

**THE BEHAVIOR OF ASYMMETRIC FRONTAL COUPLINGS WITH  
 PERMANENT MAGNETS IN MAGNETIC POWDER AND HIGH  
 TEMPERATURE ENVIRONMENTS**

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Abstract: The main purpose of this paper is the comparative analysis of the behavior of frontal couplings with Nd-Fe-B permanent magnets in difficult environments, specific to metallurgy – such as environments with magnetic powders and high temperature – in two constructive variants: symmetric couplings and asymmetric couplings (with divided poles). The results show the superior performance of asymmetric couplings under the given conditions.

Keywords: permanent magnets, permanent magnet couplings.

### 1. INTRODUCTION

The meaning assigned to asymmetric frontal coupling (with divided poles) in this paper is that of a coupling in which the number of permanent magnets on the conductive semi couple (to be found on the shaft of the electric machine) is different from the number of permanent magnets on the conducted semi couple (to be found on the shaft of the marking machine).

Using asymmetric couplings (instead of symmetric ones) is technically justified by their superior behavior in a dynamic regime, as well as by their high stability at resisting torque variations as well as at the accelerations and decelerations imposed by the speed regulation principles in modern driving chains.

### 2. DIMENSIONS OF PERMANENT MAGNET COUPLINGS

The method used to this purpose is specific to the design of electric machines excited by permanent magnets. The couplings used for the simulation are couplings with Nd – Fe – B permanent magnets. The characteristics are to be read as follows:  $d_{ax}$  – the diameter of the shaft on which the semi couple is fixed;  $d_m$  – the diameter of the permanent magnet (cylindrical);  $l_m$  – the length of the permanent magnet

(cylindrical) ;  $g_{Al}$  – the thickness of the aluminum envelope containing the magnets;  $g_{10l}$  – the thickness of the soft iron (OL37) envelope used as flux concentrator near the axis;  $g_{20l}$  – the thickness at the semi couple’s end;  $D_{es}$  – the exterior diameter of the semi couple.

Table 1

	$d_{ax}$	$d_m$	$l_m$	$g_{Al}$	$g_{10l}$	$g_{20l}$	$D_{es}$
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
symmetric	5	20	10	3	5	3	63
asymmetric	5	6(10)	10	2	5	3	63

### 3. DETERMINATION OF THE DISTRIBUTION OF MAGNETIC FIELD AND ENERGY

In order to determine the distribution of the magnetic field (characterized by the vectors B magnetic induction, and H - intensity of magnetic field), the A vectors magnetic potential has been determined (equation 1) by observing on border the Dirichlet and Neumann type conditions (C. I. Mocanu, 1981).

$$(1) \begin{cases} \operatorname{rot} \left[ \frac{1}{\mu} \cdot (\operatorname{rot} \bar{A} - \bar{I}) \right] = 0 \\ \bar{n} \times \bar{A}(P) = 0 & P \in Fr_1(D) \\ \frac{\partial \bar{A}(P)}{\partial \bar{n}} = 0 & P \in Fr_2(D) \end{cases}$$

unde:

$\bar{I}$  - magnetic polarization;  
 $Fr_1(D)$  - boundary with Dirichlet condition;  
 $Fr_2(D)$  - boundary with Neumann condition.

For the vector magnetic potential only the Oz axis component was taken into consideration (the problem being bidimensional). As the initial condition for the vector potential the value  $A(x, y) = 0$  was employed.

The actual solving of field problems has been performed by means of the PDE - ase soft [\*\*\*PDE-ase, 1995].

In the case of normal environments (without magnetic powders) the integration domain, is the one shown in fig. 1- for symmetrical couplings, and in fig. 2 respectively – for asymmetric couplings.

The domains in the two figures are as follows:  
 $D_0$  – the actual integration domain;  
 $D_1$  – the domain occupied by the permanent magnet;  
 $D_2$  – the domain occupied by the aluminum envelope;  
 $D_3$  – the domain occupied by the steel envelope;  
 $D_{41}$  – the domain occupied by the electrical engine shaft;  
 $D_{42}$  – the domain occupied by the working machine shaft.

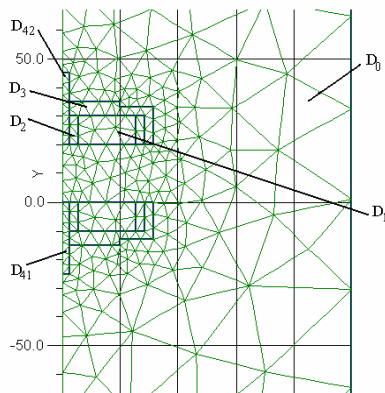


Fig.1 The integration domain for frontal symmetric couplings in normal environments

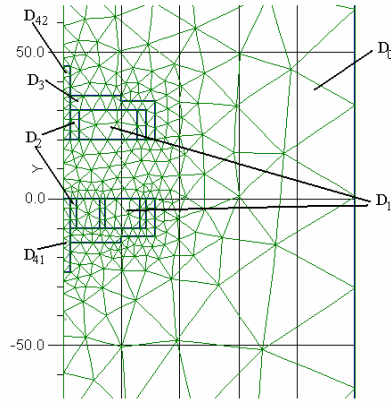


Fig.2 The integration domain for frontal asymmetric couplings in normal environments

For environments with magnetic powders, due to the existence of permanent magnets on the two semi-couples, as well as of a flux concentrator (the steel envelope), it was considered that on the surface between the air gap (the distance measured between the two semi-couples, along the axis) the magnetic powder settled in a uniform layer 1 mm thick.

The new integration domains, for the two types of couplings, in the case of environments with magnetic powders are shown in fig 3 and 4.

Besides the normal environment case there appears the  $D_5$  domain, occupied by the compacted powder (with actually exists all over the integration domain). Its relative permeability has been considered:  $\mu_r \text{ powder} = 5$ .

The following aspects should be mentioned:

1. The coupling is placed near a source of heat so that the  $Fr_1(D)$  border – where the Dirichlet condition for the electromagnetic field applies – is considered to have a maximum value of temperature  $T_{\max} = 100^{\circ}\text{C}$ ;
2. The temperature value for the environment was considered over the entire  $D_0$  domain  $T_0 = 40^{\circ}\text{C}$  at the initial moment of the analysis;
3. Both the variation of the relative permeability of the steel materials at the variation of the magnetic polarization at the modification of temperature in the integration environment (including the one of permanent magnets):

- The steel used for the flux concentrator is considered to have a variation of the relative magnetic permeability of the form

$$(2) \mu_r = FS + \frac{1500}{1 + 0,25(\text{gradA})^2}$$

- The steel used for the construction of the electric machine shaft and the working machine respectively is considered to have a variation of form

$$(3) \mu_r = 100 + \frac{2000}{1 + 0,2(\text{gradA})^2}$$

- The magnetic polarization is considered to have a variation with the temperature of the form (\*\*\*) , 2000)

$$(4) I_Y[T] = 0,6 \cdot [1 - 8 \cdot 10^{-4}(T - T_0)]$$

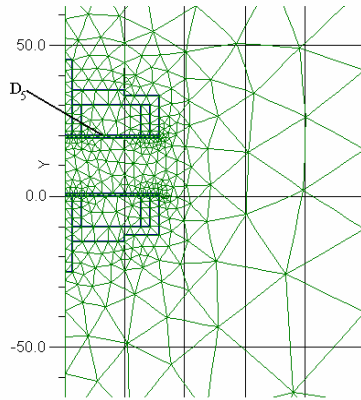


Fig. 3 The integration domain in the case of symmetric frontal couplings placed in magnetic powder and high temperature environments

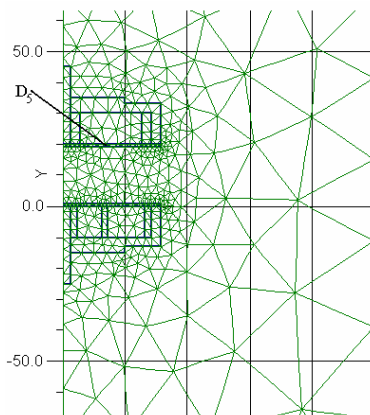


Fig. 4 The integration domain in the case of asymmetric frontal couplings placed in magnetic powder and high temperature environments

Each distribution of the magnetic field is specific in this case to a certain air gap value. The air gap value (the distance between magnets) has varied within the interval:  $\delta_{Nd-Fc-B} = [2 \div 16]$  [mm].

Fig. 5 shows the magnetic field distribution ( $\mathbf{H}$ ) for a 16 mm air gap, in the case of a symmetric frontal coupling, while fig. 6 shows the same distribution – for the same air gap – in the case of an asymmetric frontal coupling (of the same external size as the symmetric one, but with a double number of magnets on one of the semi couple's).

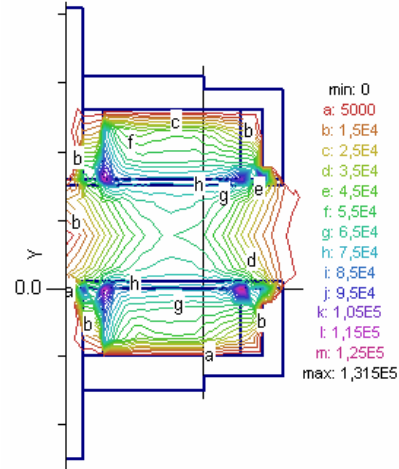


Fig. 5 The distribution of the magnetic field for symmetric frontal couplings placed in magnetic powder and high temperature environments

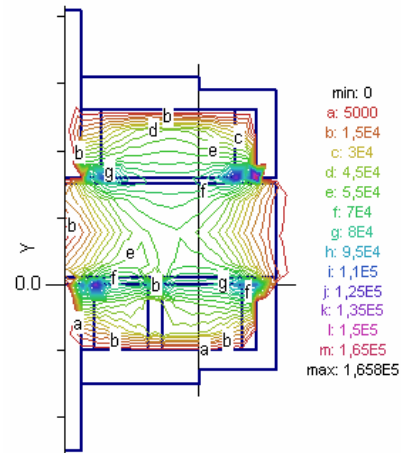


Fig. 6 The distribution of the magnetic field for asymmetric frontal couplings placed in magnetic powder and high temperature environments

In order to determine the magnetic energy the following approach has been taken (I. Voncila, N. Badea, S. Ivas, 1999):

- The module of magnetic induction,  $B$ , was determined by means of the relation

$$(5) B = \sqrt{B_x^2 + B_y^2} \text{ [T];}$$

- The module of the intensity of the magnetic field,  $H$ , was determined by means of the relation

$$(6) H = \sqrt{H_x^2 + H_y^2} \text{ [A/m];}$$

- The magnetic energy – over the volume unit –  $W_m$  was determined by means of relation

$$(7) W_m = \frac{1}{2} \cdot B \cdot H \text{ [J/m}^3\text{]}.$$

#### 4. DETERMINATION OF THE MAGNETIC FORCES AND RIGIDITIES

The algorithm used to calculate the magnetic forces and rigidities was the following:

- The specified forces – over the volume unit – were determined;

The components on the two axes of the specific forces were determined by means of the relation (I. Voncila, N. Badea, S. Ivas, 1999):

$$(8) f_x = -\frac{\partial W_m}{\partial x} \text{ [N/m}^3\text{]; } f_y = -\frac{\partial W_m}{\partial y} \text{ [N/m}^3\text{];}$$

- The resulting specific force was determined by the relation

$$(9) f = \sqrt{f_x^2 + f_y^2} \text{ [N/m}^3\text{];}$$

- The magnetic rigidities were determined as follows:

$$(10) k_x = -\frac{\partial f_x}{\partial x}; \quad k_y = -\frac{\partial f_y}{\partial y}.$$

#### 5. RESULTS OBTAINED

The comparison – regarding the two constructive variants of couplings with Nd-Fe-B permanent magnets – was performed on the basis of the following visualizations:

- The variation of the specific force at the air gap modification;
- The temperature variation within the couplings – relative to the environment temperature – at the air gap modification;
- The variation of the specific force within the couplings on the  $O_y$  axis (the axis of air gap increase) at the modification of the distance between the semi-couplings.

The results obtained are shown in the following figures.

Fig. 7 shows the variation pattern for specific resulting forces for the two types of couplings under focus – in magnetic powder and high temperature environments, at an air gap variation within the interval:  $\delta_{Nd-Fe-B} = [2\div 16]$  [mm].

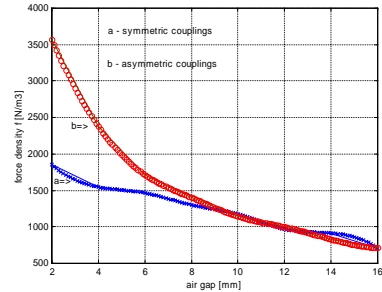


Fig. 7 The variation pattern of specific resulting forces in the case of frontal couplings with Nd-Fe-B permanent magnets placed in magnetic powder and high temperature environments at air gap increase

- a) for symmetric couplings
- b) for asymmetric couplings

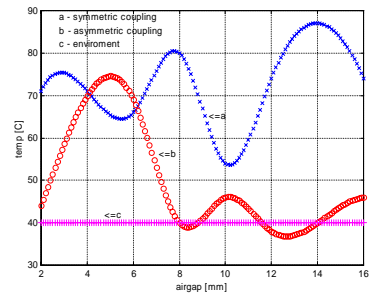


Fig. 8 The temperature variation – relative to the environment temperature – within frontal couplings with Nd-Fe-B permanent magnets placed in environments with powders and high temperature at the air gap.

- a) for symmetric couplings
- b) for asymmetric couplings
- c) environment temperature

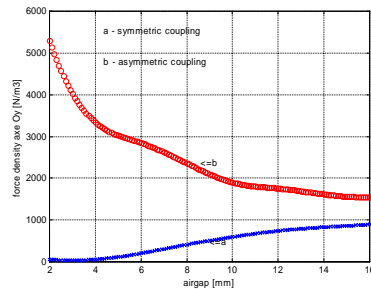


Fig. 9 The variation of the specific force on the  $O_y$  axis for within frontal couplings with Nd-Fe-B permanent magnets placed in environments with powders and high temperature at the air gap.

- a) for symmetric couplings
- b) for asymmetric couplings

## 6. CONCLUSIONS

The analysis has prompted the following:

- The magnetic field intensity – for the same air gap value – is bigger for asymmetric than for symmetric couplings;
- The specific resulting force developed by asymmetric couplings – for low air gap values – is obviously, bigger than in symmetric couplings;
- For asymmetric couplings – placed in magnetic powder and high temperature environments – the air gap increase does not lead to recording oscillations of the specific resulting force. As a result the static and dynamic stability for asymmetric couplings is much better than for symmetric couplings in the same environment conditions;
- For symmetric couplings – placed in environments with powders and high temperatures – the temperature in the area of the permanent magnets undergoes a significant increase at the air gap increase, at the risk of rapidly losing the magnetic properties of the permanent magnets;
- On the contrary, for asymmetric couplings, the temperature decreases at the air gap increase, although at low values of the air gap the temperature is high it is lower than the one of symmetric couplings at the optimum value of the working air gap ( $\delta_{\text{opsymNd-Fe-B}} = 8$  [mm]);

- For symmetric couplings, although the  $O_y$  component of the resulting specific force increases at the air gap increase, there is the risk of functional instability (“breaking” the coupling) immediately after the optimum value of the working air gap has been exceeded;

- For asymmetric couplings, this  $O_y$  component of the resulting specific force decreases continuously as the air gap increases (the optimum value of the air gap for these couplings being a fourth  $\delta_{\text{opasymNd-Fe-B}} = 2$  [mm] of the value for symmetric couplings); even for equal values of the air gap (equal to the optimum for symmetric couplings), the  $O_y$  component of the resulting specific force for asymmetric couplings is superior to the one developed under similar condition, within the symmetric couplings.

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