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TRIBOLOGICAL AND DESIGN PARAMETERS OF LUBRICATED SLIDING BEARINGS

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Summary
High performance, longevity and tribological behaviour of lubricated sliding bearings are in close connection with selected design and tribological parameters. Among others, the most important are load carrying capacity, dimensions, clearance, material and surface properties. Selection of these parameters is discussed and some recommendations in accordance with operating conditions are shown.

Key words: *Sliding bearings, design, tribological properties*

1. INTRODUCTION

High performance and reliability are the requirements that define the design and the tribological parameters of lubricated sliding bearings. The main purpose of the design process is to develop a sliding bearing, which will be capable to meeting a particular performance specification, within which the tribological parameters are among the essential ones [1, 2, 3]. Unfortunately, the engineering science does not provide a direct method of doing this.

Compared to other engineering design work, the procedure of design and calculation of lubricated sliding bearings is unusual in that the theory cannot directly be applied in order to obtain the design of a bearing, but only to establish whether the selected solution will be capable of carrying the required load under certain operating conditions [4].

The reason for this is that the theory and practice are opposed to each other in a certain way. The theory says that the highest load capacity is achieved with an infinitely thin lubricant film, high-viscosity oil, and with a particularly small bearing clearance. On the other hand, the practice indicates that the roughness of actual surfaces, the deformations, and misalignment make the metal-to-metal contact inevitable if the lubricant film thickness and clearance are particularly small.

That is precisely the reason why the design process of lubricated sliding bearings is realized through a number of stages:

- through selection of the type of bearing,
- through selection of approximate size and
- through the analysis of the selected solution in order to establish whether it is adequate for the required performance.

If necessary, the initially assumed dimensions are modified through “trial and error” procedure until the optimal solution is acquired.

This means that, in the assessment of the operating and tribological characteristics, it is necessary to be knowledgeable about certain relations, which are, most often, the result of research and experience.
This paper represents an attempt to define guidance for the selection of certain parameters of lubricated sliding bearings and to point to their importance, first of all, from the standpoint of the tribological characteristics. Many other

papers presented at this Conference provide certain basic information related to sliding bearings to which interested readers are referred.

2. OPERATING CHARACTERISTICS: HYDRODYNAMIC VERSUS BOUNDARY LUBRICATION

The conditions in which sliding bearings operate vary widely with different types of mechanisms. First of all, this is related to the loads carried by sliding bearings in engines and machines (Table 1).

Table 1. Specific load of lubricated sliding bearings [5]

Application of sliding bearings	Specific load, N/mm^2
1. Diesel engine:	
- Main bearings	6,3 – 12 (30)*
- Big-end bearings	8 –16 (80)
- Wristpin	14 – 16 (30)
2. Petrol engine:	
- Main bearings	4 – 5
- Big-end bearings	12 -16
3. Air compressor:	
- Main bearings	1 – 2
- Big-end bearings	2 – 3,5
4. Centrifugal pumps	0,7 – 1,25
5. Electric motors	0,85 – 1,85
6. Steam turbines	0,85 – 1,85
7. Gear reducers	0,85 – 1,85

* Maximum specific load

However, in the past 25 years, the power of engines and other machines has considerably increased, but without increasing their size or weight. The greatest increase of the load is with engine bearings and they amount to over 30% compared to the period of 20 years ago (Fig. 1).

Those increased speeds and loads has required a number of bearing improvements, which are realized, first of all, through the improvement of the tribological characteristics of both the bearings themselves and the materials of which they are made.

From the tribological standpoint, there can be differentiated two modes of lubrication of sliding bearings: hydrodynamic or full film lubrication and boundary lubrication. The hydrodynamic is the most desirable method of lubrication of sliding bearings. However, implementation of that method of lubrication demands that the bearing does not reach the critical load and that there is a minimum relative velocity of the surfaces. That means that the dependence between the load and the sliding speed has the greatest influence on the implemented type of lubrication (Fig. 2).

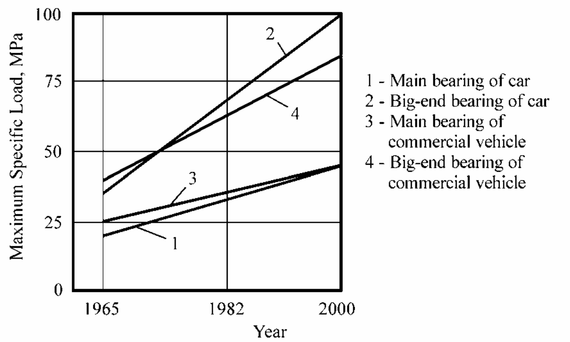

Figure 1: *Increase in specific bearing load of diesel engine [6]*

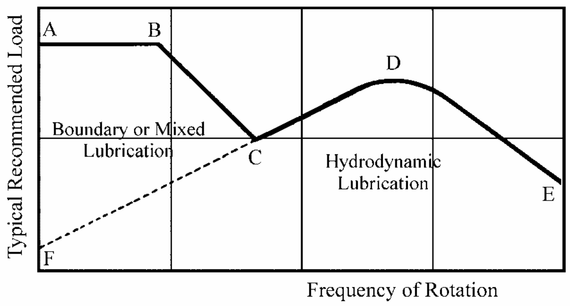

Figure 2: *Typical load-speed characteristic of sliding bearing*

It is obvious that, at low speeds and relatively high load, a sliding bearing operates in the range from the boundary to the mixed lubrication.

2.1 Hydrodynamically lubricated sliding bearing

Complete separation of sliding surfaces with lubricant can be achieved by the hydrodynamic lubrication. The selection of the design and the tribological parameters in the region of the hydrodynamic lubrication should most importantly ensure adequate thickness of lubricant film and temperature of the bearing. The theory on which the calculation is based is rather complex and presupposes that the bearing operating conditions are known. Basically, they include the knowledge about the recommended values for the load, size, clearance, and properties of the lubricant [7].

Various recommendations appear in the literature concerning the selection of the above values. Thus, for example, for the known load and speed, on the basis of the diagrams presented in Figure 3, the preliminary sizes of the journal hydrodynamic sliding bearings and, from Figure 4, the sizes of the thrust hydrodynamic sliding bearings can be selected. Alternatively, for the selected size of a bearing, the load capacity for a given speed can be determined from the given diagrams. These values are related to the steady-load condition. If the load varies in magnitude and/or direction, the procedure for the selection of bearing parameters is more complex and calls for additional design considerations.

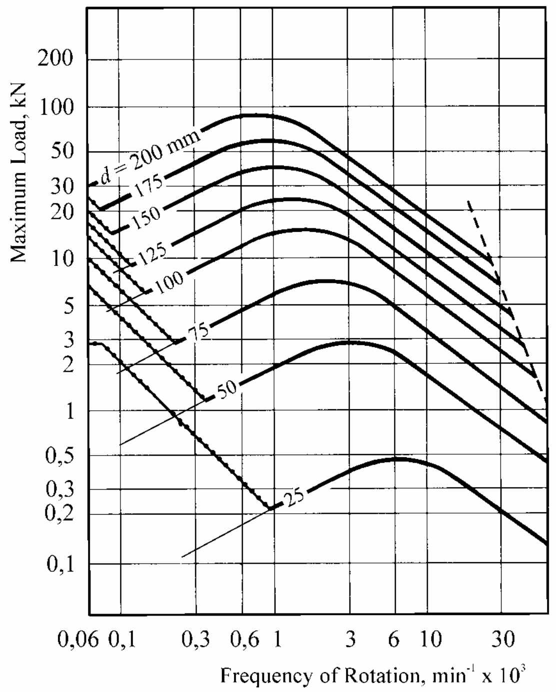

Figure 3: *General guide to journal bearing load-carrying capability [8]*

When designing the lubricated sliding bearings, it is important to determine properly the minimum acceptable clearance because it's size influences the load capacity, the thickness of lubricant film, and heating of the bearing. The recommendation for the selection of clearance with the steadily loaded bearings is shown in Figure 5, dependent on the frequency of revolution, while Figure 6 presents the recommended clearance for diesel engine bearings.

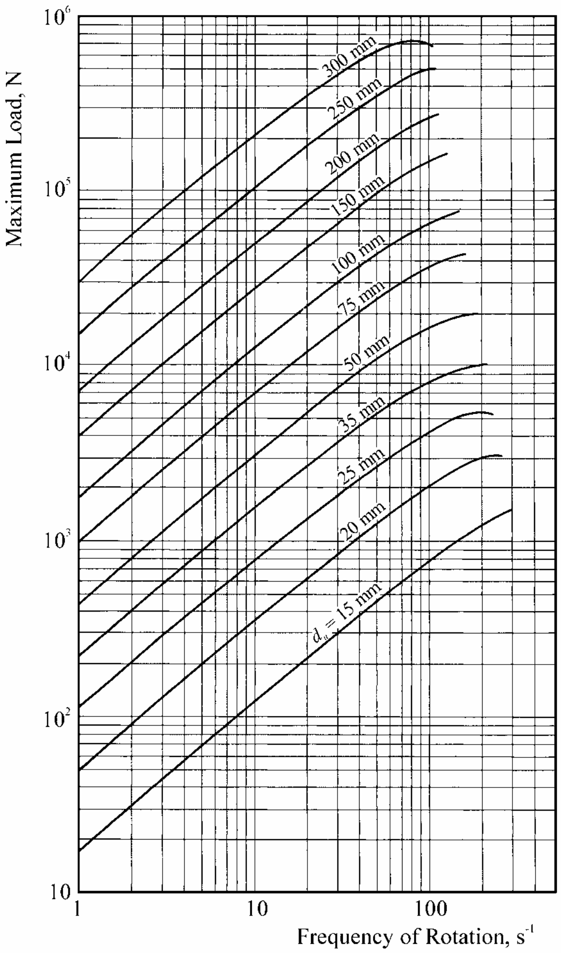

Figure 4: *Guide to thrust bearing load-carrying capability [8]*

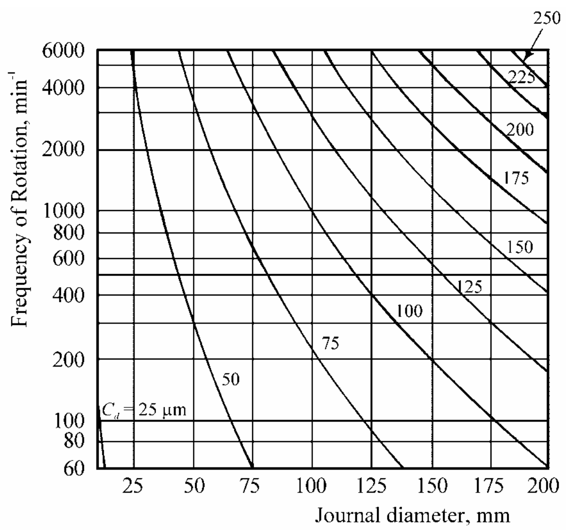

Figure 5: *Minimum diametral clearance for steadily loaded bearings*

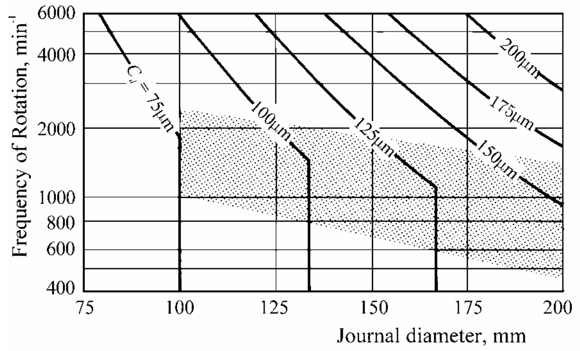

Figure 6: *Diametral clearance for diesel engine bearings*

The selection of the viscosity value of the lubricant also has a very important role in view of the fact that it also influences, in case of the hydrodynamic sliding bearings, the thickness of oil film and losses due to friction. The viscosity value is also often determined by other factors but, for a preliminary selection, the data presented in Figure 7 can serve the purpose, which have been obtained from different sources on the basis of the calculations done [9, 10, 11].

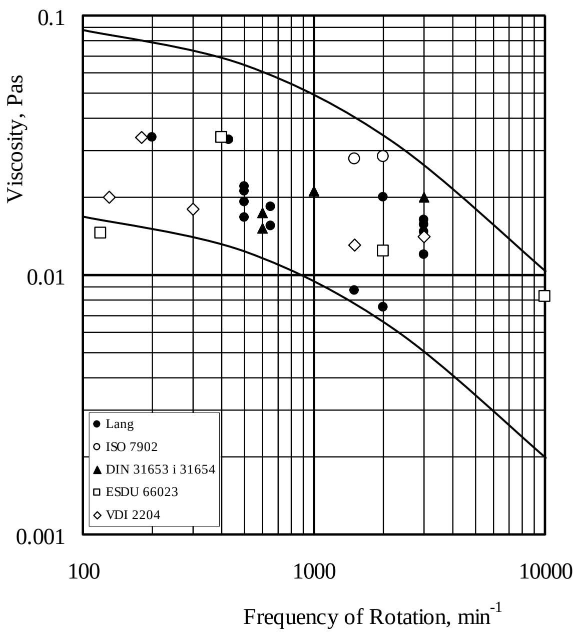

Figure 7: *Selection of sliding bearing lubricant viscosity*

2.2 Boundary lubrication of sliding bearings

There is a large number of sliding bearings that operate, occasionally or steadily, in the region of boundary lubrication. Under such conditions, the design variables are the material, the lubricant, and the size of the bearing. The properties of lubricants and materials determine the specific load of a bearing.

In view of the fact that the friction of the bearings with boundary lubrication is higher than the friction of the hydrodynamic bearings, it means that they operate at higher temperatures and, therefore, the state of the bearings can be controlled by *pv* products. *PV* value represents the measure of the developed heat, which a bearing can withstand, and it is usually expressed in kW/m^2. This factor is used as a starting point in determining the bearing materials and sizes. The usual value for the bearings that operate more or less continuously is 700 kW/m^2. Adequate load and speed also significantly depend on the allowed value of wear. It often happens that, with the lubricated sliding bearings, which operate in the region of boundary lubrication, the allowed stress is also taken as a criterion, particularly in the cases where the velocities are relatively low [12].

A special role plays the properties of the lubricants, i.e. their ability to form layers of suitable tribological properties on the surfaces of a bearing. This is, most often, achieved by the use of an antiwear additive.

3. MATERIAL SELECTION: TRIBOLOGICAL PROPERTIES OF BEARING MATERIALS

Another substantial difference, according to which the approach to the design of the lubricated sliding bearings differs from many other mechanisms, is the selection of the characteristics of the materials from which they are manufactured.

Apart from adequate strength, the materials for the sliding bearings must also possess other characteristics in order to satisfy the requirements for reliable and long-lasting operation. The limits of the mechanical loading are a function of strength of the bearing material, while the limits of the thermal loading are determined by the thermal stability of the selected material.

It is known that, with the hydrodynamic sliding bearings, there is no direct relation between the physical and mechanical properties of the material and the bearing performance. The parameters, such as the thickness of the lubricant film, the pressure, and the temperature of a bearing, do not depend on the type of the bearing material, but they have a profound influence on the behavior, and thereby, on the selection of the bearing material.

This indicates that the bearing material must also possess a series of other properties that are related to the deformation characteristics of the material and to the properties of the surface layer. They are denoted as the tribological characteristics and include, first of all, the following [13, 14]: conformability, embeddability, compatibility, wear resistance, corrosion resistance and fatigue resistance.

The tribological behavior denoted by the above terms is not just a function of the bearing material, but also of the mating material, the lubricant, the design, and the conditions of the environment in which the bearing operates. All the complexity of the tribological properties of the bearing materials and their strong system-dependent properties is thus revealed.

4. CONCLUSION

There have been numerous research works on the lubricated sliding bearings in the past half a century and they have considerably extended the knowledge about this important machine element. This enables current implementation of the designs of high accuracy and reliability.

However, apart from the knowledge of the operation of bearings from the theoretical aspect, information is also necessary on the basis of which a designer can select the initial values. The subject of this paper is to provide some technical data that can be used as design parameters for the lubricated sliding bearings.

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