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THE DESIGN OF REACTIVE SHIELDED MAGNET CLUTCHES

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THE DESIGN OF REACTIVE SHIELDED MAGNET CLUTCHES /10*

S. M. Gertsov**

A technique for designing reactive, shielded magnet clutches is presented. The error of the design does not exceed 10%.

Shielded magnet clutches (SMC's) have found wide application in the chemical branch and in a number of other branches of industry for the transmission of synchronous rotation into a corrosive medium, vacuum, and so on.

There are a number of SMC constructions, which can be divided into three basic classes on the basis of the nature of the moment which is generated: active constructions, with the interaction of two magnets (Figure 1a); reactive constructions (Figure 1b), in which the moment is generated due to the difference of the permeances in the gear air space along the longitudinal and lateral axes; hysteresis constructions (Figure 1c) which create the moment due to loss in the hysteresis layer.

The fundamentals of the theory of reactive SMC's are given in [1]; however, this reference contains no practical technique for designing SMC's. This deficiency is partially compensated in [2], but in this reference, the calculation of the magnet circuit of the SMC is made very roughly, without an accurate determination of the permeance of the gear zone. In this article, we present a comparatively simple technique for designing reactive SMC's that ensures a high degree of accuracy for it.

Reactive SMC's have the following advantages over active SMC's in a number of cases; 1) a smaller mismatching angle of the guiding and guided parts; 2) they allow turning of the guided part relative

*Numbers in margin indicate pagination in the foreign text.

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to the guiding part without noticeable demagnetization of the magnet; 3) they make it possible to use magnets of relatively simple form with high magnetic energy.

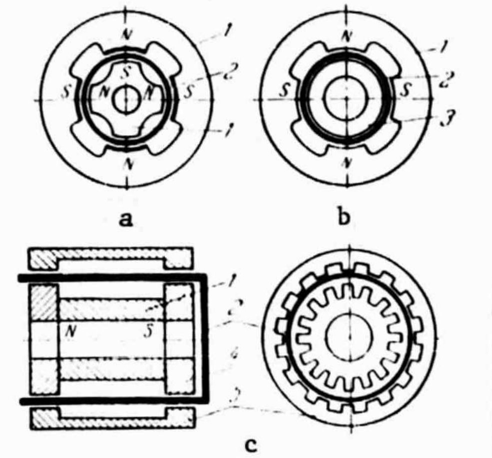

Figure 1: Types of clutches. a) active b) reactive c) hysteresis 1- magnet 2- shield 3- hysteresis layer 4- cap of magnetically soft steel 5- external part of magnetically soft steel.

Once the dimensions are chosen, the design of a shielded magnet clutch reduces to determining the maximum static moment which can be transmitted by the clutch. The dynamic moment, which determines the working properties of the SMC, is less than the static moment by a quantity equal to half of the moment of the loss in the shield [1]. However, when the shield is designed from nonmagnetic steel of brand 1X18H9T or the titanium alloys BT-3, BT-5, the moment of the loss in the shield is insignificant (with the rotational speeds and thicknesses of the shields which are usually found).

The calculation of the maximum static moment begins with the energy balance of the system. In a reactive SMC, there is a change in magnetic energy when one part of the clutch is turned relative to the other. It is obvious that the mechanical work produced during this turning will be equal to the change in the magnetic energy:

$$-A_{\text{мех}} = \Delta A_{\text{магн}}. \tag{1}$$

We will consider the change in the magnetic energy of the clutch. A graph of the magnet is presented in Figure 2. The magnetic flux of the magnet is plotted along the axis of the ordinates, and the magnetizing force is plotted along the axis of the abscisses.

We will assume that the SMC is magnetized in the assembly (which is in fact usually the case). Immediately after the magnetization, the position of the point Б is determined by the longitudinal permeance of the clutch G_d, i.e., by the permeance with the matched position of the gears. When the internal part of the clutch (the rotor) is turned

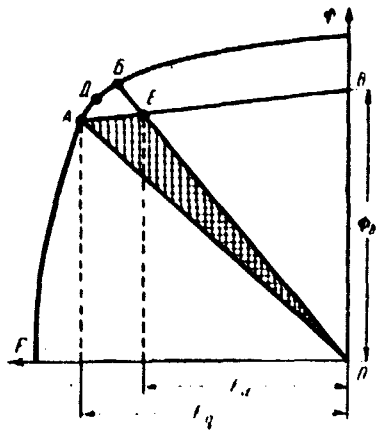

Figure 2: Graph of the magnet

relative to the external part (which we will call the stator) by the angle $\alpha = \frac{\pi}{2}$, i.e., when it is turned into the position of maximum mismatching of the gears, the position of the operating point A will be /
determined by the lateral permeance of the clutch G_q. When the rotor of the SMC is returned to the initial position, the point A moves along the return line to the point E. The area of the shaded triangle AOE determines the change in the magnetic energy of the system in turning the guiding part relative to the guided part by the angle $\alpha = \frac{\pi}{2}$. This change in the magnetic energy is determined from the following relation:

$$\Delta A_{magn} = \frac{\Phi_n^2}{2} \cdot \frac{G_d - G_q}{(G_d + \beta)(G_q + \beta)}, \tag{2}$$

where Φ_n is the reference flux (Figure 2);

β is the return coefficient.

As experiments show, the dependence of the static moment of the clutch on the electrical mismatch angle $z\alpha$ is practically sinusoidal:

$$M = M_{max} \sin z\alpha,$$

where z is the number of gears on each part of the clutch.

The work which we are looking for will then be determined from expression (3):

$$A_{мех} = \int\limits_{\alpha=0}^{\alpha=\frac{\pi}{z}} M_{макс} \sin(z\alpha)\, d\alpha = \frac{2M_{макс}}{z}. \qquad (3)$$

$$M_{макс} = \frac{\Delta A_{мех} z}{2}.$$

By solving (1) - (3) simultaneously, we will obtain an expression for the maximum static moment of the clutch:

$$M_{макс} = \frac{z}{2} \Phi_n^2 \frac{G_d - G_q}{(G_d + \beta)(G_q + \beta)}. \qquad (4)$$

Thus calculating the maximum static moment reduces to determining the longitudinal and lateral permeances of the air gap. This problem has been successfully solved by a number of authors for inductor generators and step electric motors. However, due to the presence of the shield, the relative air gap in the magnet clutch may be much greater than those examined in these references.

Diagrams of the magnetic field for various values of the relative air gap and angle of mismatching, as well as for various widths of the gears, were constructed to determine the specific permeance of the gear air gap.

The diagrams of the field were constructed by modeling on current-conducting paper by means of the EGDA-9/60 integrator [3]. As an example, the field diagrams are presented in Figure 3 in the matched and the mismatched position of the gears with a relative air gap of $\delta' =$ 0.15; $\delta' = \frac{\delta}{t}$ t is the gear scale; δ is the air gap.

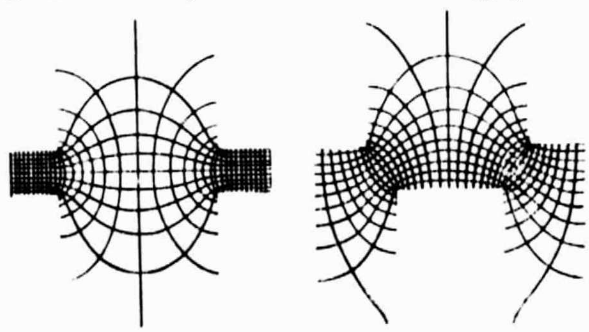

Figure 3: Field Diagrams in the air gap.

The dependences of the specific permeance (the permeance for one gear division per unit length) on the relative size of the air gap for the three values of the width of a gear $b_з$ = (0.3; 0.4; 0.5)t are presented in Figure 4.

The total permeance is determined as the product of the specific permeance per length of the gears l_a and the number of gears; in connection with the fact that the reactive SMC depicted in Figure 1b has two operating air gaps, the value of the permeance which is obtained is decreased by a factor of two.

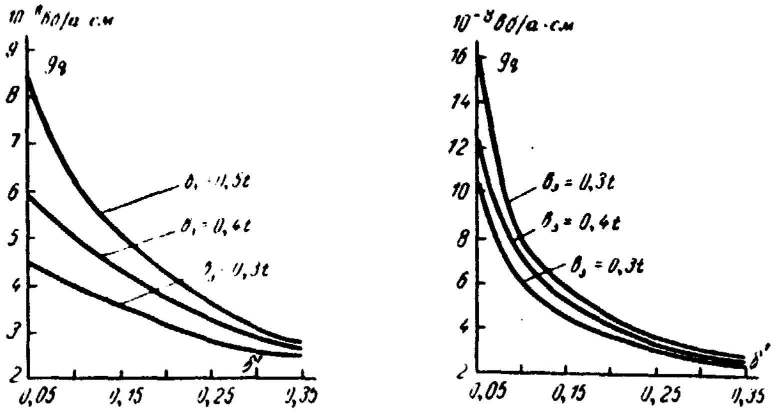

Figure 4: The change in the longitudinal specific permeance g_d (for 1 gear division and 1 cm length) and the lateral specific permeance g_q as functions of the relative air gap δ'.

Thus, the total permeance of the air gap is

$$G_d = \frac{g_d l_a z}{2}, \quad G_q = \frac{g_q l_a z}{2}. \tag{5}$$

It is more convenient to carry out the calculation of the maximum static moment in relative units. In this case, the graph of the magnet is constructed in relative units.

The values of the permeances in relative units are determined in the following way:

$$G'_d = G_d \frac{H_c l_m}{B_r S_m}, \tag{6}$$

$$G'_q = G_q \frac{H_c l_m}{B_r S_m},$$

where H_c, B_r are the coercive force and the residual magnetic induction of the magnet;

l_m, S_m are the length and cross-sectional area of the magnet.

When the calculation is carried out in relative units, the value of the maximum static moment is determined from expression (7):

$$M_{макс} = \frac{z}{4}(\Phi'_\delta)^2 \frac{G'_d - G'_q}{(G'_d + \beta')(G'_q + \beta')} B_r H_c S_m l_m. \qquad (7)$$

<u>Choosing the number of gears and the geometrics of the gear zone.</u> In contrast to the inductor generators and step electric motors, where the number of gears is uniquely determined by the given frequency of the patch angle, the number of gears in reactive SMC's, as a rule, is not limited by output parameters. In choosing the number of gears, one therefore tries to obtain the greatest transmittable moment in the given dimensions, or the minimum dimensions of the SMC with a given maximum static moment.

To determine the optimal number of gears, we will examine an electromagnetic clutch for which the magnetizing force is constant (F = const). The following dependence is justified for it:

$$M = \frac{F^2}{2}\frac{dG}{d\alpha} \qquad \text{or} \qquad M_{макс} = \frac{F^2 z}{2}(G_d - G_q).$$

Since $G_d - G_q = z\frac{l}{2}(g_d - g_q)$, by setting $g_d - g_q = \Delta g$, we conclude that the maximum static moment is proportional to the square of the number of gears and to the change in the permeance of the air gap:

$$M_{макс} \equiv z^2\Delta q.$$

It is necessary to find the maximum of the expression $z^2\Delta q$ as a function of the relative air gap δ'. /12

In the general case, it is necessarv to express the function $\Delta g = f(\delta')$ analytically to solve this problem. Since this function is essentially non-linear, an approximation of it will inevitably lead to additional errors. Therefore, a number of particular solutions for expression (8) have been found, and the dependence

$$z^2\Delta g = f(\delta')$$

has been constructed for the values found. This dependence has been determined for the three values of the width of a gear $b_з$ = (0.5; 0.4; 0.3)t; for generality of the solution, a number which is a multiple of the number of gears z'; z' is used instead of z; z' takes the values of 1, 2, 3...

The dependences which are obtained are presented in Figure 5. An

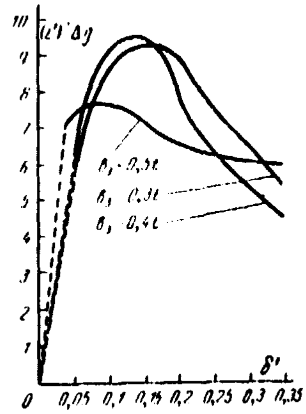

Figure 5: Determining the optimal number of gears.

analysis of these dependences has shown that for $b_з$ = 0.5t, the function is maximal at δ' = 0.075; for $b_з$ = 0.3t and $b_з$ = 0.4t, the maximum of the function is located at δ' = 0.15; here the greatest value of the function is reached at $b_з$ = 0.4t.

We can thus draw the following conclusions.

1) the optimal width of a gear must be 0.4 of the gear division, i.e., $b_з$ = 0.4t.

2) here the number of gears must be chosen so that the relative air gap is δ' = 0.15;

3) the height of a gear must not be less than half of the gear division [3]; $h_з \geq t/2$;

4) the permeance of the gear zone does not change significantly in varying the inclination angle of the edges of a gear by ± 10%.* It is therefore advisable to choose this angle in the range 7-10° to decrease the saturation of the base of the gear.

<u>Choosing the principal dimensions of the clutch.</u> An analysis of equation (7) shows that the expression

$$(\Phi'_{\delta})^2 \frac{G'_d - G'_q}{(G'_d + f')(G'_q + f')}, \tag{9}$$

which is proportional to the area of the triangle AOE (Figure 2) has its greatest value in the case where the SMC is operated near the point

*A. A. Terzyan. Induktornyy generator s pul'siruyushchim potokom (An inductor generator with pulsed flux). Candidate's dissertation, 1963.

of the maximum energy of the magnet Д , i.e., between the points А and Б .

Expression (9) is strictly determined and is equal to 0.111η for an optimally designed reactive SMC. On this basis, it is easy to transform equation (7) into the formula of a machine constant for a reactive SMC:

$$D_m^3 l_m = \frac{38{,}4 M_{\text{макс}} \delta}{k_r k_p B_r H_c \eta}, \tag{10}$$

where η is the fullness factor of the magnet in relative units;

$k_r = S_m/D^2_m$ is the coefficient of the geometry of the magnet;

$k_p = D_p/D_m$ is the ratio of the diameter of the rotor to the diameter of the magnet.

For a gap of 0.1 - 0.2 cm; k_p = 1.1 - 1.3.

Expression (10) makes it possible to determine the principal dimensions of the clutch as a function of the transmittable moment and the properties of the magnet. After determining the diameter and length of the magnet and choosing the number of gears, we can calculate the length of the gears from the following considerations; the requirement $G_q \sim 0.92$ must be satisfied for operation near the point of maximum energy; the total lateral permeance G_q can be found from expression (6) and the length of the gears, from (5).

The technique that has been proposed makes it possible to design reactive SMC's with an error that is not greater than 10%. This has been verified on a number of manufactured clutches.

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