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USE OF IN-HOUSE DESIGN MODULES WHEN CHOOSING BEARING ASSEMBLIES FOR PUMPS BEING DESIGNED

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Among the main components that largely affect the operational reliability of centrifugal pumps are bearing assemblies. Based both on the generalization of theoretical data and practical skills in selecting bearings, specialists of JSC VNIIAEN developed basic design modules, in which a general approach to the selection and analysis of the performance of bearing assemblies is laid. These design modules can work either as separate units or as part of an integrated module that allows us to calculate the thermal balance of the bearing assembly system with taking into account a number of factors, such as lubrication conditions, cooling methods, mandatory verification of the recommended design features of both individual system elements and basic critical performance indicators of a bearing. Functional cause-effect relationships of the module can help better understand the problems that arise during the operation of bearings. This paper discusses JSC VNIIAEN's in-house design modules for selecting pump bearing assemblies, and proposes a new method for designing bearing assemblies, with the method based on the integrated use of individual modules represented as an integrated module in the form of a computer-aided design (CAD) system. The flexibility of the methodology used allows us to supplement and improve the developed design modules included in the integrated module in the form of a CAD system by using the results of scientific research, feedback from operational locations, and constant monitoring of various information sources.

Keywords: *rolling bearings, sliding bearings, design modules, lubrication, cooling, performance, thermal balance of the system.*

Introduction

For more than 50 years, JSC VNIIAEN has been creating high-quality pumping equipment (almost 800 types of pumps). This equipment is successfully used in many large nuclear and thermal energy complexes; oil, chemical and food industry facilities; water supply and irrigation facilities; construction and mining works; metro systems; agloblast-furnace and steel production; livestock complexes; public infrastructure, etc.

The durability and efficiency of a pump depends to a large extent on the correctly selected and well-elaborated design of bearing assemblies.

JSC VNIIAEN has a large number of developments regarding the study of bearing assemblies. It periodically collects and analyzes the feedback on the efficiency of bearings from the operational locations of in-house designed pumps, as well as monitors foreign designs. This contributes to the adoption of the most balanced and economically sound decisions in the development of new bearing designs, as well as to the improvement of in-house design modules.

This article discusses JSC VNIIAEN-elaborated basic principles of selection and calculation of bearing assemblies with the help of in-house design modules during design of centrifugal pumps. A new approach to the design of bearing assemblies is also presented. It combines these design modules into an integrated module in the form of a CAD system, taking into account a number of factors and performance standards.

Peculiarities of Using JSC VNIIAEN's In-house Design Modules

In JSC VNIIAEN's centrifugal pumps are used two well-known structural types of bearings as bearing assemblies for pump rotors. They are sliding bearings (either hydrodynamic or hydrostatic) and rolling bearings. Their designs are based on the use of both sliding and rolling bearing assemblies with different lubricating and cooling methods.

From the materials studied, scientific research, as well as the generalization of the long-term experience in designing bearing assemblies, specialists of JSC VNIIAEN developed basic design modules for selecting and analyzing the performance of bearing assemblies.

The first versions of the design modules were developed on the basis of the Fortran programming language, which over time were significantly improved and optimized. For greater clarity and ease of use, the previously created modules were rewritten and supplemented for calculations with Mathcad.

The developed design modules make it possible to determine the loads on bearings, choose the constructive type of bearing assemblies, choose the method of supplying lubricant and cooling, obtain the performance of bearings, and determine the temperature state with different cooling methods.

Determination of the Loads Acting on a Bearing

In this design module are determined the loads acting on bearing assemblies of a pump rotor both in the entire range of its operation and in possible non-stationary cases.

When determining the loads, it is necessary to take into account the hydraulic forces arising in pump discharge devices (spiral casings, guide vanes, etc.), forces from the pump inlet pressure, forces from the rotor mass, imbalance, and the load from the action of the coupling [1]. Since part of the forces can change not only magnitude, but also direction, depending on the operating parameters of the pump, this is taken into account when it is necessary to determine the reactions of bearing assemblies for different combinations of load directions, the maximum and minimum bearing assembly reactions being selected from all the options considered for each of the bearing assemblies.

The main criterion in determining the load-carrying performance of bearings is the excess of the current load over the necessary minimum. For sliding bearings, this is an important condition for avoiding adverse operational effects associated with the insufficient loading of these bearings (vibrations of the shaft due to the instability of its movement in the lubricating film of the bearing) [2]. If rolling bearings are under insufficient load, then their rolling bodies slip, which leads to damaging their races, separators, rolling bodies, and premature failure. This can be accompanied by noise, increased vibration, and temperature [3].

On the basis of the above, the optimal size, structural design, and structural elements of a bearing are selected.

Calculation of the Method of Supplying Grease to the Bearing

In the pump bearings produced by JSC VNIIAEN are used the following lubrication methods: forced (from an external oil system), oil bath (from an oil bath built into the bearing housing), and combined. With the oil bath method, the lubricant is supplied to the bearing most often through the use of an oil ring. In the case of rolling bearings, the use of lubricant greases is also considered.

The module for calculating the lubricant supply method is used to determine the flow rate of the lubricant supplied by the oil ring, as well as the critical rotational speeds of the ring [2]. These parameters are the main bearing assembly performance criteria that allow us to check the effectiveness of lubricant supply and select the optimal design dimensions of oil supply elements.

The research work carried out at JSC VNIIAEN on the experimental and design studies of the performance of both sliding and rolling bearings with oil ring lubrication indicates that the correct choice of the optimal size of the oil ring allows us both to increase the bearing load-carrying capacity and decrease the bearing temperature. The optimality criteria for the ratio of the geometric dimensions of oil rings in calculations were selected based on the analysis of the results of these works, as well as generalized information on the optimal ratios of the geometric dimensions of the oil ring [1, 4, 5].

Determination of Basic Bearing Performance

The calculation of sliding bearings is carried out by using methods based on the hydrodynamic theory of lubrication, as well as the thermal balance equation at the steady state of operation [2].

For sliding bearings, one of the main design characteristics that confirm their operability is the lubricant carrier film thickness, which must exceed the minimum acceptable value. Other important characteristics during the design and operation of a sliding bearing include the minimum required lubricant flow rate (to maintain the fluid friction mode and cool the work area of the sliding bearing), the power loss in the bearing, and the maximum temperature of the lubricant in the film.

The calculation of bearing assemblies on the basis of rolling bearings is reduced to the calculation of their service life according to the procedure described in ISO 281, and it is performed for the worst operational conditions (such as minimum and maximum loads, minimum lubricant viscosity, etc.). During the calculation, taken into account is the life coefficient, which affects the estimated service life of a rolling bearing [3] and which can vary depending on the manufacturer of bearings.

For rolling bearings, the main performance characteristics that confirm their operability are their durability and power loss.

Calculation of the Cooling System of a Bearing Assembly

The calculation module of the cooling system helps check the effectiveness of heat removal by the oil cooler from the bearing by either finding the required cooling area or determining the maximum bearing temperature which should not exceed the maximum allowable value.

The determination of the maximum temperature of a bearing assembly is performed under the worst operational conditions on the basis of calculated heat evolutions, as well as lubricating and cooling conditions [6, 7].

The main methods of removing heat from bearings in the pumps produced by JSC VNIIAEN are either to remove it through the bearing housing, a smooth / ribbed oil cooler tube or to air-cool the bearing housing by means of a fan impeller.

Integrated Module

The design modules described above can work either as separate units or as elements of an integrated module that allows us to calculate the thermal balance of a bearing assembly system with taking into account a number of factors, such as lubricating conditions, cooling methods, and mandatory verification of the recommended design features of both individual system elements and basic critical performance indicators of bearings [8].

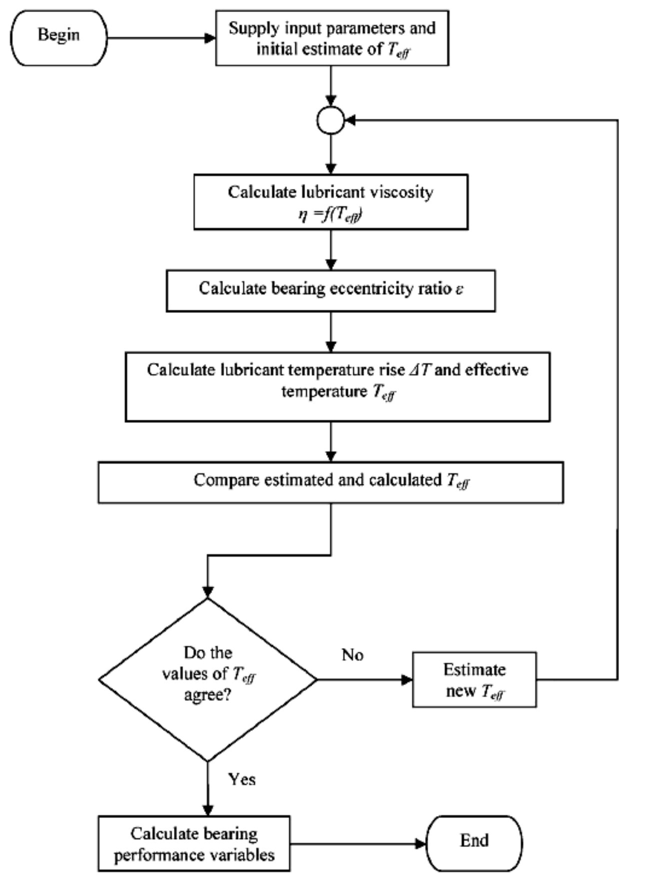

Fig. 1. The block diagram of the design model of a sliding bearing

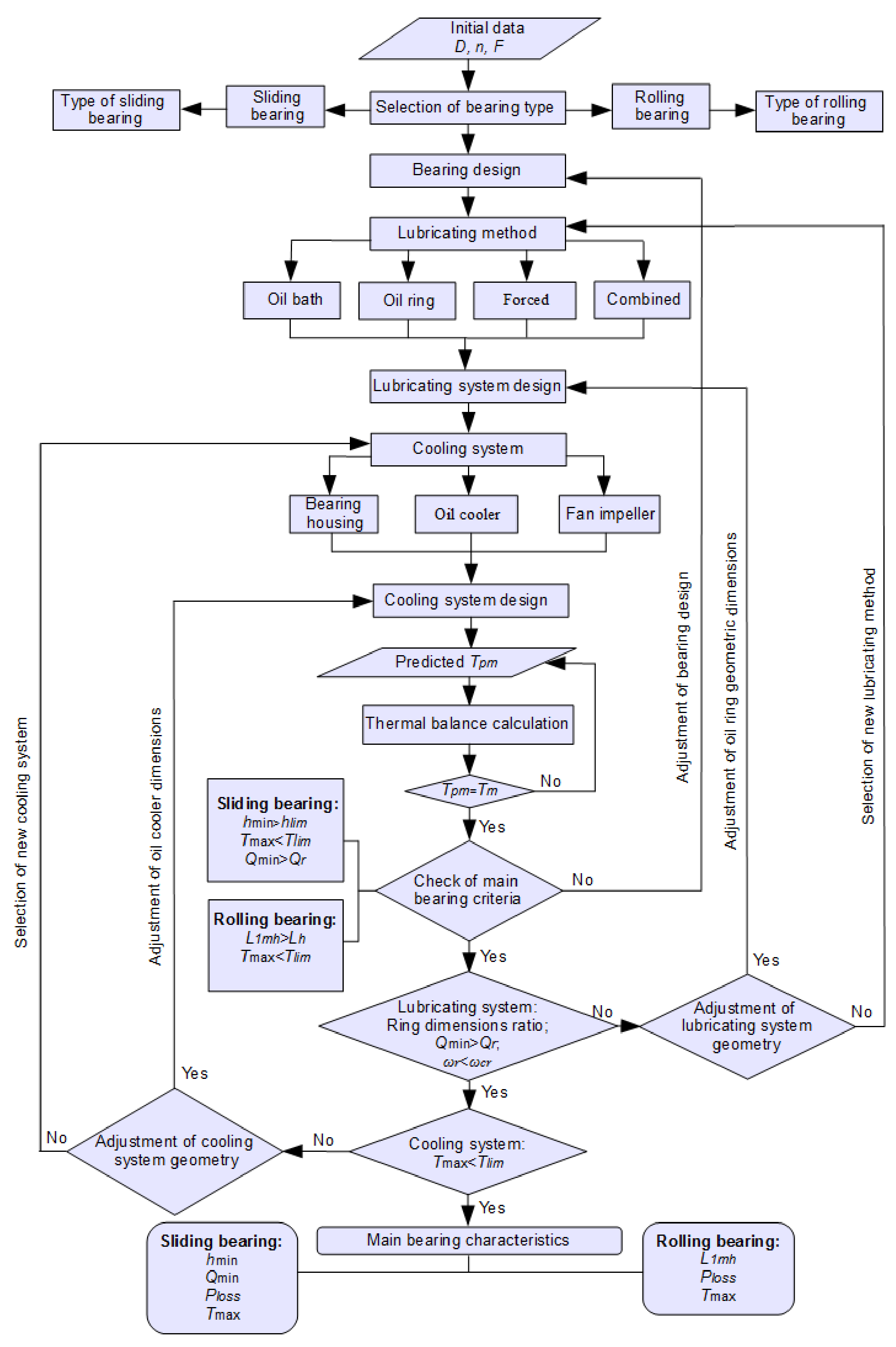

Fig. 2. The block diagram of the design model of a bearing assembly

The main principle integrating different design modules in the form of a CAD system is the balance between the generated and removed heat in the bearing, that is, the stabilization of the bearing operating temperature after it reaches thermal equilibrium.

In the development of the integrated module in the form of a CAD system, the experience of approaches to the selection and design of bearing assemblies of centrifugal pumps was taken into account, and materials on similar topics were searched for [3, 9, 10]. The block diagram of one of its analogs is shown in Fig. 1 [10].

In Fig. 1, the following notation is used: T_{eff} is the effective temperature of the lubricant, ºC (obtained from the thermal balance of the system); η is the viscosity of the lubricant at the effective temperature, cSt; ΔT is the increase in the lubricant temperature, °C.

The block diagram shows a model for calculating a radial sliding bearing with forced lubrication. The diagram includes modules for determining the loads and basic performance characteristics of the bearing, the modules being integrated into a cohesive analytical model. The thermal calculation of bearing assemblies is reduced to finding the thermal balance of the bearing by the method of successive approximations by means of heat removal through the bearing housing [1, 2].

Most often, in publicly available sources, when bearing assemblies are selected and calculated, design modules are used only for a specific type of bearing designs, lubrication system, and cooling method. This is the main distinguishing peculiarity in the approach for calculations regarding the selection of bearing assemblies with the considered JSC VNIIAEN-developed module that integrates the interrelated modules for selecting bearing assemblies of various design types, lubricants, as well as lubricant and cooling supply methods into one system.

This approach allows us to get a more realistic picture of the temperature condition of a bearing assembly, as evidenced by bench tests of various bearing designs, as well as field tests of JSC VNIIAEN-developed pumps. Functional cause-effect relationships of the thermal balance module of the system make it possible to better understand the problems encountered during the operation of bearings.

The block diagram of the design model of the bearing assembly developed and used by JSC VNIIAEN is shown in Fig. 2.

In Fig. 2, the following notation is used: D is the shaft diameter under the bearing, m; n is the rotor speed, r/min; F is the bearing load (radial, axial), N; $T_{p.m}$ is the predicted mean oil temperature in the bearing, °C; T_m is the mean bearing lubrication temperature obtained from the thermal balance of the system, °C; $h_{\min}$ is the minimum oil film thickness, microns; $h_{\lim}$ is the limit oil film thickness that provides the fluid friction mode, microns; $T_{\max}$ is the maximum oil temperature in the bearing, °C; $T_{\lim}$ is the maximum allowable oil temperature in the bearing, °C; $Q_{\min}$ is the minimum required oil flow rate that is necessary to ensure the operability of the bearing assembly, m^3/h; Q_r is the flow rate of the oil supplied by the oil ring, m^3/h; ω_r is the rotational frequency of the oil ring, 1/s; ω_{cr} is the critical oil ring rotational speed at which an intensive oil splash begins, 1/s; L_{1mh} is the design bearing life, h; L_h is the required bearing life, h; P_{loss} is the friction power loss in the bearing, kW.

The design model considered makes it possible to carry out both design and verification calculations of bearing assemblies, include additional modules with new calculation methods in the system, and improve it as a whole.

Conclusions

This paper discusses the in-house design modules for the selection of bearing assemblies for the JSC VNIIAEN-produced pumps both as individual units and as part of a CAD system. The criterion for combining interrelated modules is the thermal balance of the system.

The novelty of the presented approach lies in the fact that it combines the individual modules for the selection of bearing assemblies into an integrated automated system, and takes into account a combination of factors, such as lubricating conditions, cooling methods, mandatory testing of the recommended design features of individual system elements, and the main critical performance indicators of a bearing. This approach allows us to get a more realistic picture of the temperature condition of a bearing assembly, as evidenced by bench tests of various bearing designs, as well as field tests of JSC VNIIAEN-developed pumps.

Representation of the integrated module in the form of a block system allows us to supplement and improve the developed design modules in the form of a CAD system by using the results of scientific research, feedback from operational locations, and constant monitoring of various information sources.

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Застосування розрахункових модулів власної розробки при виборі підшипникових опор насосів, що проектуються

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Одними з основних вузлів, від яких багато в чому залежить надійність роботи відцентрових насосів, є підшипникові опори. На основі узагальнення теоретичних даних і практичних навичок при виборі підшипників фахівцями АТ «ВНДІАЕН» розроблені основні розрахункові модулі та програми, в яких закладений загальний підхід до вибору та аналізу працездатності підшипникових опор. Дані розрахункові модулі можуть працювати як окремі одиниці, так і входити в об'єднаний модуль, який дозволяє розраховувати тепловий баланс системи підшипникового вузла з урахуванням сукупного ряду факторів, таких, як умови змащування, способи охолодження, проведення обов'язкової перевірки рекомендованих конструктивних особливостей окремих елементів системи та основних критичних показників працездатності підшипника. Функціональні причинно-наслідкові зв'язки модуля можуть допомогти краще розібратися в проблемах, що виникають під час експлуатації підшипників. У статті розглянуті розрахункові модулі власної розробки з вибору підшипникових опор насосів АТ «ВНДІАЕН» і запропонована нова методика проектування підшипникових опор, яка ґрунтується на взаємопов'язаному застосуванні окремих модулів, що подані як об'єднаний модуль у вигляді системи автоматизованого проєктування (САПР). Гнучкість методики, що використовується, дозволяє доповнювати і удосконалювати розроблені розрахункові модулі, що входять до об'єднаного модуля у вигляді САПР, використовуючи результати науково-дослідних робіт, відгуки з місць експлуатації та постійний моніторинг різних інформаційних джерел.

***Ключові слова**: підшипники кочення, підшипники ковзання, розрахункові модулі, змащування, система охолодження, робочі характеристики, тепловий баланс системи.*

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OPTIMAL DESIGN OF SMOOTH SHELLS WITH AND WITHOUT TAKING INTO ACCOUNT INITIAL IMPERFECTIONS

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This paper considers the application of the random search method for the optimal design of both axially-compressed smooth cylindrical ideal thin-walled shells and a shell with initial imperfections. In stating a mathematical programming problem, the objective function is the minimum weight of the shell. As constraints imposed on the region of permissible solutions, the following constraints are adopted: on the critical load of local buckling, on the critical load of buckling of the shell axis; strength condition, and condition for constraining the dimensions of a shell (radius and wall thickness of a shell). With the optimal design of a shell with initial imperfections, the statement of the mathematical programming problem remains the same as for an ideal shell, with only local buckling constraint changing. The aim of this paper is both to study the zone of influence of the optimum shell weight on the value of compressive force and to determine the range of the external compressive loads at which the general and local buckling shell constraints are decisive. A numerical experiment was carried out. Dependences of the weight, wall thickness, radius of the middle surface, and the ratio of the middle surface radius to the wall thickness on the magnitude of the compressive load both for an ideal shell and a shell with initial imperfections were investigated. As a result of the numerical experiment, it was established that the presence of initial imperfections in an axially-compressed smooth cylindrical shell leads to an increase in its weight compared to that of an ideal shell. The weight does not increase over the entire range of compressive loads, but only with the loads at which both local and general buckling constraints are decisive. If the optimal solution pertains to the strength constraint, which is typical for large compressive loads, there is no influence of initial imperfections on the optimal design. The weight of an ideal shell and that of a shell with initial imperfections in the optimal design turn out to be the same.

Keywords: *thin-walled cylindrical shell, initial imperfections, optimal design, random search.*

Introduction

Thin-walled constructions in the form of shells are used in many branches of engineering and construction. The variety of types of shell structures, different loading and operating conditions, the complexity of stress and strain state analysis led to the creation of both specific techniques and computational methods, often mathematically quite complex and therefore almost unavailable to wide circles of engineers.