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Practical Application of Eddy Currents Generated by Wind

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Practical Application of Eddy Currents Generated by Wind

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Abstract. When a conductive material is subjected to time-varying magnetic fluxes, eddy (Foucault) currents are generated in it and magnetic field of opposite polarity as the applied one arises. Due to the internal resistance of the conductive material, the eddy currents will be dissipated into heat (Joule heating). Conventional domestic water heaters utilize gas burners or electric resistance heating elements to heat the water in the tank and substantial part of the energy to use for it is wasted. In this paper the origin of electromagnetic induction heat generated by wind turbine in special heat exchange camera connected to water boiler is discussed and material evaluation performed using mathematical modelling (comparing the 2D finite element model with analytical and numerical calculation results).

1. Introduction

Wind turbines are often used to obtain the additional heat, but the existing solutions do not offer direct wind mechanical energy transformation into heat energy [1] (Figure 1).

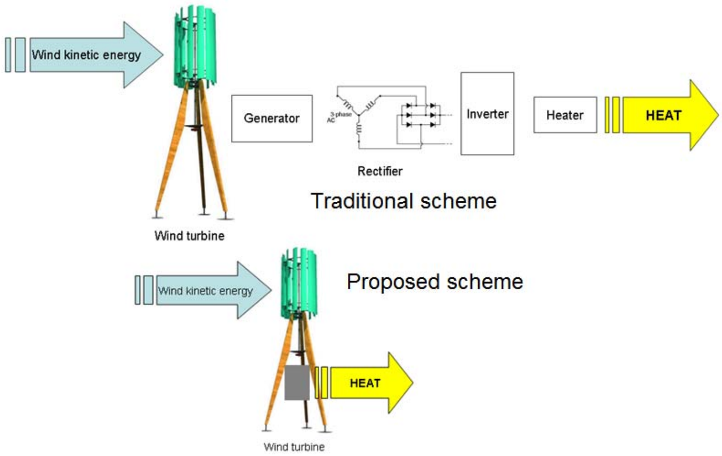

Figure 1. Schematic of commonly used and proposed wind energy – heat conversion.

Usually the wind mechanical energy is supplied to an AC electric generator shaft, where it is converted into electricity; the electricity is converted into commercially usable, for example, 220V 50Hz electricity by using the inverter. Next, with this 220V 50Hz electricity the heater, boiler,

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etc. heating device is powered to generate the heat. One way to heat using wind is to drive a heat pump, but generalization of the wind heating concept is friction heating. The friction heat generators has stationary and rotatable friction discs with a thin fluid film between the discs. Disc interface pressure is created perpendicular to the disc surfaces, and heat is generated by the shearing of the thin fluid film. [2,3].

In this work direct mechanical wind energy into heat energy conversion mechanism is analyzed: using alternating magnetic field (heat is produced in accordance with the Joule - Lenz's Law and hysteresis losses). That is, if a conducting body is placed in a variable magnetic field, which in our case is caused by permanent magnets in rotor attached to a wind turbine shaft, an eddy electric field will be induced, in the volume of the body causing the eddy currents with the electric current density vectors *j*. These currents are also called Foucault currents [4]. Core loss occur in magnetic cores of ferromagnetic materials under exitation of alternating magnetic field. It can be divided into hysteresis, eddy current and excess loss, if a ferromagnetic material is used. Almost no research on this subject, except for certain patents applied on the rotation movement transformation to heat [5].

2. Model description

Rotor shaft is attached to mechanical energy source (wind turbine etc.) – it carries the rotation mechanical energy and creates a time varying magnetic field. The core of it is made from ferromagnetic material (electrical steel) and strong permanent magnets (NdFeB with remanent flux density 1,42 T) are attached. Magnets are aligned with opposite magnetic poles alternately to produce a time varying magnetic field when rotor turns. Radial as well as axial magnetic flux geometry can be used. An axial magnetic field double rotor configuration has been considered as optimal and is analyzed in this work. Two rotor discs with NdBFe (N52) permanent magnets are mounted on the shaft and an axial magnetic field is generated in the space between them (Figure 2).

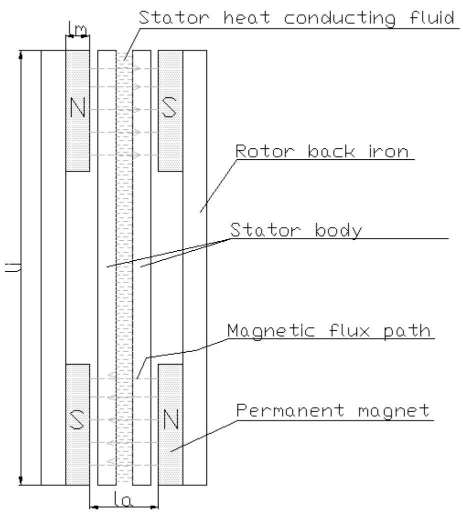

Figure 2. The cross section of magnetic circuit.

Magnetic circuit with air gap length of l_a, permanent magnet length of l_m and back iron length l_i is considered (see Figure 2). The stator body as well as heat conducting fluid material are non ferromagnetic (copper, aluminum or other material with high electrical conductivity), it's thickness is magnetically equivalent to the air gap. Air gap magnetic flux density can be expressed as fallows:

$$B_a = \frac{2 \cdot B_r l_m}{\mu_m \left(\frac{l_a}{\mu_a} + \frac{l_i}{\mu_i} + \frac{2 \cdot l_m}{\mu_m} \right)} \qquad (1)$$

where B_r is the remanent flux density of the permanent magnet. For the NdFeB N52 permanent magnets with $B_r \approx 1{,}45$ T, thickness of the magnet $l_m = 13$ millimeters, magnetic permeability of the magnet $\mu_m = 1{,}05$, air gap length $l_g = 32$ millimeters, permeability of air $\mu_a = 1$, $\mu_i >> l_i$, the magnetic field density in the air gap can be calculated from equation (1) and is equal $B_a = 0{,}63$ T. Performin numerical calculation of model described above, it is seen (Figure 3.), that the magnetic flux lines bulge outward and effect is the increase of air gap cross sectional area for a factor approximately 1,25. So the real magnetic field density in the air gap is $B_a = 0{,}50$ Tesla, what is in good comparison with numerical results.

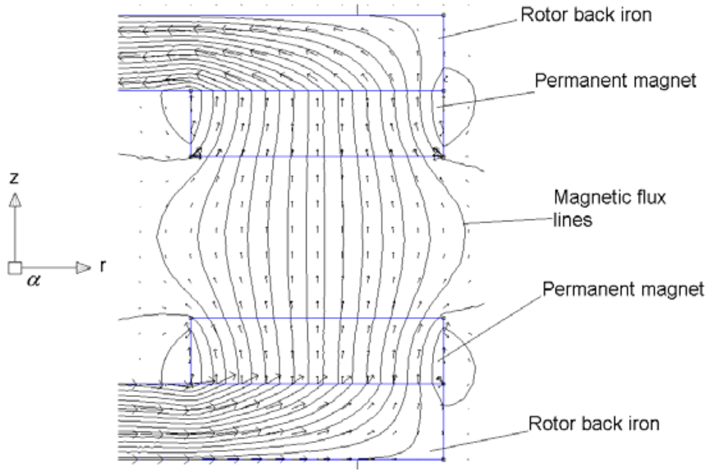

Figure 3. Finite element magnetics simulated magnetic field distribution.

3. Calculation of Eddy current losses

When magnetic field changes in time, from Faraday's law fellows that an electromotive force and thus a current is induced in stator material. Since the material is conductor, eddy currents will be induced as the excitation field varies and power loss called eddy current loss will be caused by the induced eddy currents.

Eddy current distribution in stator conductor can be obtained using Faraday's law of induction and Ohm's law [6]:

$$I_{eddy} = j_{eddy} \cdot S = \sigma d r E_{0,\alpha} = \frac{\sigma d r^2 i \omega B_{0,z}}{2}, \quad (2)$$

where σ is electrical conductivity of stator body material, d - thickness of stator body material, ω - angular frequency of time varying magnetic field created by rotating permanent magnets in rotor and r - radius of induced eddy current path. $\vec{B}_{0,z}$ is resultant magnetic field of permanent magnets in rotor B_{PM} and is created by induced eddy currents in stator conductor B_{eddy}: $B_{0,z} = B_{PM} + B_{eddy}$

B_{eddy} is magnetic field produced by current loop, therefore the equation for the current in the stator conductor is:

$$I_{eddy} = \frac{\sigma d r^2 i \omega}{2}\left(B_{PM} + B_{eddy}\right) = \left(B_{PM} + \frac{\mu_0 I_{eddy}}{2r}\right) \quad (3)$$

Introducing new parameters $\Omega = \frac{\sigma d r \omega \mu_0}{4} = \frac{\sigma d r \pi f \mu_0}{2}$ and $K = \frac{B_{PM} 2r}{\mu_0}$ the equation for the current moule in stator conductor is expressed:

$$\left|I_{eddy}\right| = K\sqrt{\frac{\Omega^2}{\left(1+\Omega^2\right)^2} + \frac{\Omega^4}{\left(1+\Omega^2\right)^2}} = K\frac{\Omega}{\sqrt{1+\Omega^2}} \quad (4)$$

Changing magnetic field induces eddy currents in conductive stator material, which generates to primary opposite magnetic field. When frequency of the time varying magnetic field increases, primary magnetic field compensate secondary (causes by induced eddy currents in the stator conductor) and resultant magnetic field in the stator conductor equals zero. It is seen from calculated dependence of induced eddy current from rotation speed (magnetic field frequency) in Figure 4.

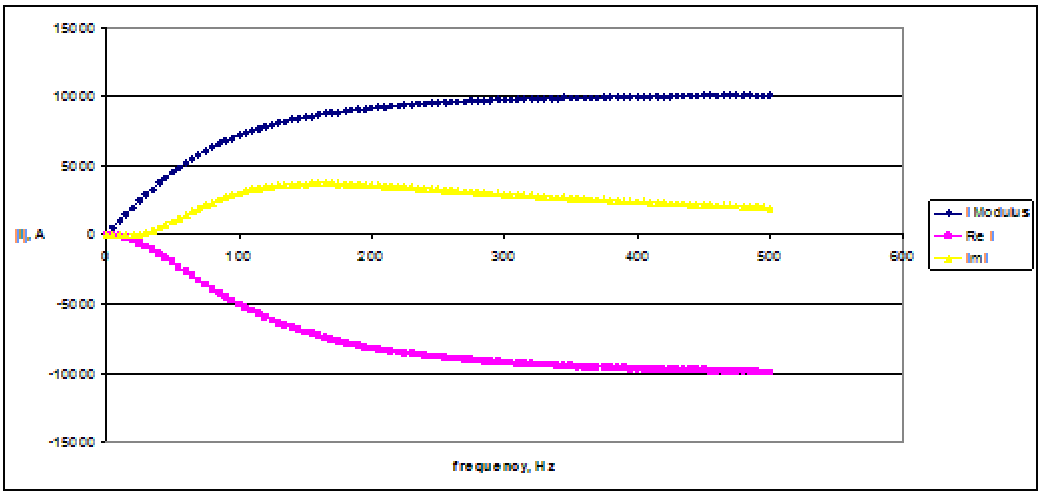

Figure 4. Dependence of the module of induced eddy current from magnetic field frequency.

As the inductance of the stator body is small, heat dissipated in the stator conductor can be calculated according to a Joule heating law $P_{Joule} = I^2 R$, where I is a current and R resistance of the loop. As the skin depth at 30 Hz frequency is larger as wall thickness of stator body, the resistance can be calculated as $R = \frac{2\pi r}{\sigma r d} = \frac{2\pi}{\sigma d}$. Calculated results are compared in Figure 5.

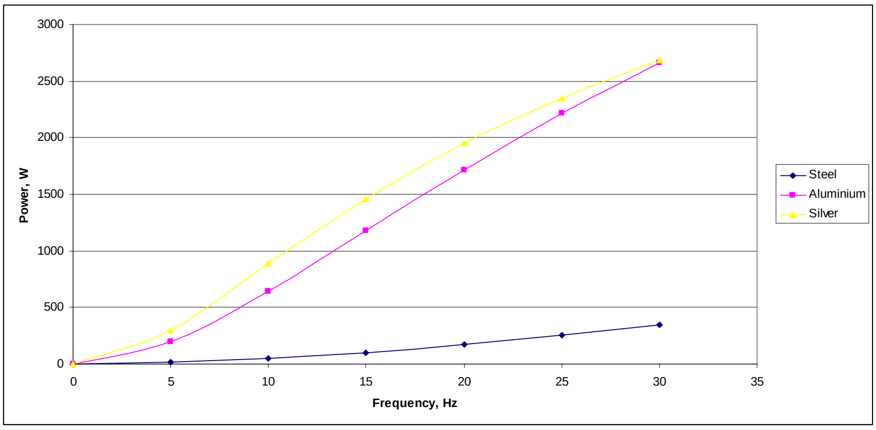

Figure 5. Comparison of dissipated heat power at the different stator materials.

For the given system parameters: rotor turning at 180 rpm, 10 magnetic pole pairs, magnet width 26 mm, stator body wall thickness 10 mm, the electrical conductivity of stator body 38 MS/m, dissipated heat power (resistive eddy current loss) is calculated as 2790 W. From the figure 5. it is seen that the stator body should be made of material with high electrical conductivity such as aluminium to achieve maximum dissipated heat power loss, but use of expensive materials with even higher electrical conductivity such as silver isn't necessary because power curve reaches saturation and further increase of conductivity is useless. It is necessary to use strong NdFeB permanent magnets in the rotor to obtain maximum air gap magnetic flux density. Also the Curie temperature of the magnets should be taken into account because of heat conducted from stator. Numerical and analytical results are in comparison, small difference between calculated lines is caused by the fact that time varying magnetic field in two dimensional FEMM problem was created using frequency changing electric currents instead of moving mesh. Further reasearch on materials with high electrical conductivity but also ferromagnetic behaviour so to decrease the air gap lengt – increase magnetic flux density in the stator material thus maximizing eddy current loss will be made.

4. Conclusions

In this paper basically the eddy currents generated by wind power in stator material is analysed. Finite element method magnetics is also used and obtained and numerical results compared with analytical solutions. Rotating permanent magnets caused time varying magnetic field induced eddy currents can be used in direct wind kinetic energy conversion to thermal energy. Stator body should be made of material with relative high electrical conductivity to achieve maximum dissipated heat power loss, but use of supercounductive materials is't required. It is necessary to use strong NdFeB permanent magnets in the rotor to obtain maximum magnetic flux density in an air gap. The influence of conductivity of stator body material to the moment as well as balance of eddy current generated moment and wind turbine mechanical moment will be analysed in further work.

5. References

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