

# LOAD CARRYING CAPACITY OF DYNAMICALLY LOADED JOURNAL BEARING

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## Abstract

Sliding bearings are the most wide-spread forms of shaft supports having a frequent occurrence in the machine design. Sliding bearings can be used for supporting small shafts of instruments, precise spindles of machine tools, as well as for supporting large shafts of huge machines. You can find sliding bearings in machines and instruments working in extreme conditions, e.g. in vacuum, in space, at very low or at very high temperatures, under heavy mechanical, chemical and heat influence. Naturally, the geometry, load-carrying capacity, life and reliability of a sliding bearing depend on the tribosystem belonging to this bearing, on the structure, the operational variables, and the tribological characteristics of this system. The dynamically loaded, heavy-duty sliding bearings are especially important in the field of mechanical engineering (e.g. in internal combustion engines) because their performance determines the work of the whole machine.

*Keywords:* machine parts, sliding bearings, tribology.

## Introduction

The load-carrying capacity of a sliding bearing is determined by its friction state influenced by the friction coefficient, the friction power loss and the surface temperature as well as the wear and the surface damages of the friction pairs. In condition of boundary lubrication, the load-carrying capacity of a sliding bearing is limited by its wear rate or by its scuffing load (seizure load, weld load). In condition of fluid friction, the load-carrying capacity of a sliding bearing is determined by the pressure in the oil film, the oil film thickness and the surface strength of the bearing elements. At mixed friction conditions, the capabilities of sliding bearings are influenced by both above mentioned friction conditions, by its rate.

## Load-Carrying Capacity in Condition of Boundary Lubrication

In condition of boundary lubrication, the solid surfaces of the bearing elements contact each other at the highest peaks of the surface roughnesses, where the pressure and friction cause mechanical and thermal stresses, take away material particles from the surfaces, the bearing elements wear off.

If only the boundary lubricant layer covering the friction surfaces wear away, and it would recover during the friction processes, the wear rate will be extremely low in condition of effective and reliable lubrication, the life of sliding bearing will be very long. When not only the boundary lubricant layers wear away but the solid surfaces of the bearing elements, too, the load carrying capacity of a sliding bearing will be determined by the wear processes depending on the structure, the operating variables, and the tribological parameters of its tribological system. The load-carrying capacity of a sliding bearing working under conditions of boundary lubrication is characterized by critical values of operating variables (critical load, critical speed, critical temperature), by failure curves or surfaces, each belonging to a special failure mode (seizure, scuffing, wear rate, surface fatigue, etc.). Nowadays wear maps characterize these failure modes, where generally the load and the speed are the variables. Wear maps need very much experiment results, therefore, they are only provided for static and not for dynamic load. The wear maps show the critical values of operating variables not allowed to be exceeded in order to achieve a given load-carrying capacity or life.

Variable loads disadvantageously influence the load-carrying capacity of a sliding bearing in boundary lubrication, increase the wear rates and decrease the scuffing load. The allowed load is at alternating load lower than at static one.

The porous or the composite sliding bearings working without lubrication have very low fatigue strength: they cannot be used at heavy alternating loads.

## Load-Carrying Capacity in Condition of Fluid Friction

The relationship between the load-carrying capacity and operating variables in condition of fluid friction is not the same as in boundary lubrication. The load-carrying capacity of a sliding bearing in hydrodynamic lubrication is determined by the fluid film thickness in the bearing being at dynamic loading larger than at static one owing to the squeeze effect, so increasing the load-carrying capacity. The load-carrying capacity will be higher at higher frequencies of load alternation.

In fluid film lubrication, the film pressure and the temperature induce stresses in the surface layers of bearing elements. At dynamic load these stresses produce fatigue cracks in the bearing materials. Naturally, the time of crack induction is shorter, the crack propagation rate is larger with increasing frequency of load alternation. This leads to decrease of the load-carrying capacity and life of a sliding bearing. Thus, high frequency of load alternation increases the hydrodynamic load-carrying capacity (the lubricant film thickness) but decreases the life of a bearing.

At fluid film lubrication the dynamic load-carrying capacity of a bearing is determined by the strength of bearing materials. At hydrodynamic lubrication the largest values of stresses in bearing material are produced by the pressure peaks in the lubricant film, so with decreasing this pressure at the same load the load-carrying capacity and the life of a bearing can be increased. However, the calculation of the pressure peaks in the hydrodynamic lubricated bearings, and especially their change cause many difficulties.

It is obvious that many simplifications have to be made in solving Reynolds' equation, in the calculation of pressure distribution and load-carrying capacity of a statically loaded hydrodynamic lubricated bearing in order to achieve a reasonable analytical solution. The results of the solution of an infinitely long bearing [1, 2, 3, 4] or an infinitely short bearing [5] can be converted to a finite width bearing only making further simplifications (e.g. choosing the form of pressure distribution in direction perpendicular to the sliding speed). Even the boundary conditions used for calculation of pressure distribution in a lubricant film influence the accuracy of the solution enormously. For more accurate determination of the performance of a hydrodynamic lubricated bearing therefore numerical methods are often used [6, 7].

The calculation of the minimum film thickness necessary to maintain the condition of fluid friction and the calculation of pressure distribution are more elaborated for dynamic load than for static one. Even using Reynolds' simplifications it is impossible to achieve an analytical solution. Therefore, the squeeze hydrodynamic effect arising from the displacement of the shaft in the bearing and the above mentioned tangential hydrodynamic effect used to be calculated independently and then added up according to special methods. The calculation of squeeze hydrodynamic pressure and force causes as many difficulties as that of the above introduced tangential hydrodynamic effect [8, 9, 10, 11].

First FRÄNKEL [12] and OTT [13] worked out methods to calculate performances of a dynamically loaded sliding bearing assuming that the path of the shaft centre was known. In practice, however, the situations

are the opposite, the variations of load and speed are known, and the path of shaft centre and the minimum film thickness have to be calculated.

For calculation of a sliding bearing under alternating loads many methods have been worked out. Adding up the tangential and the squeeze effect, BOOKER constructed the Mobility Charts that can be used to determine the path of a shaft centre [14]. BLOK's method [15] is similar to Booker's. HAHN [16] and SOMEYA [11] superimposed the pressure arising from the tangential and the squeeze effects at the calculation of the path of the shaft centre. HOLLAND divided the alternating load into a tangential and a squeeze component creating a relative simple method to calculate the performance of a bearing [17].

CZÉGI worked out new methods for calculation of dynamically loaded sliding bearings which can be used for simple and quick determination of the minimum film thickness. Expressing the equilibrium of alternating loads and hydrodynamic forces with a simplified differential equation, he gave the solution for different load variations including periodical ones. Czégi emphasized the minimum film thickness was determined by the load impulse rather than the magnitude of loads. On this base he worked out his impulse method for calculation of film thickness in bearings working under conditions of squeeze effect [18, 19].

These methods do not give the pressure peak causing the highest stress in the bearing material. Only computers have the possibilities to solve the Reynolds equation, with numerical methods, under dynamic conditions. WADA [20], ALLAN [21], KNOLL, PEEKEN [22] solved Reynolds equation with FEM for statically loaded journal bearing using realer boundary conditions, taking into account the bending and the tilting of the shaft and determining the optimum geometry of a bearing where the load-carrying capacity is the highest.

Reynolds equation for dynamic condition was solved with FEM by GOENKA and OH [23], who investigated the effect of deviation of the bearing geometry and the form failures on the pressure distribution.

Using FEM it is possible to take into consideration the deformation of a bearing and a shaft in solving Reynolds equation, in calculating pressure distributions. The solution gives the pressure peaks and helps to construct the optimum geometry of a bearing (where the pressure peak is the lowest at a given load).

At the same time, many difficulties arise in solving the above mentioned tasks with FEM: the computing method is too consumptive of time and often has no convergence. To overcome these difficulties, it is necessary to have a high-level knowledge in mathematics and computer technics and special solving methods.

MOSSMANN [24] used FEM to determine performances of a big end bearing, in an internal combustion engine. Creating six models of the big end bearing he demonstrated that the smaller the joints area between the bearing and the rod, the larger the deformation of the bearing is. This deformation can change the pressure distribution in the lubricant film. Large bearing deformations decrease the pressure peak, increase the minimum film thickness and so the life of bearing. If the bearing is too stiff being unable to follow the bending of the shaft, at the edge there will be a very thin lubricant film causing high pressure and temperature and low load-carrying capacity. When a bearing has proper geometry, an unfavourable high pressure peak and temperature cannot develop. The above mentioned computing methods are suitable to check the correctness of the bearing geometry.

### Strength of Bearings

The load-carrying capacity of a dynamically loaded sliding bearing enormously depends on the materials and the geometry of the bearing. Owing to the requirements of the bearing materials, the heavy-duty sliding bearings or their running surfaces are made of tin-based or lead-based white metal, copper-lead or tin-aluminium alloys. White metals meet the most requirements: they have excellent running properties, embedability, ductility, emergency running. At the same time their fatigue strength is low and it decreases with increasing the temperature.

Copper-lead alloys and tin-aluminium alloys have higher fatigue strength than the white metals, so heavy-duty sliding bearings are made of them. Their embedability and emergency running properties are less favourable, they are inclined to seizure, the bearings made of these alloys demand more attention at exploitation.

The strength of bearing materials connected to steel plate increases enormously with decreasing the thickness of their layer. So a dynamically loaded heavy-duty sliding bearing consists of a steel bush (house) covered inside with one or more layers of lining bearing metals. The lining of a smaller bearing is made of white metal. The lining of a large heavy-duty sliding bearing contains a layer of copper-lead or tin-aluminium alloys covered by an overlay of lead-tin or lead-indium improving the running properties.

Phosphor-bronze has the highest strength but its ductility and embedability are very poor causing irregular load distribution and an incline to seizure. Dynamically loaded heavy-duty sliding bearings cannot be made of them except when the shaft has a very high stiffness and its bending causes not too much overload at the bearing edge.

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