Analysis of Contact Stresses Occurred Between Rolling Elements of Large Bearings with Hollow Rollers Provided with Automatic Lubrication System

BARABAȘ Sorin
Transilvania University of Brasov, Romania, sorin.barabas@unitbv.ro
FLORESCU Adriana
Transilvania University of Brasov, Romania, afota@unitbv.ro

Abstract
Bearings lubrication in wind power assemblies, which have permanent operation in difficult conditions with high variability of both, the load and speed, is a problem widely studied because of difficulties arising. Lubrication process is influenced by geometry of raceway, temperature, rotation speed, static and dynamic loads, type and quantity of lubricant. All these factors determine the quality of process with consequences on wear, lifetime and efficiency of energetic assembly. A correct lubrication film lubrication between moving parts, reduce direct contact. Also it is studied an innovative model of lubrication system mounts in the hollow cylindrical rollers, controlled by an automated system. Comparison of tensions occurred in cylindrical rollers with hollowness and rollers provided with covers allow favorable conclusions. Finite element analysis was performed with Nastran software.

Keywords
hollow roller, automatic lubrication, finite element analysis

1. Introduction

Use of hollow roller in construction of large bearings is a concept who lead to many advantages. Companies like Schaeffler, SKF, Timken, utilizes hollow rollers having different types and design. Choosing a correct hollowness of roller allow the significant reductions in contact stress, wear, work temperature.

Most important issues arising to use of hollow rollers are increase of contact stress, variable loads due to environment conditions (the wind speed, the weather with extreme temperatures and humidity) and difficulties of heat treatment (carburizing heat treatment causes large deformations especially hollow rollers). Lubrication has a very significant role in this equation. To improve efficiency of lubrication, it is necessary to maintain the lubricant film thickness to constant values. For this, is necessary that the amount of lubricant introduced to the raceways be strictly controlled and in accordance with the lubricant consumed or evacuated. Lubrication process is influenced by temperature, rotation speed, geometry of raceway, static and dynamic loads, type and quantity of lubricant. [1, 2] All these factors determine the quality of process with consequences on lifetime and efficiency of energetic assembly. The lubrication is a result of maintenance of bearing that occurs at set intervals based on experimentation that ignores extreme events. Lubrication systems, real-time operating, were made by companies producing large bearings [3, 4].

Lubrication modifies its properties depending on the type of lubricant, on work temperature and losses in volume over time. Depending of lubrication, the contact between rolling elements may be [5]: elastohydrodynamic contact, mixed friction contact, wear contact and contact with presence of particles between the surfaces.

The forces transmitted in case of an ideal elastohydrodynamic contact are normal forces. With the appearance of dry contact and wear [6, 7], particles of material occurrence is inevitable. These particles that are between those two bodies in contact very quickly lead to damage of the bearing.

The bearing life and the lubricant life are determined by the time at which 10% of a population of bearings is expected to have failed [8] and have different values in same conditions. All lubricant life models are empirical models that is based on numerous tests [9]. In this paper was studied the possibility to consider the factors that influence the processing of lubrication, interrelated. In this regard, at high temperatures, takes place degradation and ultimately the lubricant loses its consistency and at low temperatures the lubricant flow mechanism will be different.

For the bearings with hollow rollers, increasing of contact stress and decrease of the stiffness of assembly, execution of a proper lubrication is more necessary

In Figure 1 is presented the advantages and disadvantages of using of hollow rollers in large bearings who equips the wind energy power plant.

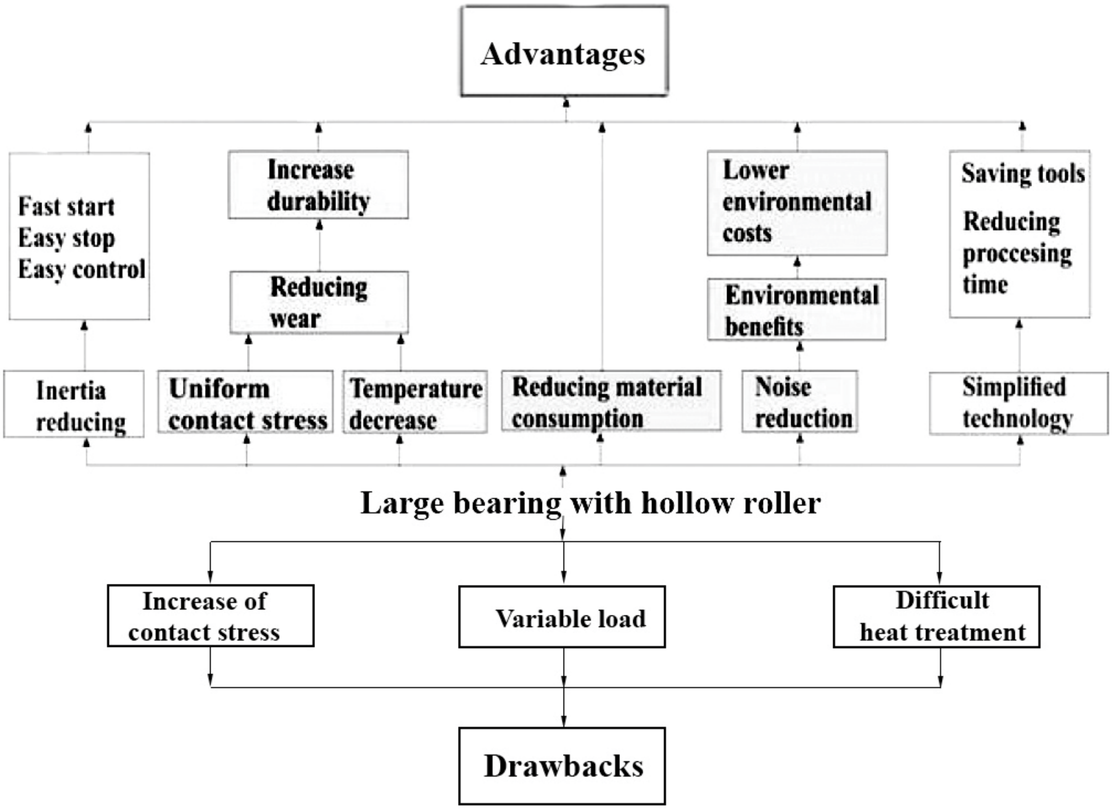


Fig. 1. Using of hollow rollers in large bearings - advantages and drawbacks

Utilization of hollow rollers has mainly been to achieve high speed, accuracy and low maintenance. With increasing the power of wind the control of high speed turbines is more difficult. At low speed, starting is more difficult and the reduction of the inertial forces becomes mandatory.

2. Lubrication of Large Bearings

The easiest to set up, with the greatest impact on the technological process, is traverse speed (V_t) [5, 8]:

The amount of lubricant can be calculated by the formula:

$$V_l = f_v \left[\rho_b \frac{10^{-3} \pi T (D^2 - d^2)}{4} - \frac{m_b}{7.8 * 10^{-3}} \right] \quad (1)$$

where: - V_l is lubricant volume[mm^3];

- f_v is a parameter who depends by rotation speed (approx. 0.3…0.5);
- ρ_b is bearing steel density;
- T is bearing width [mm];
- D is exterior diameter [mm];
- d is interior diameter [mm];
- m_b is bearing mass [kg].

The contact stress and the deformations occurred in the contact zone, between roller and raceway, strongly influence the lubrication film. The elastohydrodynamic theory [5, 7, 8] uses, for calculation of thickness of lubrication film, the point contact equation (Hamrock and Dowson, eq. (2)) and line contact equation (Dowson, eq. (3)) (Fig. 2).

$$H = 3.63U^{0.68}G^{0.49}W^{-0.073}\left(1 - e^{-0.68k}\right)R_r \quad (2)$$

$$H = 2.65U^{0.68}G^{0.54}W'^{-0.13}R_r \quad (3)$$

where: - H is minimum lubricant thickness [mm];
- U is a speed parameter who depends by rotation speed and lubricant viscosity;
- G is material parameter;
- W, W' are load parameters for point contact and line contact;
- k is a parameter who depends by contact area;
- R_r is curvature between roller and raceway [mm];
- h_r, h_i are deformations in roller and inner ring [mm].

3. Proposed Lubrication System

The concept of lubrication system implemented in hollow rollers of large bearings installed in wind power plants presents the latest fundamental elements of innovation consisting of positioning inside the hollow roller of an automated system equipped with control unit, temperature sensors, opening / closing module of the area with lubricant, wireless transmitter to the computer, power supply and monitoring software, command and control of the functional parameters of the bearing [10].

In Figure 2 it can be seen the proposed lubrication system scheme, following that research conducted during the project to establish the exact design and operation of each module. Thus the locking - unlocking system may comprise electrically operated valve or thermal or magnetic operated closing valves.

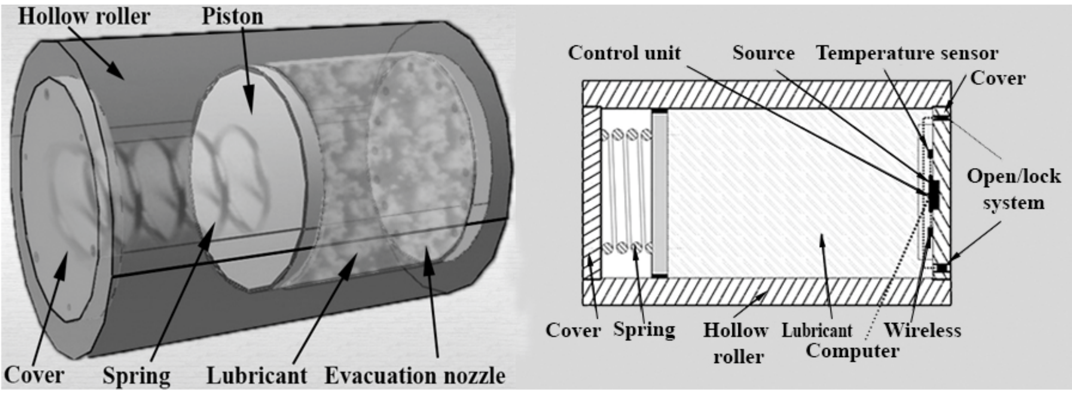


Fig. 2. Proposed concept of lubrication system

The source can be a sustainable battery or carbon brushes. The control unit can be programmable or programmed. The assembly may be inside or outside of the roller.

Through opening the valves, the lubricant liquid is pushed toward the runways, driven by the piston spring mounted under pressure. In opposite cavity, decompression of spring creates a pressure drop who allows absorption of spent lubricant on the raceways.

4. Finite Element Analysis of Hollow Roller with Covers

The results obtained by applying the finite element method were calculated in the position of maximum load when the force is perpendicular to roller. Redistributed components of normal loading force in angular positions is considered being smaller, without affecting the result.

The amount of radial force and thrust force can vary according to the factors of influence. Wind speed is the determining factor random variation of forces in the capital. Finite element analysis was made in Nastran software.

Were chosen rollers with D_{ext} = 128 mm and L = 180 mm. Material of roller is SAE 3310, carburized at 60 HRC. The diameter of bearing is D_{rul} = 2350 mm. Were chosen four cases according to the following values: hollow roller D_i = 80 mm and solid roller; hollow roller D_i = 80 mm and covers with thickness B = 2 mm; hollow roller D_i = 80 mm and covers with thickness B = 4 mm.

It was considered the case of variable loading with value Q = {25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275, 300} kN.

In Table 1 is shown the results of finite elements analysis for contact pressure and Von Mises stress.

Table 1. Contact pressure and Von Mises stress for different loads

Loads [kN]	25		50		75		100	
Roller type	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]
1	2390.3	1031.2	2391.5	1031.8	2392.7	1032.4	2393.8	1033
2	2399.6	1038.9	2400.8	1039.6	2402	1040.3	2403.1	1041
3	2400.4	1037.6	2401.6	1038.2	2402.8	1038.8	2403.9	1039.4
4	2398.5	1036.8	2399.6	1037.7	2400.7	1038.6	2401.6	1039.4
Loads [kN]	125		150		175		200	
Roller type	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]
1	2394.8	1033.6	2395.8	1034.2	2396.8	1034.8	2397.6	1035.6
2	2404.1	1041.7	2405.1	1042.3	2406.1	1042.9	2406.9	1043.4
3	2404.9	1040	2405.9	1040.6	2406.9	1041.2	2407.7	1042
4	2402.5	1040.2	2403.3	1040.9	2404.1	1041.6	2405	1042.3
Loads [kN]	225		250		275		300	
Roller type	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]	Contact pressure [N/mm^2]	Von Mises stress [N/mm^2]
1	2398.4	1036.4	2399.2	1037.2	2400	1038	2400.6	1038.7
2	2407.7	1043.9	2408.5	1044.4	2409.3	1044.9	2409.8	1045.1
3	2408.5	1042.8	2409.3	1043.6	2410.1	1044.4	2410.5	1044.5
4	2405.9	1043.1	2406.8	1043.9	2407.7	1044.7	2407.9	1044.9

where 1-solid roller; 2-hollow roller (D_i = 80 mm); 3-hollow roller (D_i = 80 mm, with covers 2 mm thickness); 4- hollow roller (D_i = 80mm, with covers 4 mm thickness).

5. Conclusions

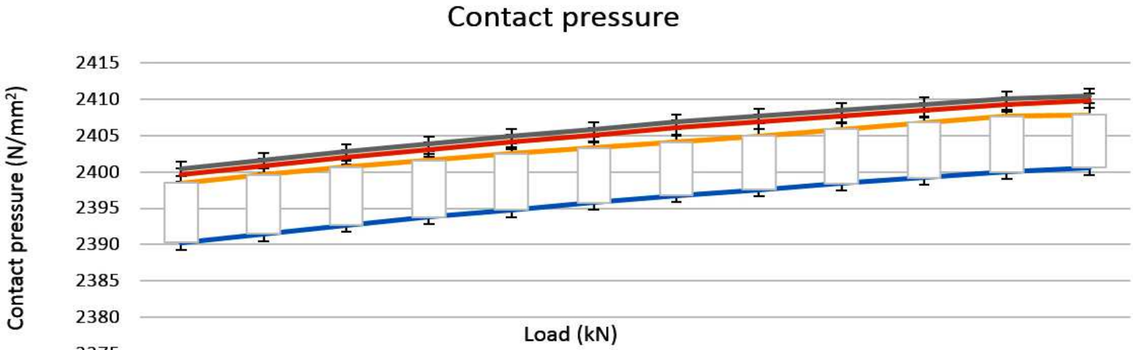
The lubrication system proposed is absolutely new and enables a maintenance of large bearings, better and more accurate. Tracking, monitoring, and control of lubrication is automated or managed by operator using computer, in real time. Adopting this system of lubrication allows takeover of spent lubricant in opposite cavity of hollow rollers. In this way, increases economic efficiency of wind power system.

Actuation of lubricant system is automatic, without the need to stop wind power plant, is thus prevents accidental increase of temperature by breaking the lubricant film. Implementing such a system does not involve a major technological change in construction bearings. Research conducted using finite element analysis demonstrates the possibility of introducing the proposed system without significant increases of contact stresses. In Fig. 3 is shown increasing of the contact pressure for different loads compared for the 4 types of rollers, solid roller, hollow roller and hollow roller with covers with thickness B= 2 mm and B-4 mm.

Research conducted using finite element analysis, demonstrates the possibility of introducing the proposed system without significant increases of contact stresses.

References

1. Harris, T.A., Kotzalas, M.N. (2006): *Advanced Concepts of Bearing Technology - Rolling bearing analysis*. CRC Press, 5th ed., ISBN 978-0-8493-7182-0, p. 42-70, New York, USA



	25	50	75	100	125	150	175	200	225	250	275	300
	2390.3	2391.5	2392.7	2393.8	2394.8	2395.8	2396.8	2397.6	2398.4	2399.2	2400	2400.6
	2399.6	2400.8	2402	2403.1	2404.1	2405.1	2406.1	2406.9	2407.7	2408.5	2409.3	2409.8
	2400.4	2401.6	2402.8	2403.9	2404.9	2405.9	2406.9	2407.7	2408.5	2409.3	2410.1	2410.5
	2398.5	2399.6	2400.7	2401.6	2402.5	2403.3	2404.1	2405	2405.9	2406.8	2407.7	2407.9

Fig. 3. Graph of contact pressure depending of the loading force

2. Bonneau, D., Fatu, A., Souchet, D. (2014): *Thermo-hydrodynamic Lubrication in Hydrodynamic Bearings*. Wiley, ISBN 978-1-84821-683-9, Croydon, UK
3. *** (2015): *Optimizing wind farm performance*. SKF Group, February 2015, p. 4-10
4. Dvorak, P. (2011): *How to automate bearing lubrication*. Available at: http:/www.windpowerengineering.com /design/mechanical/bearings/how-to-automate-bearing-lubrication/. Accessed at: 16.10.2016
5. Ebert, F.J. (2014): *Fundamentals of Design and Technology of Rolling Element Bearing*. Chinese Journal of Aeronautics, ISSN 1000-9361, Vol. 23, iss. 1, p. 123-136, doi:10.1016/S1000-9361(09)60196-5
6. Blau, J.P. (ed.) (1992): *Friction, Lubrication, and Wear Technology*. ASM International, ISBN 978-0-87170-380-4, Vol. 18. p. 745-757
7. Brewe, D.E., Hamrock, B.J. (1982): *Analysis of Starvation Effects on Hydrodynamic Lubrication in Nonconforming Contacts*. Journal of Tribology, ISSN 0742-4787, Vol. 104, iss. 3, p. 410-417, doi:10.1115/1.3253237
8. Huiskamp, B. (2004): *Grease life in lubricated-for-life deep groove ball bearings*. Evolution – the business and technology magazine from SKF, no. 2, p. 26–28
9. Lugt, P.M. (2013): *Grease Lubrication in Rolling Bearings*. Wiley, ISBN 978-1-118-35391-2, p. 9-21, New Delhi, India
10. Barabas, S., Florescu, A. (2016): *Analysis of bearings behaviour with cylindrical rollers with variable center of gravity*. Proc. of Int. Conf. COSME 2016, p. 133-138 (in print), Brasov, Romania

Received in November 2016