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INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2015
Brasov, 28-30 May 2015

SAVING ENERGY ESTIMATION FOR USE OF HOLLOW ROLLERS IN BEARINGS UTILIZED IN WIND ENERGY TURBINES

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Abstract: *The main objective of this paper is to establish the benefits obtained by implementing hollow rollers in the construction of large sized bearings, mounted in wind turbines by using innovative constructive solutions. Using hollow rollers has the immediate effect of decreasing inertia rotor system, with significant results in increased energy efficiency. This is due to decreased friction forces between rollers and raceways and by the uniform contact stress occurring at the ends of the rollers. Favorable results are expected in the economic field, by reducing material consumption and by increasing the durability of bearings. Using 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 price decreases*

Keywords: *saving energy, hollow rollers, dynamic dispatch*

1. INTRODUCTION

Use of bearings with hollow rollers in wind energy turbines is an innovative concept in saving green energy by increasing efficiency, with great benefits in maintenance technology and economic profits.

There have been attempts to use several hollow rollers 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 new and 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.

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.

In Romania, the renewable energy production reached a record level at the end of last year when the total capacity of projects in the system reached 4255 MW, 82% higher than the end of the year 2012, according to the National Authority in Energy Regulation data, the producers of renewable energy receive subventions as green certificates which all the consumers pay. To regulate the growth of invoices the government decided on July 1st 2013 to delay until 2017-2020 some green energy certificates. Romania assumed that 24% of electricity consumption from the year 2020 to come from renewable sources but the National Authority in Energy Regulation announced that this target was already achieved on January 1st 2014.[10]

2. ENERGY SAVING PROFILE OF WIND POWER SYSTEM

The energy saving 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 energy saving 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. (Fig.1)

Estimation of energy saving for wind turbine using bearings with hollow roller was made after constraints application [2]:

$$P_{SE} = P_T \times \sum_{i=1}^{n} P_{SE\,(F_i)} \tag{1}$$

where: P_{SE} is energy saving for a wind turbine;

P_T is output energy before implementation of bearings with hollow rollers;

$P_{SE(Fi)}$ is estimated value of saving energy of each constraint.

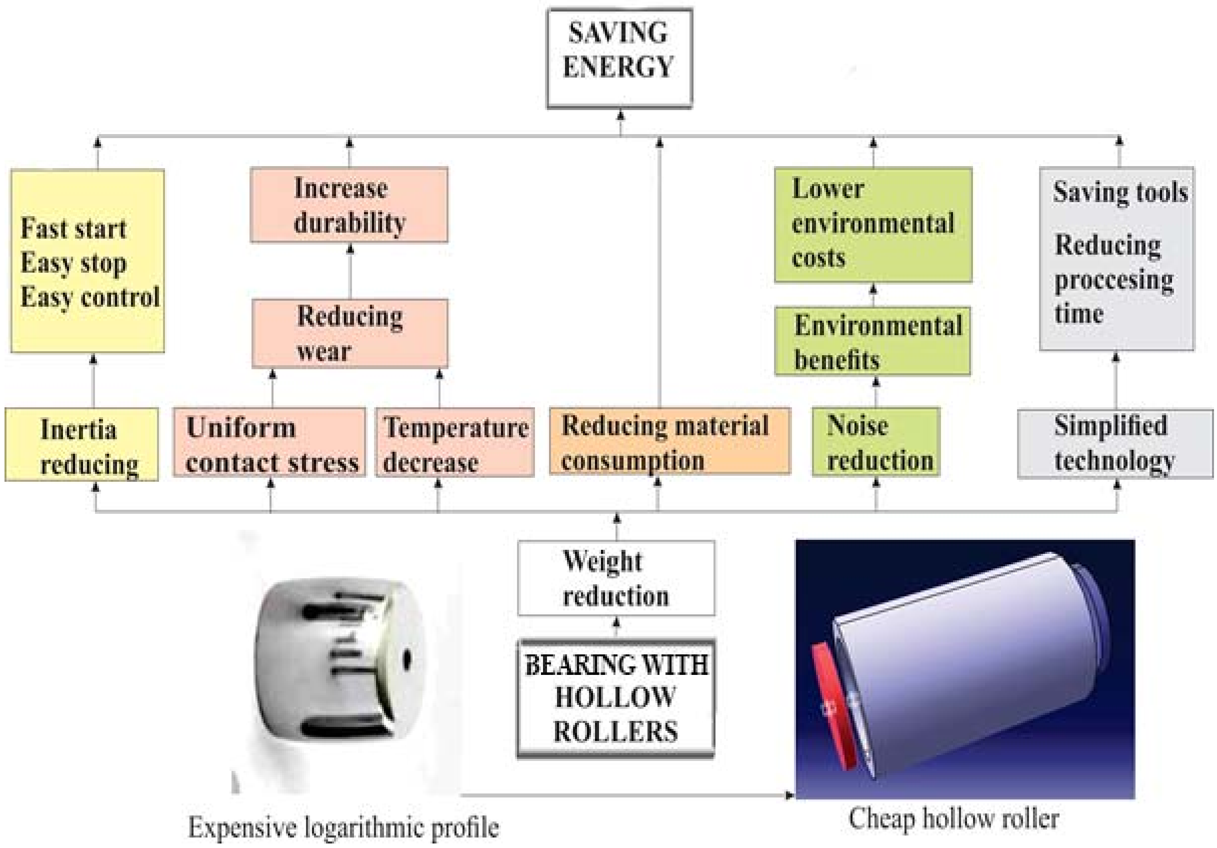

Figure 1 – The parameters who influences the saving energy in case of implementation in wind energy system of bearings with hollow rollers

3. MATHEMATICAL MODELING OF SAVING ENERGY OF WIND TURBINE

3.1 Inertia reducing. Reduction of inertia of system is one of most important effect of using of hollow rollers. Fast start, easy stop and easy control bring an increase of energy efficiency [6].

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.

$$J_r \cdot \dot{\omega} = M_a - M_g \quad (2)$$

where: J_r is rotor moment of inertia
ω is rotor speed;
M_a is aerodynamic torque;
M_g is generator torque.

$$J = \sum m_i \cdot r_i^2 \quad (3)$$

$$P_T = \omega \cdot M_g \quad (4)$$

$$M_a = \gamma \cdot \mathbf{R}^3 \cdot \mathbf{v}_w^2 \quad (5)$$

where: r_i is the radial distance from the inertia axis to the particle of mass m_i and the summation is taken over all particles;

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 relations (2) and (3). Direct relation between wind speed and inertia lead to a decrease of cut-in speed in case of decrease of inertial mass of rotor. (Fig.2) [7].

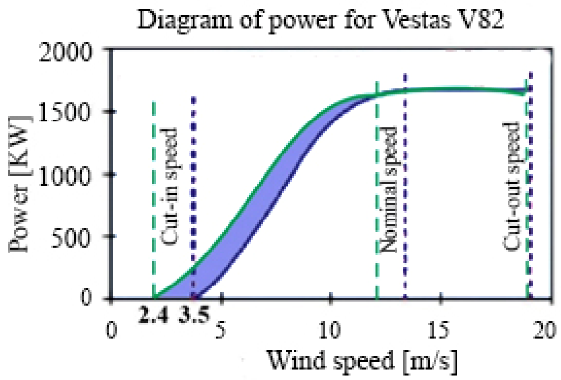

Figure 2 - Typical wind turbine power output equipped with bearings with filled rollers (blue) and expected power output for wind turbine equipped with bearings with hollow rollers (green)

In Fig. 2, with blue is quantity of gained power at a single starting, in case of wind turbine with bearings with hollow rollers and depend of power coefficient of every turbine. 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.

3.2 Increase durability. It is based on temperature decrease in the system, on reducing wear due to uniform contact stress to the end of the rollers. For large bearing durability in millions rotation is [4, 5]:

$$L_{na} = a_1 \times a_2 \times a_3 \times a_v \times a_r \times a_c \times a_a \times \left(\frac{C}{P}\right)^p \quad (6)$$

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.

Were chosen rollers with D_{ext} = 120 mm and L = 220mm from SAE 3310, carburized at 65HRC. 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**.**

For bearing with solid rollers and for all bearings with hollow rollers was made the finite element analysis with Nastran software. The results was showed in diagram in Fig.3 [3]

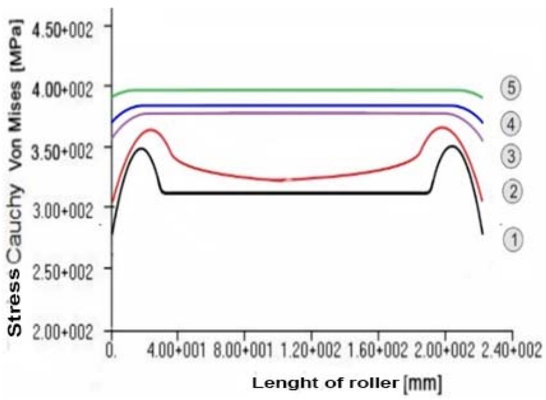

Figure 3 - Graph of contact stress in roller depending on cavity-results obtained by finite element analysis-1) solid roller D = 120mm, 2) hollow roller Di = 60mm, 3) hollow roller Di = 80mm, 4) hollow roller Di = 90mm 5) hollow roller Di = 100mm

Curve 1 belongs radial cylindrical roller bearing straight and solid (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. Their mounting on large bearing do not 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. Both 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. 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 (eq.6) as against 20 years for classic bearing.

3.3 Reducing material consumption. For a roller with D_i= 80mm the difference between a solid roller and a hollow roller is approx. 35 kg. (Table 1)

Table 1 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. For a product with 20 years life the saving energy for product for 1 year is approx. 1.5 % if we approximate the gained weight with gained energy. The saving energy in environmental domain is based on noise reduction due to possibility of use of phono-absorbant foam with lubricant in cavity of rollers. The saving energy in technology domain for one product for one year is based to reducing of tools consumption. The both require complex computation and are approximate at 2% and respectively at 6 %. The total energy saving is approx. 26%.

4. CONCLUSIONS & ACKNOWLEDGEMENT

Total saving energy is estimated to a 1.65MW/h x 26% = 0.43 MW/h. This saving energy is gained through the use of one bearing of hollow roller with D_{ext} =1900mm. The roller diameter is D=120 mm and the cavity has diameter D_i=80 mm. Main area, on which it pursues a growth effect is energy performance by implementing a new bearing with hollow rollers in large assemblies of wind energy, leading to increase their sustainability through capacity building maintenance.

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.

Market study, technical, financial and operating reports has encouraging results.

This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of Labor, Family and Social Protection, Romania, co-financed by the European Social Fund – Investing in People, within the Sectorial Operational Programme Human Resources Development 2007-2013.

REFERENCES

1. Abu-Jadayil, W.M., Jaber, N.M., ”*Numerical prediction of optimum hollowness and material of hollow rollers under combined loading*”. Materials and Design no.31, ISSN: 0261-3069, 2010, pag.1490–1496.
2. Bhateja, C.P., Hahn, R.S.,”*A Hollow Roller Bearing for Use in Precision Machine Tools*”, CIRP Annals, Man. Technology, Volume 29, Issue 1, 1980, pag. 303-307.
3. Baraba, S.A., erban, C.,”*Heat treatment for 20NiCrMo7 and 15NiCr13 steels used in construction of extralarge bearings*”. Recent Journal Vol. 11 No. 2 (29), July 2010 ISSN 1582-0246.
4. Blau, J.P.,”*ASM Handbook, Friction, Lubrication, and Wear Technology*”. ASM International, Vol. 18, 1992.
5. Doll, G. L., Kotzalas, M. N. and Kang, Y. S. Life-Limiting Wear of Wind Turbine Gearbox Bearings: Origins and Solutions Timken Company
6. Hosseini, S.A.A., Khadem, S.E.,”*Free vibrations analysis of a rotating shaft with nonlinearities in curvature and inertia*”. Mechanism and Machine Theory, pag. 272–288, 2009.
7. Kakuta, K.,”*High Speed Rolling Bearings for Gas Turbines*”. Japanese Journal of Tribology, Vol. 35, 1990, pag. 877-889.
8. Wei, Y., Balendra, R.,”*FE analysis of a novel roller form: a deep end-cavity roller for roller-type bearings*”. Journal of Materials Processing Technology 145, 2004, pag. 233–241.

9. ***Tapered roller Bearing Catalogue, INA Schaeffler.

10. http://www.reportsandintelligence.com/global-waterjet-cutting-machine-2014.