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# Enhancing wind turbine efficiency: characteristics of cylindrical-conical hydrodynamic fluid friction bearings



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### ABSTRACT

*One of the main causes of energy loss in wind turbine systems is friction between moving parts, particularly the multiplier, braking system and shaft supports. Conical- cylindrical plain bearings with a friction-reducing design help reduce energy consumption during turbine operation. Conical-cylindrical hydrodynamic bearings play a crucial role in wind turbines, reducing friction and energy losses, and effectively transmitting mechanical energy from wind blades to generators, thereby enhancing the overall efficiency of wind turbines. The research has developed a mathematical model to analyze the load-bearing capacity and energy losses due to friction. Using the calculation program developed on the basis of mathematical modeling and algorithms, a set of calculation experiments was performed to calculate the load-carrying capacity, moment and frictional power loss in a combined angular contact bearing depending on the shaft speed, lubricating oil supply pressure, radial clearance and relative eccentricity. This study investigates the characteristics of cylindrical-conical hydrodynamic fluid friction bearings and their critical role in optimizing the performance of wind turbines. By analyzing the load-carrying capacity, friction torque, and power losses under varying geometric and kinematic conditions, the research highlights how these bearings contribute to the overall efficiency and reliability of wind energy systems. The findings provide valuable insights into the design and operation of hydrodynamic bearings in highly loaded wind turbine applications, supporting the development of more sustainable and efficient wind energy technologies.*

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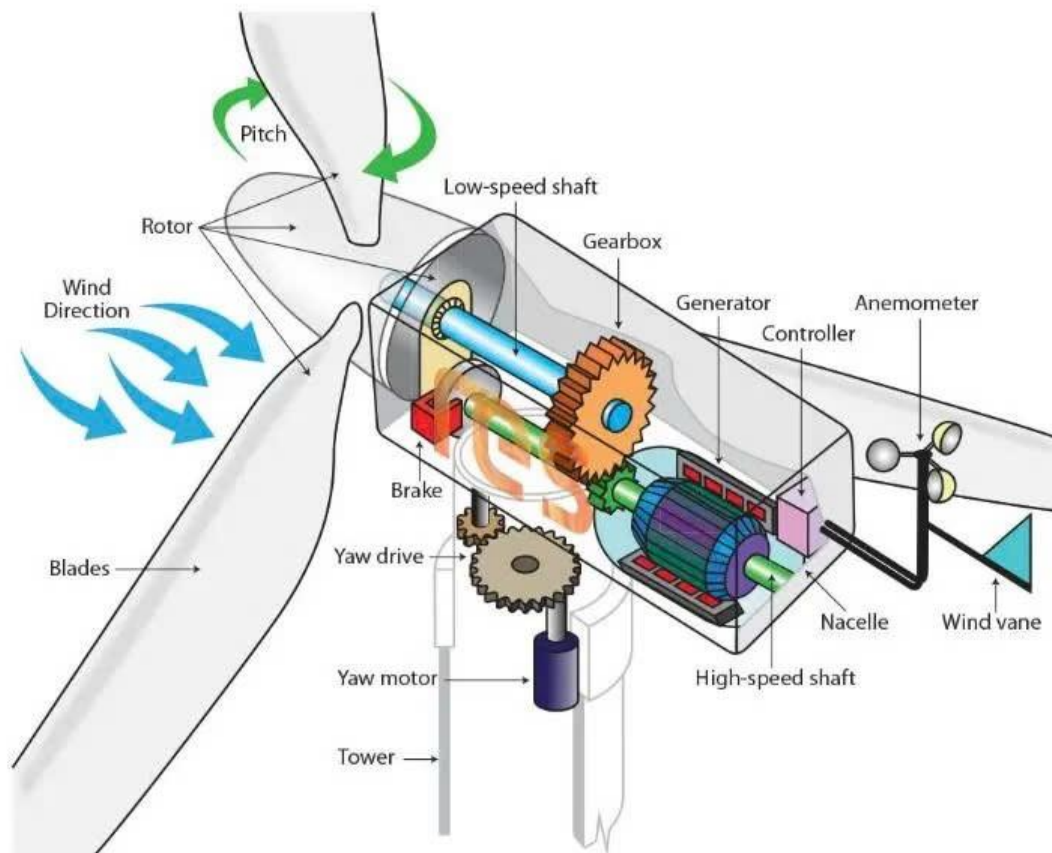
## 1. Introduction

The growing use of wind energy is not only driven and motivated by political considerations, such as policies to reduce carbon emissions, but also by the growing competitiveness of wind turbines in recent years. According to the International Renewable Energy Agency (IRENA.org), as of 2023, global installed wind energy capacity exceeds 900 GW, with onshore wind dominating but offshore wind growing rapidly. Wind energy accounts for approximately 7÷8% of global electricity generation. Vietnam has experienced rapid growth in wind energy, with installed capacity reaching 5,000 MW by 2023. Wind energy contributes around 4÷5% of the country's electricity mix.

Cylindrical-conical hydrodynamic fluid friction bearings play a critical role in the efficient operation of wind turbines, particularly in

supporting rotating components such as shafts and planetary gear systems. These bearings are designed to handle complex load conditions, including radial and axial forces, while minimizing energy losses. Figure 1 shows the main rotor components of a wind turbine, including the blades, shaft, and bearings. This abstract explores the energy characteristics of cylindrical-conical hydrodynamic fluid friction bearings and their significance in wind turbine applications (Marakhin et al., 2023).

One of the main causes of energy loss in wind turbine systems is friction between moving parts, particularly the multiplier, braking system and shaft supports. Conical- cylindrical plain bearings with a friction-reducing design help reduce energy consumption during turbine operation (Nguyen, 2024; Kazakov et al., 2021). When friction is minimized, the mechanical energy from the wind blades can be transferred to the generator more



*Figure 1. Layout of the rotor main elements of the wind generator- illustrates the main components of a wind turbine rotor, including the blades, shaft, and bearings. It highlights the critical role of cylindrical-conical hydrodynamic fluid friction bearings in supporting the rotating components and ensuring efficient energy transfer.*

efficiently; helping to improve the rate at which the wind's kinetic energy is converted into electrical energy, increasing the overall performance of the wind turbine, thereby increasing efficiency. In addition, with its cylindrical cone design, this plain bearing can distribute the load evenly across the contact surface, reducing the pressure on individual parts and increasing the load-bearing capacity (Nguyen et al., 2021). It follows that conical-cylindrical plain bearings have a larger contact surface than conventional plain bearings and when fully lubricated, they are able to significantly increase load carrying capacity and reduce friction, helping to reduce frictional energy losses, increase system life and improve system efficiency.

## 2. Mathematical model of a conical-cylindrical fluid friction bearing

Reynolds equation for a conical-cylindrical plain bearing (see Figure 2) in cylindrical coordinates:

$$\frac{\partial}{\partial r} \left( r h^3 \frac{\partial p}{\partial r} \right) + \frac{1}{r^2 \sin^2 \alpha} \frac{\partial}{\partial \varphi} \left( h^3 \frac{\partial p}{\partial \varphi} \right) = 6\omega\mu \frac{\partial h}{\partial \varphi} \quad (1)$$

Where:  $r$  - Radial coordinate (m);  $\varphi$  - Angular coordinate (rad);  $h$  - Gap of the lubricating layer

(m);  $\alpha$  - Cone angle (rad);  $\omega$  - Angular velocity (rad/s);  $\mu$  - Dynamic viscosity of the lubricant (Pa·s);  $p$  - Fluid pressure (Pa).

Gap function (Nikitin, 1981):

$$h(\varphi, r) = h_0 (1 - \varepsilon \cos \beta) \cos \alpha \quad (2)$$

Where:  $h_0$  - Initial gap of the lubricating layer (m);  $\varepsilon = e/h_0$  - Relative eccentricity;  $\beta = \frac{\varphi}{\sin \alpha}$  - Angle defined (rad).

Based on the results of pressure field analysis (Nguyen, 2024; Nikitin, 1981), we can apply them to calculate the necessary values below. Integration of pressure fields obtained on the basis of the solution of the Reynolds equation (1) allows us to obtain the values of hydrodynamic forces on the corresponding coordinate axes:

$$\begin{aligned} R_x &= \int_{r_1}^{r_2} \int_0^{\varphi_k} r p \sin \beta \cos \alpha d\varphi dr \\ R_y &= \int_{r_1}^{r_2} \int_0^{\varphi_k} r p \cos \beta \cos \alpha d\varphi dr \\ R_z &= \int_{r_1}^{r_2} \int_0^{\varphi_k} r p \sin \alpha d\varphi dr \end{aligned} \quad (3)$$

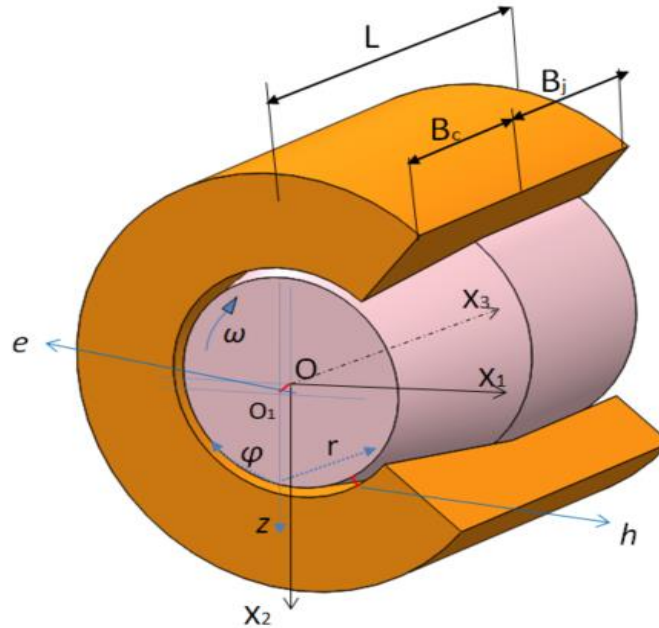


Figure 2. 3D model of the bearing and shaft - presents a 3D model of the cylindrical-conical hydrodynamic fluid friction bearing and its interaction with the shaft. It shows the geometric configuration of the bearing, including the cylindrical and conical sections, which are designed to handle both radial and axial loads.

Where:  $R_x, R_y, R_z$  - Hydrodynamic force components along the  $x, y, z$  axes (N);  $r_1 = \frac{R_1}{\sin \alpha}$  - inner radius of the bearing (m);  $r_2 = \frac{R_2}{\sin \alpha}$  - outer radius of the bearing (m).

The total moment of friction forces  $M_f$  is determined as the sum of the moments on the conical and cylindrical sections. The moment of friction force in the lubricant can be determined by the formula:

$$M_f = \int_{r_1}^{r_2} \int_0^{\varphi_k} r \sin \alpha \frac{h}{2} \frac{\partial p}{r \partial \varphi} r d\varphi dr \quad (4)$$

The total load capacity  $W$  of the hybrid bearing will be determined based on the following expression:

$$W = \sqrt{R_x^2 + R_y^2 + R_z^2} \quad (5)$$

Power losses  $\Delta N$  are determined by the formula:

$$\Delta N = M_f \omega \quad (6)$$

### 3. Results of calculation of characteristics of conical-cylindrical fluid friction bearing

Using the calculation program developed on the basis of mathematical modeling and algorithms, a set of calculation experiments was performed to calculate the load-carrying capacity,

moment and frictional power loss in a combined angular contact bearing depending on the shaft speed, lubricating oil supply pressure, radial clearance and relative eccentricity  $\bar{e} = e/h_0$ . When performing the calculations, the following geometrical and operating parameters were used:

- $B_c = 30$  mm - Width of the cylindrical section;
- $d = 40$  mm - Shaft diameter;
- $B_k = 30$  mm - Width of the conical section;
- $D = 60$  mm - Outer diameter of the bearing;
- $h_0 = 60$ -150  $\mu$ m - initial gap of the layer ;
- $p_a = 1.05 \dots 1.5$  MPa - supply pressure;
- $p_o = 1$  MPa - Atmospheric pressure;
- $\mu = 10^{-3}$  - Dynamic viscosity at  $T_0 = 293$  K.

The results of calculations of the bearing capacity and power losses in the support, depending on the relative eccentricity and on the angular velocity at different values of the gap of the lubricating layer are presented in Figures 3 and Figure 4.

As the results presented in Figure 3, the load-bearing capacity increases with increasing eccentricity. It is worth noting that the growth is nonlinear, especially at high values of the eccentric load-bearing capacity, which increases significantly. However, this dependence is also characteristic of the corresponding power losses. The general idea is that with an increase in the relative eccentricity and a decrease in the initial clearance, the load-bearing capacity and energy losses increase.

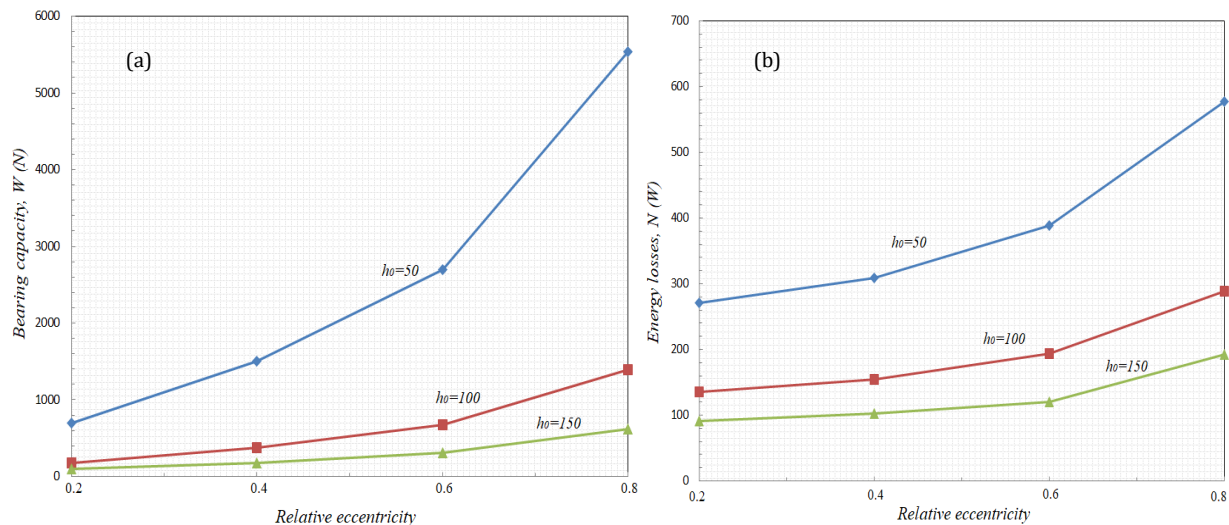


Figure 3 - Dependence of bearing load capacity and power losses on eccentricity for different gap values - consists of two subplots (a and b) showing the relationship between the bearing's load capacity, power losses, and relative eccentricity for different values of the lubricating layer gap.

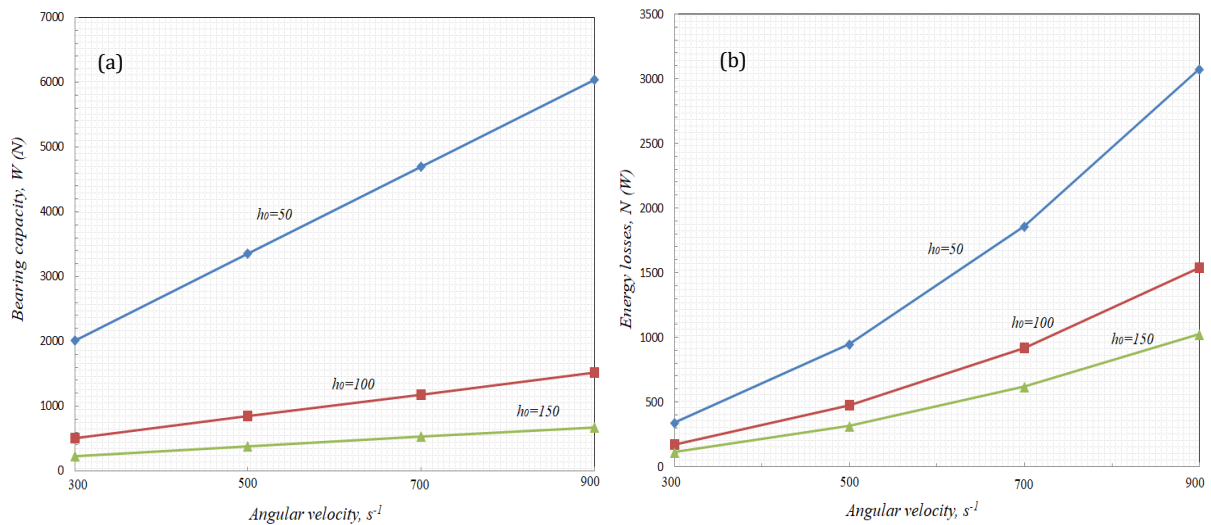


Figure 4. Dependence of the bearing load capacity and power losses on the angular velocity at different gap values - consists of two subplots (a and b) showing the relationship between the bearing's load capacity, power losses, and angular velocity for different values of the lubricating layer gap.

In Figure 4, we see that the growth of the load-bearing capacity depends on the shaft rotation speed, this growth is linear. At the same time, energy losses grow nonlinearly with a gradual increase in the shaft rotation speed. The general idea is that with an increase in angular velocity and a decrease in the initial clearance, the load-bearing capacity and energy consumption rapidly increase.

#### 4. Conclusion

In this study, a hybrid radial-axial fluid friction bearing with conical and cylindrical sections was modeled to analyze its load-bearing capacity and energy loss due to friction. The results revealed that these factors depend heavily on rotation speed, radial clearance, and shaft eccentricity.

These findings align with established research on conical bearing stability (Korneev, 2012) and advanced thermal-elastohydrodynamic modeling (Hannon & Braun, 2007), which underscore the importance of precise design and analysis for high-performance applications.

For future applications in wind energy, research will focus on improving lubrication supply and developing radial bearings capable of stabilizing rotor rotation at critical speeds. Conical-cylindrical plain bearings, with optimized design and lubrication, offer a promising solution for wind turbines, potentially lowering energy

consumption, extending system lifespan, and cutting maintenance costs while increasing power generation efficiency.

#### Contributions of authors

The sole author contributed to all aspects of this manuscript.

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