

CALCULATION METHODS FOR STEADILY LOADED AXIAL GROOVE HYDRODYNAMIC JOURNAL BEARINGS. LOW VISCOSITY PROCESS FLUID LUBRICATION

1. INTRODUCTION

This Item extends the scope of Item No. 84031 (Derivation 4) to the design and analysis of bearings lubricated by process fluids. It is assumed that Item 84031 (Item 85028 may also be required) is available for use in conjunction with this Item which gives guidance more appropriate to low viscosity process fluids than the guidance for oils given in Item 84031.

The use of process fluid lubrication eliminates the requirements for a conventional lubrication system thereby offering design simplification and a reduction in the number of associated components such as seals. As a consequence maintenance is reduced and an overall cost reduction can be achieved. Process fluid lubrication is likely to be successful when speeds are high and/or loads are low. Process fluids are also used where a special environmental factor, such as high or low temperature, nuclear radiation, fire hazard, or risk of contamination rules out the use of an organic fluid.

The substitution of a process fluid for oil, however, makes the choice of materials more critical.

2. MATERIAL SELECTION

The selection of materials for process fluid lubricated bearings can present some problems not usually considered of great importance with oil lubricated bearings. Material selection may be more critical because of the environment in which the bearing operates and/or because of the nature of the process fluid.

Process fluid lubrication may have been chosen because a hostile environment ruled out the use of mineral oils and the materials used for the bearing must, of course, be suitable for this environment.

Sufficient data are not available to be able to predict accurately the fluid/material behaviour in process fluid lubricated bearings particularly where lubrication is poor. Such data as are available on material selection for a given fluid have been obtained largely by trial and error. Table 7.1 provides some guidance on materials normally used in process fluid lubrication. Derivations 5 and 6 give data on materials used for unlubricated applications and many of these materials give improved performance in the presence of a fluid.

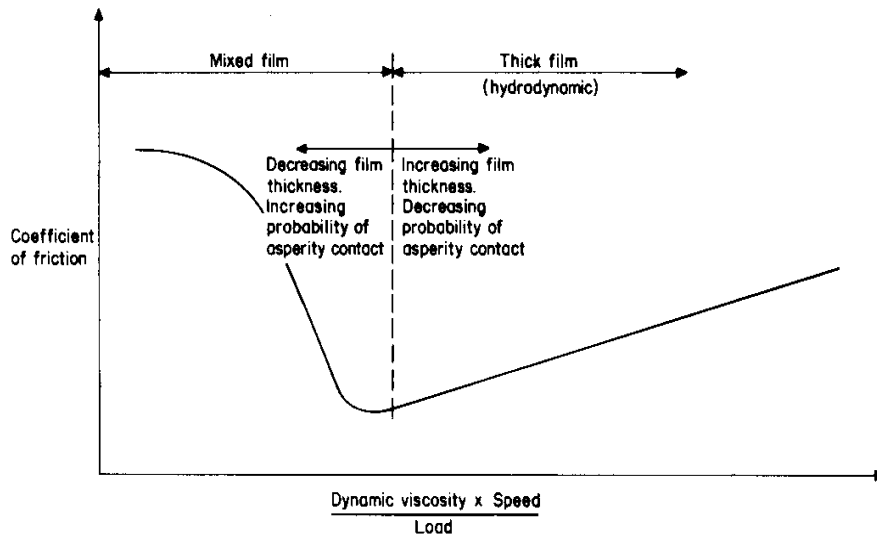
2.1 Compatibility between Bearing and Journal Materials

Oil lubricated bearings are usually designed to operate with relatively thick lubricating films exceeding about 20 times the surface $Ra^{\dagger}$ value of the journal (see Section 7.1 of Item 84031) and surface asperity contact only occurs briefly at start-up. With low viscosity process fluids, such as water, it is not always practicable to design the bearing to satisfy this minimum film thickness criterion and significant asperity contact may thus be inevitable. As a consequence it is essential to choose compatible materials for the journal and the bearing surfaces that can tolerate asperity contact without scoring.

Sketch 2.1 illustrates the increasing probability of asperity contact as viscosity and/or speed decreases and as load increases for a given bearing geometry. For typical initial journal and bearing surface roughnesses, asperity contact starts to become significant when the lubricating film thickness is less than about 10 times the surface Ra values (8 times the surface $R_q^{\ddagger}$ values).

[†] Ra is the roughness average of the surface (formerly known as centre-line-average, CLA).

[‡] R_q is the RMS (root mean square) roughness and for a typical surface is about 1.3 times the Ra value.



Sketch 2.1 Regimes of lubrication

With a combination of a hard journal surface and a relatively soft bearing surface, the softer material wears preferentially. This wear may continue until ultimate bearing failure unless the materials have, in addition, a running-in capability. Provided a sufficiently fine surface finish has been specified for the harder material, the softer surface will then polish and the wear rate will stabilise at a very low value. It should be noted that some materials exhibit high initial wear rates when running-in and the debris produced must be tolerated by the system.

The wear that occurs during the running-in process modifies the geometry of the bearing and can ease misalignment problems. However, where hard materials are used for both the journal and the bearing surfaces, running-in wear is only minimal. As a consequence, every effort should be made to minimise the bearing misalignment with hard-on-hard material combinations. In addition, a design clearance ratio should be chosen that maximises the lubricant film thickness and a fine surface finish should be specified for both the journal and the bearing.

Tables 7.1 and 7.2 give guidance on material combinations that, by experience, may be suitable.

2.2 Compatibility between Materials and Fluid

Many process fluids are chemically reactive or have other properties that render them hostile to certain materials.

The bearing materials should not, of course, be corroded or softened by the process fluid over the working range of temperatures and pressures. Bearing clearances may be increased by corrosion or may be decreased by the accumulation of corrosion products. The corrosion products may be abrasive or be otherwise undesirable in the system.

Certain materials, such as some plastics, are hygroscopic and swell in the presence of water. Other bearing materials rely on a thin surface coating of, for example, PTFE which may be destroyed or rendered ineffective by the fluid.

Where the viscosity of the fluid is low and/or the bearing speeds are high, some materials may be eroded by high flow velocities especially where abrasive particles are present.

2.3 Tolerance of Dirt Contamination

Process fluids are often heavily contaminated with abrasive particles and individual particles can damage the bearing and journal surfaces if they make solid bridging contact (see Reference 1).

Relatively soft bearing materials, able to embed dirt particles, in conjunction with hard journal surfaces may provide some tolerance to abrasive particles. However, where the degree of contamination is high, hard abrasion-resistant materials for both the journal and the bearing are often preferred but tolerance of misalignment may be compromised and it may be more difficult to ensure compatibility between the materials (see Section 2.1).

Filtration or some other form of dirt separation is sometimes used to protect the materials (see Section 3.1).

2.4 Thermal Expansion and Heat Dissipation

Many materials that might be used in process fluid lubricated bearings, particularly plastics, have higher coefficients of expansion and lower thermal conductivities than metals. Care should be taken that differential thermal expansion between the journal and the bearing or between the bearing and its housing does not adversely affect the bearing clearance or cause distortion. Care should also be taken to ensure adequate heat dissipation from the bearing surface (see Reference 2).

The coefficient of linear expansion and the thermal conductivity of some materials are given in Table 7.1. Further information can be found in Reference 3.

2.5 Maximum Service Temperature and Dimensional Stability

Under some operating conditions where the bearing temperature is high, plastic deformation of the bearing material may occur. In order to inhibit this, it is usual to limit the maximum bearing temperature, T_{max} . The maximum allowable bearing temperature depends on the yield strength/ temperature characteristics of the material used for the bearing surface. With lightly loaded bearings (see Section 4.1) the guidance on maximum service temperature for some materials given in Table 7.1 may be applied. Where the bearing carries a load greater than recommended in Section 4.1, the maximum allowable bearing temperature may be appreciably less than the values give in Table 7.1. Further guidance can be found in Reference 3.

The dimensional stability of the materials used should be considered. Some materials, such as certain plastics, have a tendency to distort over a period of time without the application of appreciable force. This distortion is accelerated by elevated temperatures but can usually be overcome by ensuring an adequate support for the bearing surface material.

2.6 Materials for Water Lubricated Bearings

Many bearing materials have been found to perform well in water. In general asbestos reinforced resin, filled or reinforced PTFE, nylon and carbon/graphite are the most suitable bearing materials particularly when used with a hard journal. Nitrided stainless steel, chromium plate, cobalt alloys, martensitic stainless steel, age-hardened stainless steel and cobalt/chromium/tungsten/molybdenum alloys have all been found to be suitable journal materials with water lubrication because of their ability to resist corrosion and wear.

In general, metal-on-metal combinations are to be avoided. Hard coatings such as chromium oxide and tungsten carbide have been found to be successful particularly when working against ceramics, carbides and other very hard materials. The combination of two very hard materials, however, is usually only practical in small sizes and where accurate shaft-bearing alignment can be maintained.

The performance of plastics such as nylon, phenolics and filled PTFE is poor at high speeds and loads where the excessive heat generated can melt or oxidise the plastic. Rubber is prone to harden at elevated temperatures and may cause abrasive wear of the shaft material when loads are high and/or speeds are low.

Guidance on some successful material combinations for water lubrication is given in Table 7.2.

3. FURTHER DESIGN CONSIDERATIONS

3.1 Filtration

In order to minimise the probability of damage to the bearing and the journal surfaces, hard particles large enough to bridge the lubricant film, allowing for the roughness of the opposing surfaces and the generally irregular shape of the particles, should be prevented from entering the bearing clearance (see Reference 1).

With process fluids the lubricant film thickness is often much smaller than it would be in an oil lubricated bearing and so even relatively small particles may be potentially harmful. In addition, oil lubricated bearings are usually provided with a recirculating lubrication system where particles captured by a filter are permanently removed from the system. Process fluid lubricated bearings, on the other hand, must often rely on a “once-through” flow of liquid which may continuously introduce abrasive particles in large numbers. Filtration may, therefore, be impractical. Nevertheless, water lubricated bearings are sometimes provided with a pumped circulating feed of filtered clean water. A 5µm filter is normally used for this application.

Dirt diverters or separators can be provided as an alternative to filtration. These enable clean liquid to be fed to the bearing while dirtier liquid is made to bypass the bearing.

3.2 Fluid Temperature Limitations

The designer should ensure that no disastrous decomposition or phase change of the process fluid occurs at the maximum bearing temperature, T_{max} . The usable temperature range for some fluids is given in Table 7.3.

A high ambient pressure for the bearing will, of course, increase the boiling temperature of the fluid but may exacerbate bearing instability problems (see Section 3.3).

3.3 Bearing Instability

Guidance on bearing induced instability is given in Derivation 4. However, this guidance is inadequate where the bearing is operated under high ambient pressure. Where there is doubt the designer should seek the advice of consultants able to carry out a detailed analysis.

4. PRELIMINARY BEARING DESIGN

This section gives guidance on estimating the required dimensions of the bearing. The procedure to be followed is shown in the flowchart of Figure 3.

The procedure is based on establishing a value for the specific loading, p_{mean} , under running conditions. It is assumed that start-up requirements are automatically satisfied by employing compatible bearing materials (see Section 2.1).

Subsequent analysis of the performance of the preliminary bearing design (see Section 5) may, of course, necessitate modification to these dimensions.

4.1 Specific Loading

Process fluids often have much lower viscosities than mineral oils and are less effective lubricants. In consequence, process fluid lubricated bearings must usually be designed for lower specific loadings, p_{mean} , than oil lubricated bearings. Water lubricated bearings, for example, are usually designed for p_{mean} values of about 0.4 MN/m^2 although there is some experience of operation at much higher values (see Table 7.2).

Low values of p_{mean} may necessitate large journal diameters or, where this is not practicable, long bearings with the ratio b/d exceeding unity. With such values of b/d , great care should be taken to ensure accurate alignment of the bearing particularly where a hard-on-hard combination of materials has been used (see Section 2.1). Values of b/d exceeding 2 are not recommended.

4.2 Bearing Clearance

Values of the minimum clearance ratio that experience suggests are appropriate under running conditions are shown in Figure 4. In some applications it may be required to optimise (see Section 5) the nominal clearance ratio in order to obtain, for example, an adequate film thickness. The effects of variation in clearance ratio are briefly described in Section 5.2.1 of Item 84031.

Diametral clearance is a dimension that must be held to close tolerance during manufacture. Care should also be taken to ensure that this clearance is not adversely altered during operation of the bearing (see Sections 2.2 and 2.4).

5. PERFORMANCE PREDICTION AND OPTIMISATION

A procedure similar to that given in Items 84031 and 85028 (Derivations 4 and 16) may be followed for performance prediction and so a step-by-step description is not repeated in this Item. The procedure to be followed is summarised in the flowchart of Figure 5.

It is assumed that the bearing dimensions are known or that a choice of dimensions has been made from an initial selection procedure such as that in Section 4. These values are used to obtain the performance characteristics and to check the design for the required duty. It is recommended that the performance of the bearing be checked at the extremes of the operating conditions as illustrated in Examples 2 and 4 of Item 84031. Refinement of the bearing design in order to satisfy performance criteria is illustrated in the flowcharts of Figures 3 and 4 of Item 84031.

6. REFERENCES AND DERIVATION

6.1 References

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6.2 Derivation

4. ESDU Calculation methods for steadily loaded axial groove hydrodynamic journal bearings. Item No. 84031, ESDU International, London, November 1984.
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