-hydraulic systems.

Current suppliers of pulsators include ZwickRoell (Vibrophore) and SincoTec (Universal Resonance Pulsator)

Servo-hydraulic Dynamic Bearing Rigs

With either one or three actuators, depending on budget, these machines use high dynamic force servo actuators, usually fitted with multiple super high response Moog servo valves. We are aware of one single actuator rig, which cost more than Euro 750,000, some eight years ago. Because of the large number of Moog valves, servicing costs are significant, likewise running costs; this particular rig has a 150 kW hydraulic power pack!

To achieve the required performance, real-time adaptive control is required, which works well until the control algorithm fails to converge, in which case, the rig has the necessary power available to smash itself to pieces.

To understand the basic issues and costs, consider the price of a high dynamic force servo hydraulic test machine from, say, Instron or MTS, then build it into a bearing test rig.