POLARIZED ELECTROMAGNET MECHANISM WITH SOFT MAGNET CORE

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Abstract. Determined are the static parameters of a polarized electromagnet with soft magnet cylindrical core, which is suitable for force transducer in automatic devices or for commutation in electric circuits. The method for solving the task for the dynamics of core's movement is envisaged too.

Keywords: polarized electromagnet, automation, pulse control

1. Introduction

The development of automated systems constantly increases the necessity of new driving elements. The variety in this area cannot be met using classic drives with motor-reducer drives or using classic neutral electromagnets.

During the last decades a new generation of electric drives was imposed in practice (linear, stepper, etc.); as a result in the optimization of neutral electromagnets, including synthesis of the design after given features were developed drives combining simplicity of design with dynamic mode of operation.

At present, as a result of emergence of new generation of magnetic hard materials, the interest to classic polarized electromagnets was revived.

Regardless of relatively higher price of new hard magnetic materials and more sophisticated magnetic system, polarized electromagnets have a lot of advantages, which may justify this interest. As known, the control current with these magnets is required only during the displacement of the moving component, unlike the neutral electromagnets, it is not required at standstill, regardless of the static position of the driven component. On the other side, on equal terms polarized electromagnets have better dynamic performances and higher sensitivity.

These advantages of polarized electromagnets explain the bigger interest in research and development of electric drives applying them. Such drives are by now implemented for control of vacuum breakers; it may be expected that they will be implemented for drives with two-position actuators in automatics and in particular in automation of mechanisms and transfer lines in discrete production.

With the development of new generations of hard magnet materials the question for reassessment of the choice between the traditional neutral electromagnets and polarized electromagnets arose. The main advantage of the latter – necessity of magnet exciting current only during actuation, combined with the smaller dimensions and mass, although they are still more expensive than the neutral ones makes them competitive (they reduce the energy expenses and total heating). In this connection it's interesting to investigate the characteristics of polarized electromagnet mechanisms with different design and the possibility to use them instead of classic neutral electromagnets as actuators (for example for sorting, control of switches for railroads, valves, friction clutches, etc.). In the present paper are envisaged the static characteristics of a polarized electromagnet mechanism with soft magnetic core, which is particularly suitable as an actuator with relay action.

2. Analysis of the design

The simplified replacing scheme for the magnetic fluxes is shown on figure 1. The principle design of the envisaged mechanism is shown on figure 2. It's based on the commonly used principle of differential action of the magnetic fluxes excited by a permanent magnet 1 and control coil 6. There the permeances and the fluxes between the external cylindrical surface of the core and the external magnetic circuit are not given, as their role for the total electromagnet force is negligible (compared to the fluxes passing through the frontal round poles of the core they are significantly smaller and the forces they create are almost equal and compensate each other). In the replacing scheme the permanent magnet is shown as a generator of a permanent flux when passing through the core splits in direction of the operational air gaps δ' and δ''. Flux Φ' creates electromagnet force F', which ignoring the end fluxes at relatively small air gap may be determined by Maxwell's formula, i.e. $F^{'} = \frac{\Phi^{'2}}{2\mu_0 S}$, where S is the circular surface of core's pole, Φ_0 – flux generated by the permanent magnet; Φ', Φ" – fluxes passing through the core and the operational air gaps; G_δ', G_δ" – permeances of the operational air gaps; G_0 – permeance of the non-operational air gap between the pole ring and the core.

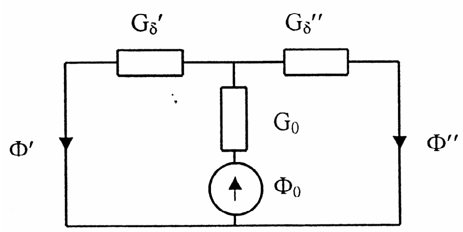

Figure 1. Simplified replacing scheme for the magnetic fluxes

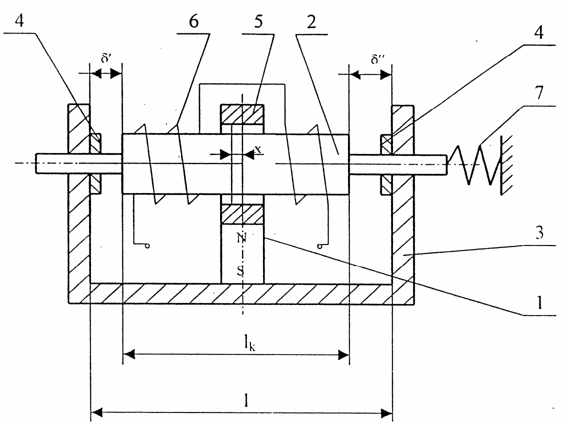

Figure 2. Principle design of the envisaged mechanism 1 – permanent magnet; 2 – core; 3 – external magnet circuit; 4 – non-magnetic pads; pole ring; 6 – coil; 7 – spring (replacing characteristic of the driven mechanism)

Analogically, the flux through the right air gap Φ" creates force $F^{'} = \frac{\Phi^{''2}}{2\mu_0 S}$. The forces F' and F'' and the resultant force acting on the core $F = |F' - F''|$, at the given design depend on the displacement of the core x with regard of its symmetric position. At symmetric position (x = 0) the air gaps are equal and are determined by the geometric dimensions l and l_k:

$$\delta^{'}_{x=0} = \delta^{''}_{x=0} = \delta_0 = \frac{l - l_k}{2}. \qquad (1)$$

For every other position $\delta' = \delta'_{x=0} - x$ and $\delta'' = \delta''_{x=0} + x$, whence with sufficient accuracy for the set goal the permeances may be determined by the expressions:

$$G^{'}_\delta = \mu_o \frac{S}{\delta_0 - x} = \mu_0 \frac{S}{\delta\left(1 - \frac{x}{\delta_0}\right)} = G_{\delta 0} \frac{1}{1 - \frac{x}{\delta_0}};$$
$$G^{''}_\delta = G_{\delta 0} \frac{1}{1 + \frac{x}{\delta_0}}, \qquad (2)$$

where $G_{\delta 0} = \mu_0 \frac{S}{\delta_0}$ is the permeance between the poles of the core and the external magnetic circuit at symmetrically placed core (x = 0).

It's easy to establish from the replacing scheme that the fluxes Φ' and Φ"are respectively:

$$\Phi^{`} = \Phi_0 \frac{G^{`}_\delta}{G^{`}_\delta + G^{''}_\delta} \text{ and } \Phi^{''} = \Phi_0 \frac{G^{''}_\delta}{G^{`}_\delta + G^{''}_\delta}. \qquad (3)$$

The total force acting on the core and by it – to the actuating mechanism will be:

$$F = F^{`} - F^{''} = k \cdot \Phi_0^2 \cdot \frac{G^{`}_\delta - G^{''}_\delta}{G^{`}_\delta + G^{''}_\delta} \qquad (4)$$

and after replacing and transformation is obtained:

$$F = k \cdot \Phi_0^2 \cdot \frac{x}{\delta_0}. \qquad (5)$$

As may be expected at symmetrically placed core (x = 0) this force equals to zero and increases linearly (at the assumed conditions for simplification) with the displacement of the core. At normal conditions the core is always placed in one of the end positions and in this case $x = x_{max}$. At presence of non-magnetic pads it's evident that $x_{max} = \delta_0 - \Delta$, where Δ is the thickness of the non-magnetic pads and for that reason

$$F_{max} = k \cdot \Phi_0^2 \cdot \frac{\delta_0 - \Delta}{\delta_0} \qquad (6)$$

and in a partial case when $\Delta = 0$ (there are no non-magnetic pads), $F_{max} = k \cdot \Phi_0^2$.

To move the core from one end position to the other end position its necessary control current I_y to pass through the coil and to create in both air gaps control flux with critical value determined by the condition:

$$\Phi_y = \frac{1}{2}(\Phi^{`} - \Phi^{''})_{x = x_{max}}. \qquad (7)$$

After short transformations for the critical value of the control current is obtained:

$$I_y = 2 \cdot \frac{\Phi_y}{W \cdot G_{\delta 0}} = \frac{2}{W \cdot G_{\delta 0}} \cdot \Phi_0 \cdot \frac{x_{max}}{\delta_0} \qquad (8)$$

where W is the total number of turns of the control coil.

The duration of the process for switching of the polarized mechanism depends on the type of the mechanical and the electromagnet transient processes. The mechanical is described by d'Alembert's equation:

$$m \cdot \frac{d^2\eta}{dt^2} + r \cdot \frac{d\eta}{dt} + c \cdot \eta = F_x - F_{n_0} \qquad (9)$$

where

η is the coordinate of movement, for $t = 0$, $x = x_{\max}$ and $\eta = 0$;

F_{n0} – the initial value of the resisting force (in the case of figure 1 – the initial spring force);

m – core's mass and reduced to it mass of the actuating mechanism;

r – coefficient of friction in the system;

c – spring factor.

The electromagnet transient process depends on the parameters of the coil and the power supply circuit and on a number of phenomena connected with the excitement of the counter voltages during displacement. The general task is insoluble using analytic methods and due to this reason iteration procedures are used [1]. Regardless of this, the measured times for the displacement of the core form one end position to the other end position are short (no more then a few ms) and depend on the specific case. Thanks to this fact the power supply system may be switched off immediately after the end of the displacement.

3. Conclusion

Analyzed is a principal design of a polarized electromagnet mechanism with a soft core, suitable for control of mechanical components normally actuated by neutral electromagnets. The results give basis to expect that from operational point of view it's significantly more economic and highly reliable. It is suitable for control of two-position valves, power electromagnets and with some modification for friction clutches.

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Received in October 2007
(and revised form in September 2008)