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Experimental research on water-lubricated marine stern tube bearings in conditions of improper lubrication and cooling causing rapid bush wear

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ABSTRACT

Water-lubricated polymer bushes are increasingly popular in sliding bearings of marine propellers, water turbines, and pump shafts. This environmentally friendly solution is relatively simple and usually proves to be durable.

However, in practical experience one may also observe cases of rapid wear or even malfunctions of this type of bearing, some of which may be caused by insufficient flow of lubricant. The main purpose of the conducted research was to identify how different bearing types operate under conditions of no lubricant flow.

The conducted research determined that certain bearings continue to work properly despite a lack of lubricant flow and cooling. This is due to low frictional resistance levels, resulting in sufficiently low heat being generated in the friction zone of such bearings and dispersed into the surroundings once the bearing's temperature has risen and stabilized at a safe level.

1. Introduction

Water-lubricated polymer bush bearings are finding increasingly wide use in shafts of marine propellers, water turbines, and pumps. This fact stems partially from their simple construction, which also means that this type of solution has a relatively low price [1,2]. Three main construction systems of this bearing type have dominated in practical applications.

The first, which is also the simplest, is an open system with the bearing lubricated by surrounding water and freely flowing through it, for example ship stave bearings [3] and certain water turbine [4] and water pump bearings [5,6,7].

In the second, somewhat more complex system, the surrounding water is pumped, filtered, and then forced through the bearing to the outside. This solution offers significant advantages. First of all, the flow of the lubricating agent through the bearing may be controlled by regulating the work of the pump. In the event of lack of flow caused by pump malfunction or clogging of the filter, a flow sensor should detect and indicate the system failure. Such indication is very important as in most cases it makes it possible to avoid more serious consequences of a potential breakdown. The filtered water is usually free of large-sized impurities – hard particles – thanks to which the risk of rapid bearing damage is limited [8]. The pump solution is readily used on ships in marine propeller shaft units [9].

The third solution is the most advantageous but also the most expensive. It consists of a system with enclosed water circulation. The bearing unit is closed on both sides by seals which effectively protect the friction couple from being polluted by outside impurities. Clean, usually salt-free, filtered freshwater of appropriate temperature is supplied to the bearing unit by a pump. The chemically neutral water, free of impurities and with appropriately selected flow parameters, with ongoing control of potential changes to these parameters on the outflow, provides highly advantageous working conditions for the bearing. Such systems are particularly sought after and therefore frequently used in inland waterway ships, river water turbines, and dewatering pump systems (land reclamation, open-cast excavation, mines, etc.).

Based on extensive practical experience, it may be stated that in most cases water-lubricated bearings have a durability of at least a decade or so. After this period, the bushes are replaced with new ones and the shaft undergoes regeneration, which is usually limited to regrinding its sliding surface. In the case of more extensive surface damage, it may be necessary to apply overlay welding and grinding. Occasionally, other innovative regeneration methods may be applied, such as remachining the shaft and placing a thin-walled stainless steel or bronze sleeve on it [10].

Thanks to research efforts carried out by R&D departments of major bearing manufacturers and scientific centres all over the world, both the durability and the reliability of this bearing type have improved. The research included important theoretical works

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aimed at pinpointing the conditions under which fluid film lubrication takes place. It was determined that excessive radial clearance and incorrect location of lubrication grooves may play a particularly strong role in reducing the bearing's hydrodynamic load-carrying capacity [11–14]. In their research, the manufacturers focused on producing a material of low frictional resistance, high durability, and minimum water soaking, resulting in a negligible swelling characteristic [15,6,16,17].

Unfortunately, as it stems from practical experience, breakdowns of this bearing type do occur. Some of them may be caused by insufficient flow of the lubricating agent through the bearing, resulting in its insufficient cooling. It should be kept in mind that a polymer bush does not conduct heat well and under normal conditions most of the heat generated in the friction zone is absorbed by the flowing lubricating agent.

Friction is the decisive factor that determines whether overheating occurs in the friction zone. In the case of a cooling system breakdown, the heat must be transferred directly to the surroundings. With increasing friction, the amount of heat generated in the bearing rises. In the event of a cooling system malfunction, the heat must be transferred directly to the surroundings. Since heat exchange with the surroundings is problematic, due mostly to the bush's low thermal conductivity coefficient, the temperature of the bush increases, as does the temperature of the shaft, to a smaller degree. If the working conditions do not change, then after some time these temperatures should stabilise. In designing a bearing, the designer attempts to ensure that the temperature which establishes itself in the friction zone is within an acceptable range.

Overheating of the friction zone usually results in polymers undergoing a very rapid adhesive wear process. In the case of composites, delamination (separation of material layers) frequently takes place. Therefore, ensuring adequate cooling is of vital importance.

The ability to work under conditions of increased temperature is very important for a polymer bush and may turn out to constitute a significant advantage of a particular material. It is for this reason that certain sliding material manufacturers pay such close attention to this issue in efforts aimed at improving their products.

Fig. 1. Melted polymer – the result of an overheated stern tube bearing caused by a cooling system breakdown; shaft diameter 350 mm.

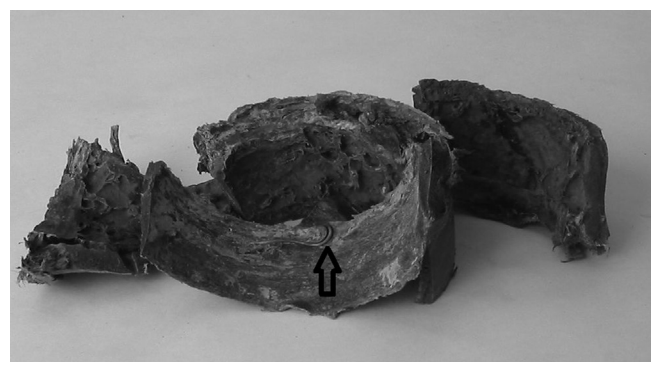

Fig. 2. Ring made of polymer hooking line which blocked water flow through fishing vessel propeller shaft bearings. The arrow indicates one of the fish hooks.

2. Origin and purpose

Existing specialist literature does not contain many descriptions of incidents of excessive wear or breakdowns in marine propeller shafts or water turbine bearings [9]. This stems from, among other reasons, the fact that the authors of expert opinions ordered by courts or ship classification societies are bound by confidentiality clauses. The manufacturers, if presenting the results of their research at all, naturally tend to present their products in the best possible light. However, it may be objectively stated that in recent years most of the reputable manufacturers have invested substantially in R&D, which has resulted in new, modern products with improved tribological properties appearing on the market [15,6,17].

Lack of information about bearing operation under limited lubrication and cooling conditions was the main motive behind the conducted research. How intensively can the bearings be loaded when no flow conditions appear? Will overheating appear in all the bearing types? Finding the answers to these questions was the purpose of the conducted research.

In real-life operations, breakdowns of stern tube bearings in propeller shafts do take place and frequently lead to very serious consequences, resulting in ships being taken out of service. Such breakdowns may be caused by malfunction of the pumping system (Fig. 1). Classification societies which validate ships for service require that flow and temperature sensors be placed in the cooling system, which in many cases has made it possible to prevent serious breakdowns.

On occasion, breakdowns caused by an overheated bearing may result from completely unexpected blocking of flow. There is, for example, a known case of a fishing line with hooks which wound itself up on a propeller shaft of a fishing vessel. The high temperature brought about by the resulting friction melted the nylon line into a monolithic ring which effectively blocked the outflow of water from the bearing (Fig. 2).

Experiment-based research into real-scale water-lubricated bearings is currently conducted in scientific centres all over the world and its results may be found in the scientific literature. One of the fundamental problems that are frequently brought up is the issue of hydrodynamic lubrication by low-viscosity lubricating agent such as water. It is for this reason that such aspects as the type of bush material, bush shape, location of lubrication grooves, and condition of the sliding surface are analysed [18,19,15,20–24,16,25,17].

3. Scope of the tests and description of tested bearings

A group of six typical marine-industry water-lubricated bearings were chosen for the tests (Table 1). All of the bearings have been accepted by classification societies for use as stern tubes of