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Influence of Inertial Forces of Large Bearings Utilized in Wind Energy Assemblies

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Abstract**—**Main objective of this paper is to establish a link between inertial forces of the bearings used in construction of wind power plant and its behavior. Using bearings with lower inertial forces has the immediate effect of decreasing inertia rotor system, with significant results in increased energy efficiency, due to decreased friction forces between rollers and raceways. The F.E.M. analysis shows the appearance of uniform contact stress at the ends of the rollers, demonstrated the necessity of production of low mass bearings. Favorable results are expected in the economic field, by reducing material consumption and by increasing the durability of bearings. Using low mass bearings with hollow rollers instead of solid rollers has an impact on working temperature, on vibrations and noise which decrease. Implementation of types of hollow rollers of cylindrical tubular type, instead of expensive rollers with logarithmic profile, will bring significant inertial forces decrease with large benefits in behavior of wind power plant.

Keywords**—**Inertial forces, Von Mises stress, hollow rollers.

I. Introduction

REDUCTION of inertia of wind power system is one of most important effect of using of hollow rollers, who leading to increasing energy efficiency, simplifying maintenance technology and growth of economic profits.

There have been attempts to use several hollow roller in a bearing for different reasons but so far, from what we investigated, implementation of large bearings with hollow rollers in construction of wind power systems is not used. An evaluation of the production tendencies, as well as a research of the development market pointed out the demand of the beneficiaries in the maintenance of working systems. The difficulties appeared in maintenance (poor lubrication, highly qualified assistance), as well as eliminating problems as vibration or noise, can be reduced or even removed, using bearings with hollow rollers. The main issue in the tower design is the appearance of vibrations, who decrease with reduction of inertial mass. Increase energy efficiency (wind power) is based on decreasing moment of inertia of rotor hence its inertial mass. That will lead directly to increase rotational speed of main shaft so will enable faster start at low speed wind of power plant. With decreasing inertia, the starting, the speed control during energy production, and stopping the turbine when required are more well done.

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Research has been conducted to an alternative roller structural form, hollow roller with different hollowness which is more flexible when responding to variations of bearing loads, and it should have less strict requirements on manufacturing precision

The power profile was achieved using control dynamic dispatch. The optimal setting of parameters with influence in power system was made by optimization techniques and probabilistic approach. The quantification of resulted energy revealed important gains in correlation with the objectives proposed: maximization energy output and constrained economic dispatch, namely, cost per KW. The proposed real-time control system is based on the following constraints: reduction of material consumption, inertia reducing, increase of durability, decrease of environmental costs, and simplification of large bearings technology [4], [13].

The F.E.M. analysis indicate that for certain range of the roller geometry the use of hollow rollers will not weaken the strength of the bearing, on the contrary, increased its sustainability. As a result, the hollow rollers could function similarly with rollers with logarithmic profile, but the manufacturing procedures are simplified and the mass of bearing is lower. The research clearly shows that different hollow rollers, tested in simulations, not only reduces the inertial mass, but behave as good in deformations and much better in the contact stress. The relation between inertial forces developed in bearing and behavior of power system was modeled, considering main factors influenced by them in dynamic connection. The critical factors with complex evaluation are energy production and quality of power who depends of inertia, level of noise, technology and cost per KW. Reducing subsidies in this area makes the proposed bearing with hollow rollers, to be of great interest as it leads to significant savings by reducing maintenance cost price of wind power stations by increasing sustainability and energy efficiency.

The mathematic model is based on a stochastic algorithm when loads are predicted to be extreme, being necessary the calculation of cut-in speed and cut-out speed of power system. The control of system with low inertial forces is easier and more accurate. The bearings with hollow rollers have advantages such as reduction of the inertial loads, weight reduction, material saving, increasing of durability.

II. Mathematical Modeling of Influence of Inertial Forces on Control of Wind Turbine

The computational model is based on scheme presented in Fig. 1.

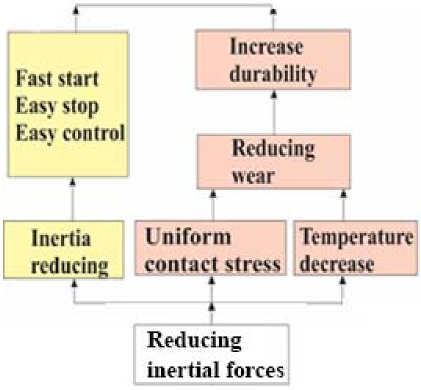

Fig. 1 The influence of inertial forces on wind turbine behavior

Fast start, easy stop and easy control bring an increase of energy efficiency.

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power.

The speed at which the turbine first starts to rotate and generate power is called the *cut-in speed* and is typically between 3 and 4 meters per second. As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the *cut-out speed* and is usually around 20-25 meters per second.

The total moment of inertia for a three-bladed turbine [1] is given by:

$$J = 3 m_b r^2 \tag{1}$$

where: m_b is the mass of one blade; r is the radius of weight center of blades.

$$J_R \cdot \dot{\omega}_R = M_a - M_g \tag{2}$$

$$M_g = \frac{P_T}{\omega_G} \tag{3}$$

$$M_a = \gamma \cdot \mathbf{R}^3 \cdot \mathbf{v}_w^2 \tag{4}$$

where: J_R is the moment of inertia of the rotor; ω_R is the rotational speed of the main shaft; ω_G is the rotational speed to the start of generator. M_a is aerodynamic torque; M_g is generator torque. P_T is is output energy; γ is a constant depending by turbine construction; R is rotor radius; V_w is the wind speed.

Influence of inertial mass on the speed is evident according to (2)-(4). Direct relation between wind speed and inertia leads to a decrease of cut-in speed in case of decrease of inertial mass of rotor. [7].

Relation (2) leads to the obvious conclusion: importance of decreasing moment of inertia of rotor hence its inertial mass, will lead directly to increase rotational speed of main shaft so will enable faster start at low speed wind of power plant.

Because of the large moment of inertia of the rotor, the main design challenges include the starting, the speed control during the power producing operation, and stopping the turbine when required.

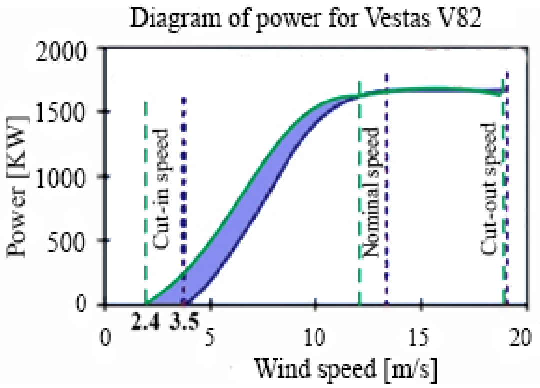

Fig. 2 Typical wind turbine power output equipped with bearings with filled rollers (3.5 curve) and expected power output for wind turbine equipped with bearings with hollow rollers (2.4 curve) [14]

For Vestas V82, the computational model in conjunction with experimental observation (the cut-in speed decrease from 3.5 m/s to 2.4 m/s) lead to concrete values of gain energy at single start-up at 250 KWh. For 15 start-up/month gain energy for one turbine is approx. 45MWh in one year that means 3% of entire capacity of turbine.

III. Mathematical Modeling of Influence of Inertial Forces on Sustainability of System

Increase of durability is based on temperature decrease in the system, on reducing wear due to uniform contact stress to the end of the rollers.

The rolling element fatigue life is inversely proportional to the maximum stress to the ninth power (Lundberg-Palmgren) (5) or Zaretsky equation (6):

$$L \approx \left(\frac{1}{\sigma_{\max}}\right)^9 \tag{5}$$

$$L = A\left(\frac{1}{\tau}\right)^{\frac{c}{e}}\left(\frac{1}{V}\right)^{\frac{1}{e}} \approx \frac{1}{\sigma_{\max}^n} \tag{6}$$

where: *A* is a constant factor of material; τ is critical shear stress; *c/e* is Lundberg-Palmgren parameter (val. 9); *e* is Weibull slope (val.1.1); *V* is elemental volume; S_{max} is maximum Hertz stress; *n* is Hertz stress life exponent (val. 9…12).

Barnsby starting from the Ioannides-Harris theory [11] introduces the stress factor K_c.

$$K_c = 1 + \left(1 - C_L^{\frac{1}{4}}\right)\frac{\sigma_{VM,\lim}}{\sigma_{VM,\max}} \qquad (7)$$

where: $\sigma_{VM,\lim}$ is fatigue limit of Von Mises stress; $\sigma_{VM,\max}$ is maximum of Von Mises stress; C_L is lubricant parameter.

In this research was used for simulate the comportment of rollers, Von Mises stress criterion. Nastran software found all stress components on each point and the results are conform with Von Mises stress equation [12]:

$$\sigma_{VM} = \frac{1}{\sqrt{2}}\sqrt{\left[(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6\cdot(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)\right]} \qquad (8)$$

For large bearing durability in millions rotation is [4], [5]:

$$L_{na} = a_1 \times a_2 \times a_3 \times a_v \times a_r \times a_c \times a_a \times \left(\frac{C}{P}\right)^p \qquad (9)$$

where: L_{na} is nominal durability in millions rotations [9]; a_1 is factor of reliability; a_2 is factor for material; a_3 is factor for running conditions; a_v is speed factor; a_r is a roughness factor; a_c is a factor for lubricant; a_a is factor of coaxiality; C - basic dynamic load [N]; P - equivalent dynamic load [N]; p - exponent for roller bearings: p=10/3;

The ratio $\left(\frac{C}{P}\right)$ is direct dependent on contact stress.

The chemical composition of steel (SAE 3310) is shown in Table I.

TABLE I
CHEMICAL COMPOSITION OF BEARING ELEMENTS

Steel	Chemical composition [%]							
	C	Mn	Si	Cr	Ni	Mo	S	P
SAE 3310	0,08 0,13	0,45 0,60	0,15 0,35	1,40 1,55	3,25 3,75	0,15	max 0,03	max 0,04

A precise analysis of the bearing must consider contact deformations because they are not equal at all points on the contact surface. [2]. Elastic deformations directly influence the size of the angular velocity vector, therefore, influence tangential velocities sizes considered in point of contact and sliding speeds.

The advantages of the logarithmic profile have been largely confirmed in research applications. A recent study also suggested that a crowned profile would be better profile, which can be used to eliminate stress concentration [5], [6]. In both cases manufacturing precision is very high and affect the cost of the bearing. If the manufacture of the roller surface is not accurate enough, the uniform stress distribution may not be achieved, because the edge-stresses cannot be eliminated, as expected but using of hollow rollers allows good results with low costs

The diameter of bearing has the D_{rul} = 1900 mm. For the inside diameter (hole diameter) were chosen four cases according to the following values: Di_1 = 60 mm, Di_2 = 80 mm, Di_3 = 90 mm, Di_4 = 100 mm. Finite element analysis shows the following results (Fig. 3).

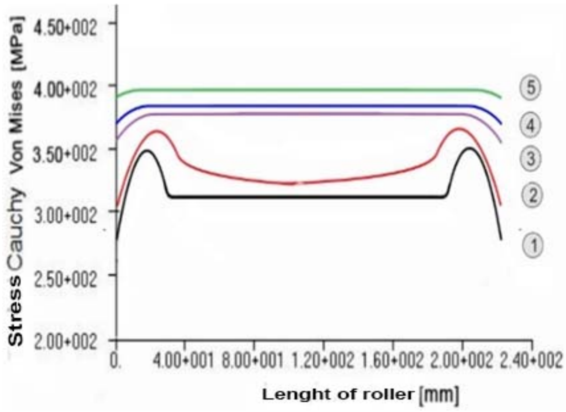

Fig. 3 Graph of contact stress in roller depending on cavity-results obtained by finite element analysis-1) solid roller D = 120mm, 2) hollow roller Di = 60mm, 3) hollow roller Di = 80mm, 4) hollow roller Di = 90mm 5) hollow roller Di = 100mm [3]

Curve 1 represents the contact stress appeared in a solid roller (Fig. 3). It can be seen that even if the end tensions does not exceed the permissible limits, bearing wear unevenly, leading to sliding movements. As shown, sliding produces frictions and leading to heat of bearing, fluidization of lubricant, shortening its durability. Curve 1 (Di = 60 mm), rollers respond the requirement to reduce inertial mass in a small measure, without an essential contribution to increasing the efficiency of large bearing assemblies. Both deformations and tensions are similar to the solid roller (Fig. 3). Curve 3 (Di = 80mm), curve 4 (Di = 90mm) and curve 5 (Di = 100mm) have end tensions, completely reduced. The bearing has uniform wear that increases durability, (stress-free to the end of roller) and respond perfectly to requirements reduction of inertial mass [1], [8].

The reduction of irregular wear is made using hollow rollers. Their degree of cavity increase or decrease masses, forces and inertial and centrifugal moments.

Due to increased elasticity to the ends of hollow roller, the Von Mises stress decrease, the graphic being constant. Under the same conditions, the stress caused by the contact between the race and the hollow roller is less than the stress caused by the contact between the race and the solid roller. Further, FEM simulation shows that a stress concentration occurs at the ends of solid cylindrical roller but for the hollow roller the stress concentration is the same on the entire length. [10]

The uniform stress combined with vibrations reduction and low temperature operation (in cavity of rollers can be stored an additional amount of lubricant) lead to gain energy for one turbine aprox.7%. Expected life of bearing with hollow rollers only can be predicted at 21-22 years as against 20 years for classic bearing.

For a roller with D_i= 80mm the difference between a solid roller and a hollow roller is approx. 35 kg. (Table II)

TABLE II
WEIGHT OF ROLLERS WITH DIFFERENT HOLLOWNESS

D_i roller [mm]	0	60	80	90	100
Weight [Kg]	78,22	58,67	43,46	34,22	23,90

For a bearing with 20 rollers the difference is approx. 700 kg, with 30% lighter in weight.

IV. CONCLUSION

The reduction of irregular wear is made using hollow rollers. Their degree of cavity increase or decrease masses, forces and inertial and centrifugal moments. Their mounting on large bearing don't present any difficulties. The processing is identical with that of the cylindrical rollers and much more easy and cheap then processing cylindrical rollers with logarithmic profile. Switching to bearing with hollow rollers doesn't require major changes in technology. The present study is dealing with the problem of their resistance in assemblies bearing – wind power. New problems are the bigger deformations and contact stress.

The research was conducted taking into account the real radial force from a wind power but the calculations was made on a bearing with cylindrical rollers on one row. In reality this bearing are used rarely, usually bearings on two or four rows. It was considered, in simulation, if a bearing with rollers on a single row responds positive, the results can be extrapolated also on the other type of bearings.

The dynamic analysis performed with the help of finite element method as well as the results of the analytical model calculations lead to the conclusion that hollow cylindrical rollers can replace rollers with logarithmic profile, more expensive and heavy, bringing in the same time an increase of life of the bearing through the reduction of uneven wear of rolling elements

Inertial forces developed in bearings, mounted in wind energy systems, due to high weight are one of the biggest problem in function of wind turbine. Reducing them, by using hollow rollers represents an advantageous solution.

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