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The use of Magnetic Coupler instead of Lever Actuated Friction Clutch for Wind Plant

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***Abstract*—The purpose of the paper is to analyze the possibility to use a magnetic coupler instead of lever actuated friction clutch, which is used in the wind plants between the shaft from turbine and the shaft from motor. There are analysed the construction parameters of magnetic coupler to obtain the necessary coupler's mechanical torque. The paper includes the calculation of a mechanical torque, applying program QuickField. In QuickField there is calculated magnetic field using finite element method (FEM).**

***Index Terms*—Electromagnetic modelling, magnetic devices, permanent magnets, wind farms.**

I. INTRODUCTION

Since the beginning of use of wind plants there have been used the lever actuated friction clutches.

Also in the researched synchronous generator with permanent magnets (SGPM) there is used a lever actuated friction clutch. The clutch is a device used to transmit the power from the driving shaft (Fig. 1(b)) to the driven shaft (Fig. 1(a)) [1].

The lever actuated friction clutch (Fig. 2) consists of two parts (Fig. 3).

a) b)

Fig. 1. Driven (a) and driving (b) shaft.

In this paper it is analysed the possibility to use a magnetic coupler (MC) instead of the lever actuated friction clutch. There are researched the design parameters, with which could be obtained the mechanical torque of MC such, that would satisfy SGPM's nominal torque equal 250 rpm.

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MC is used to transfer the interaction forces as attraction and repulsion of the permanent magnets (PM) to mechanical torque – the motion. MCs are used in pumps, compressors and mixers.

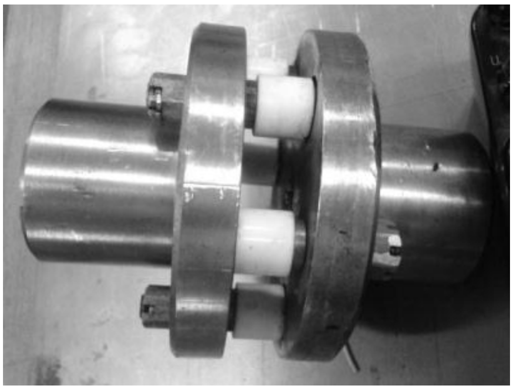

Fig. 2. Lever actuated friction clutch.

MC consists of inner half coupling 1 and outer half coupling 2, which are made of Steel 3 (Fig. 4). On the outer surface of the inner half coupling 1 and on the inner surface of the outer half coupling 2 there are placed permanent magnets 3. The outer half coupling would be connected with a shaft of the turbine. The inner half coupling would be placed on a shaft of the SGPM. The turbine would rotate the outer half coupling. The interaction (attraction and repulsion) forces between moving PMs on the inner half coupling 1 and still PMs on the outer half coupling 2 make the inner half coupling to rotate.

Fig. 3. Lever actuated friction clutch in two parts.

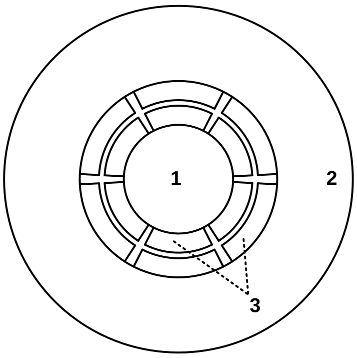

Fig. 4. Magnetic coupler's cross section.

II. MC'S DIMENSION CHOICE

The last years it is an upswing of permanent magnets, based on the rare-earth alloys, e.g. neodymium-iron-boron (Nd-Fe-B) and samarium-cobalt (Sm-Co). Such magnets have higher coercive force. The higher is the coercive force, the larger torque is transferred. The calculated and analysed MCs have Nd-Fe-B permanent magnets.

In the calculation there are taken N42M series' Nd-Fe-B permanent magnets with such parameters [2]:

1) Residual induction B_r=1,3 T;
2) Coercive force H_c=900 kA/m;
3) Relative permeability μ^*=1,15.

The base dimensions for a MC are given in Fig. 5.

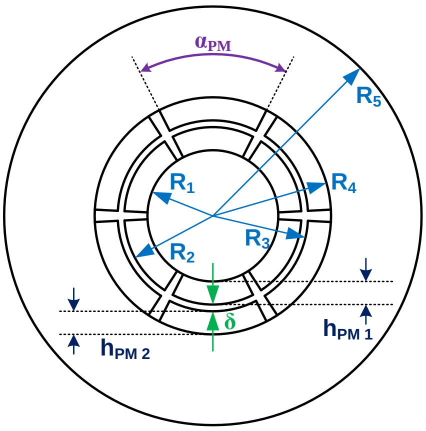

Fig. 5. Base dimensions for magnetic coupler (in cross section): R_1, R_2, R_3, R_4, R_5 – radiuses, $h_{PM\ 1}$, $h_{PM\ 2}$ – PM's height, α_{PM} – PM's width, δ – air gap.

R_1 is the radius of inner half coupling's surface. R_2 is the radius of inner half coupling taking into account the PMs height $h_{PM\ 1}$. R_3 is radius of outer half coupling's inner surface, taking into account PM's height. R_4 is the radius of outer half coupling's inner surface. R_5 is the radius of the outer half coupling's outer surface. PM's width is expressed with an angle α_{PM}. PM's height in the inner half coupling is $h_{PM\ 1}$, but in the outer half coupling – $h_{PM\ 2}$. Usually the PMs' heights in the inner and the outer half couplings are identical. Air gap between the inner and outer half couplings is δ.

First variant for MC's dimensions is chosen so: the axial length *l* is taken the same as it is for lever actuated friction clutch (*l*=62 mm); R_5 is the same as the radius of the friction clutch's outer surface – R_5=62.5 mm; R_2 is taken as other base radius, comparing the diameters of both shafts (R_2=26.5 mm); next step is the choice of the outer coupling's yokes height, that will lead to R_4.

As in the electrical machines also in the MCs have to be taken into account the residual induction in the yoke. And the adapted formula is [3]

$$h_{yoke} = \frac{\pi \cdot R_4 \cdot \beta}{p} \cdot \frac{B_{PM}}{B_{steel}}, \quad (1)$$

where *p* – pole pair number; β – proportionality coefficient (PM's angle α_{PM} divided with pole pitch); B_{PM} – residual induction of PM; B_{steel} – the allowed residual induction in the yoke (made of steel), equal 1.6 T.

Taking into account the basic radiuses R_5 and R_2, the airgap δ=2 mm (the smallest possible for such a device as MC) and that it is not effectively to make higher PMs than 10 mm and smaller than 3 mm (from previous researches), the outer half coupling's yoke should be in interval 24 till 31 mm (including both values). Proportionality coefficient β is 0.9.

The (1) can be changed this way:

$$h_{yoke} = \frac{\pi \cdot (R_5 - h_{yoke}) \cdot \beta}{p} \cdot \frac{B_{PM}}{B_{steel}} = \\ = \frac{\pi \cdot (62.5 - h_{yoke}) \cdot 0.9}{p} \cdot \frac{1.3}{1.6}, \quad (2)$$

where

$$h_{yoke} \approx \frac{229.73}{1.6 \cdot p + 3.68}. \quad (2)$$

In Table I can see the results for the yoke's height when there is changed the pole pair number.

From the Table I can see that the only useful height for yoke is 27.1 when the *p*=3, thus is obtained also the number of pole pairs.

If there were more possible yoke's heights, all those variants with different pole pairs would be calculated.

TABLE I. THE VALUES OF YOKE'S HEIGHT PRE DIFFERENT NUMBERS OF POLE PAIRS.

p	h_{yoke} (mm)
1	43.5
2	33.4
3	27.1
4	22.8
5	19.7
6	17.3

The first MC's variant, taken in the calculations, has:

1) R_5=62.5 mm; R_4=R_5-h_{yoke}=62.5-27.1=35.4 mm;
2) R_3=28.5 mm; h_{PM}=R_4-R_3=6.9 mm;
3) R_2=26.5 mm; R_1=R_2-h_{PM}=19.6 mm;
4) δ=2 mm;
5) $\alpha_{PM} = \frac{180°}{p} \cdot \beta = 54°.$

Usually to compare different MCs there is used their maximal mechanical torque.

Similarly in this case: will be found the maximal mechanical torque and the nominal mechanical torque (there we are interested in) is $0.7 \cdot M_{max}$.

III. CALCULATION OF MECHANICAL TORQUE

The calculation of the mechanical torque is made applying the program QuickField [4]. The program takes into account the saturation of magnetic circuit [4]. The program generates the magnetic field and calculates the physical values of given object using the finite element method (FEM) [4]. In this paper it is generated the magnetic field of MC and calculated the mechanical torque M.

The mechanical torque is calculated by the circle of air gap's middle [5]. The maximal mechanical torque is obtained, when the turning angle of outer half coupling is equal ninety electrical degrees. The magnetic field for first MC's variant is given (Fig. 6).

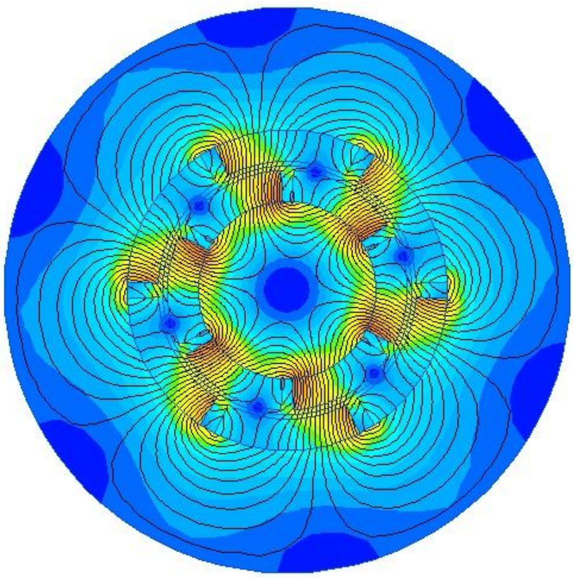

Fig. 6. Magnetic field of MC in QuickField.

A half coupling is turned for 90 el.deg., thus is obtained the maximal mechanical torque

The maximal mechanical torque for the first variant is $M_{max\,1}$=60,5 Nm. But M_{nom} has to be 250 Nm.

IV. OPTIMIZATION OF MC

With the MC's design optimization understand the changes of design parameters, when the (maximal) mechanical torque of MC is increased. As the nominal mechanical has to be 250 Nm, than in the interest is to find the MC's design, where maximal mechanical torque is $1.3 \cdot M_{nom} = 1.3 \cdot 250 = 325$ Nm.

Increasing axial length by decreasing the mounting sides to both shafts and without changes to other design parameters is obtained l=104 mm and M_{max}=101.5 Nm. There are made different variants, which together are given in Table II.

TABLE II. THE VARIANTS OF MCS DESIGN AND THEIR RESPECTIVE MAXIMAL MECHANICAL TORQUE.

Variant *i*	Pole pair number *p*	Inner PM height $h_{PM\,1}$ (mm)	Outer PM height $h_{PM\,2}$ (mm)	Axial length *l* (mm)	Maximal mechanical torque M_{max} (Nm)
1	3	6.9	6.9	62	60.5
2	3	6.9	6.9	104	101.5
3	4	8	8	104	110.0
4	4	8	10	114	120.0
5	5	8	10	124	138.0
6	5	8	12	124	143.9
7	6	8	12	144	151.4
8	6	8	10	155	157.6
9	7	8	8	175	154.1
10	8	8	8	200	160.0
11	5	10	12	200	284.8
12	5	12	12	200	328.2
13	5	12	12	220	361.3
14	5	12	14	220	373.6
15	5	14	14	200	387.2
16	6	10	12	190	333.3
17	6	12	12	200	340.0
18	6	12	14	180	369.5
19	6	12	12	190	380.9
20	6	12	14	170	349.0
21	6	10	12	185	324.6
22	6	10	10	190	323.4

To obtain a higher maximal mechanical torque, there are differently – increased the length of MC and changed the number of pole pairs and the height of PMs.

From "Table 2" there can see that the most closest values of maximal mechanical torque to 325 Nm there are:

1) *328.2 Nm (p=5,* $h_{PM\,1}=h_{PM\,2}$*=12 mm, l=200 mm);*
2) *323.4 Nm (p=6,* $h_{PM\,1}=h_{PM\,2}$*=10 mm, l=190 mm);*
3) *324.6 Nm (p=6,* $h_{PM\,1}$*=10 mm,* $h_{PM\,2}$*=12 mm, l=185 mm);*
4) *333.3 Nm (p=6,* $h_{PM\,1}$*=10 mm,* $h_{PM\,2}$*=12 mm, l=190 mm).*

And a MC's design (variant 21, Table II) for wind plant is given in Fig. 7.

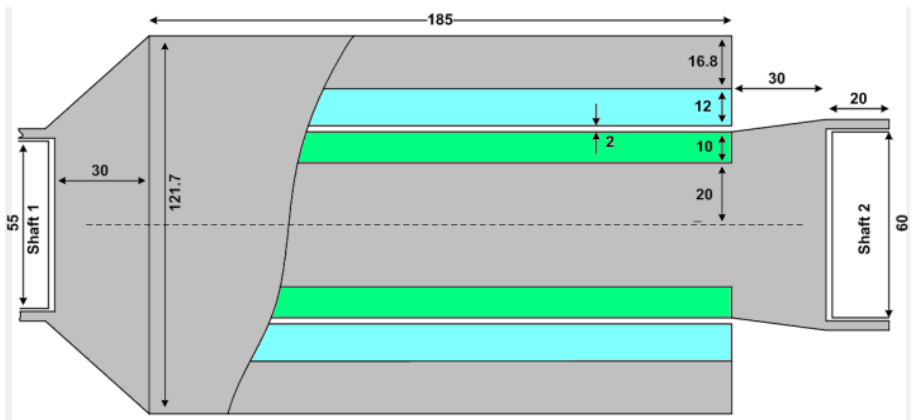

Fig. 7. MC for a use in wind plants (The design parameters are identical for 21st variant. Grey – steel 3; green – PMs on inner half coupling; blue – PMs on outer half coupling).

V. CONCLUSIONS

It is not possible to obtain identical nominal mechanical torque for a magnetic coupler if the design parameters of it are the same as for the lever actuated friction clutch.

It is obtained the necessary value of maximal mechanical torque for the used SGPM in wind plant.

The advantage of MC, used in wind plant, is that it can hold more the mechanical load and blocking than the lever actuated friction clutch.

The further research should be made, considering to necessary optimization – at which design parameters there is the best result (maximal mechanical torque divided with MC's volume).

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