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OPTIMAL SYNTHESIS OF SYNCHRONOUS HYSTERESIS MICROMOTOR

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Abstract. The paper presents an optimal synthesis of a synchronous hysteresis micromotor with shaded poles based on nonlinear mathematical programming. The substitution of the objective function and the constraints by full polynomials of the second power provides a successful operation of the programme system and allows the obtaining of complete information for the sensitivity of the approximated functions of variable parameters. By applying an improved design, considerably better technical indices have been obtained compared to other micromotors of this type.

1. Introduction

Synchronous hysteresis micromotors are characterized by simple design, low manufacture cost and reliable exploitation. The identical nature of the starting and synchronous torques of these motors might prove to be decisive factors when selecting a drive for devices with relatively high inertia moment.

An improved design of a synchronous hysteresis micromotor with shaded poles [1] is shown in Fig. 1. The micromotor stator consists of an excitation toroid winding 1, main pole pieces 2 and 8, short circuited copper washers 3 and 9, further referred to as shades for short, auxiliary pole pieces 4 and 10, and a ferromagnetic bush 5. The plastic bearings 6 and 12 are pressed into the bush hole. The unshaded and shaded poles bent purposefully to form a claw–shaped pole system are cut off the pole pieces. The rotor consists of a shaft 7 and a light aluminium cup 11 where a ring 13 is pressed in out of a hard-magnetic material.

Since an elliptic rotating magnetic field is created in the micromotor, it is necessary the magnetic fluxes of the unshaded and shaded poles in the air

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gap to be equal in order to obtain greater driving torque. For this purpose in [2] nonmagnetic rings are placed between the bush 5 and the main pole pieces 2 and 8 and in this way the magnetic resistance along the unshaded magnetic flux is increased. The equalization of the magnetic fluxes is achieved as a result of decreasing the unshaded magnetic flux.

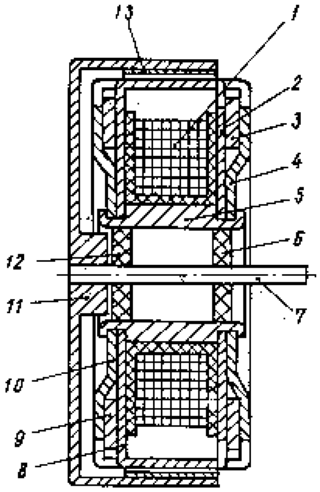

Fig. 1. Hysteresis micromotor with shaded poles

In the described improved micromotor design, the contact surface of the main and auxiliary pole pieces is from the side of the connecting stator bush and this results in decreasing the magnetic resistance along the shaded magnetic flux. In this way with unshaded and shaded poles different in width, an equalization of the magnetic fluxes at relatively greater values is obtained and that suggests a greater electromagnetic torque.

2. Mathematical simulation of electromagnetic processes in synchronous hysteresis micromotors with shaded poles

The hysteresis micromotor is generally characterized by a plurality of pole pairs p (e.g. $p = 8$) and small thickness of the rotor active layer. Under these conditions, the magnetic field distribution in the active layer can be determined with acceptable accuracy by assuming that the hodograph of the magnetic induction complex amplitude is a parallelogram [3]. So it is possible to apply the real characteristic of the rotor magnetic material.

The replacement scheme of the micromotor magnetic circuit is shown in Fig. 2, where:

$\dot{F}_m$ is the complex amplitude of the excitation winding magnetomotive force; G_σ is the leakage permeance in the field of the excitation winding; $G_{\delta\sigma}$ is the leakage permeance between two adjacent poles; $Y_{\mu k}$ is the complex permeance which replaces the shade; $Y_{\mu c1}$, $Y_{\mu c2}$ are the complex permeances of an unshaded and a shaded pole, respectively; $Y_{\mu\xi}$, $Y_{\mu\eta}$ are the complex permeances of the air gap-rotor active layer section for the unshaded and shaded flux, respectively [3]; $Y_{\mu cs}$ is the complex permeance of the stator bush.

The complex permeance

$$Y_{\mu k} = \frac{Z}{j\omega p}, \tag{1}$$

where Z is the internal complex impedance of the copper washer; ω is the angular frequency of the supply voltage.

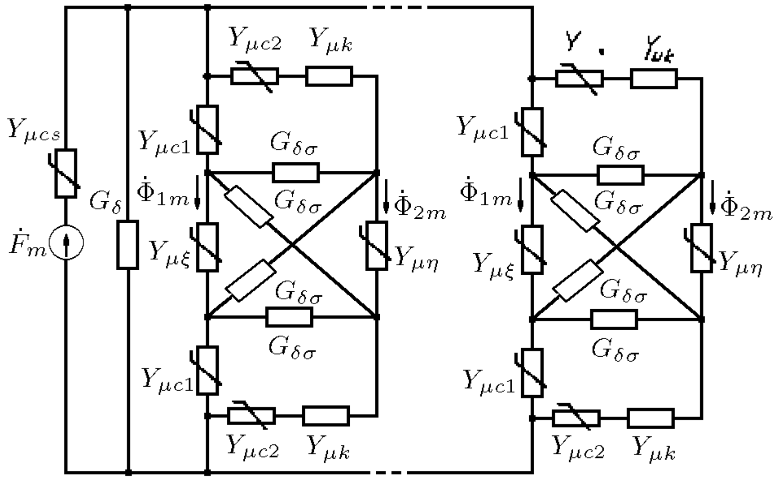

Fig. 2. The replacement scheme of the micromotor magnetic circuit

For a washer with inner radius R_1, outer radius R_2 and thickness Δ_e, the internal complex impedance Z can be given by

$$Z = \frac{2\pi R_2}{\Delta_e} j^{\frac{3}{2}} \sqrt{\frac{\omega\mu_0}{\gamma}} \frac{K_0(R_1 k j^{\frac{1}{2}}) J_1(R_2 k j^{\frac{3}{2}}) - J_0(R_1 k j^{\frac{3}{2}}) K_1(R_2 k j^{\frac{1}{2}})}{J_0(R_1 k j^{\frac{3}{2}}) K_0(R_2 k j^{\frac{1}{2}}) - J_0(R_2 k j^{\frac{3}{2}}) K_0(R_1 k j^{\frac{1}{2}})}, \tag{2}$$

where J_0, K_0, J_1 and K_1 are functions of Bessel and Kelvin of zero and first order, respectively; $k = \sqrt{\omega\mu_0\gamma}$, γ is the specific conductivity of copper; $\mu_0 = 4\pi 10^{-7} H/m$.

The magnetic circuit computation is carried out by the iteration method. The procedure is fast convergent if the ellipticity factor is assumed to be a convergency parameter:

$$\dot{K} = \frac{\dot{\Phi}_{2m}}{\dot{\Phi}_{1m}}, \tag{3}$$

where $\dot{\Phi}_{1m}$ and $\dot{\Phi}_{2m}$ are the complex amplitudes respectively of the unshaded and shaded magnetic flux in the air gap. The factor $\dot{K}$ can be shown also as

$$\dot{K} = \frac{Y'_{\mu k}[Y_{\mu c1} + 2(Y_{\mu\xi} + G_{\delta\sigma})]Y_{\mu\eta}}{Y_{\mu e1}[Y'_{\mu k} + 2(Y_{\mu\eta} + G_{\delta\sigma})]Y_{\mu\xi}}, \tag{4}$$

where $Y'_{\mu k}$ is the equivalent complex permeance of $Y_{\mu k}$ and $Y_{\mu c2}$.

When determining the complex permeance of the stator bush $Z_{\mu c5}$ and the excitation winding magnetomotive force, the irregular distribution of the magnetic flux in the bush [3] is taken into account.

Since the hysteresis micromotor with shaded poles operates with strongly expressed elliptic field, the electromagnetic torque is estimated on the basis of induction and magnetic field intensity distribution in the rotor active layer [3].

3. Optimal synthesis of synchronous hysteresis micromotor

The optimal synthesis of synchronous hysteresis micromotor is brought to solving the general problem of nonlinear mathematical programming [4]

$$\min\{f(\vec{x}) \mid \vec{x} \in R\}, \tag{5}$$

where $\vec{x} = [x_1, x_2, \ldots, x_n]^T$ is the variable vector of the optimization parameters ($\vec{x} \in E^n$), and R is the parameter space area where the problem constraints are satisfied:

$$R = \{\vec{x} \mid h_j(\vec{x}) = 0, g_j(\vec{x}) \geq 0 \quad \forall j\} \tag{6}$$

In this case the solution to this problem is found by the slipping allowance method following Nelder and Mead algorithm for finding an unconditional extremum. The procedure of this algorithm is applied simultaneously for determining both the objective function minimum $f(\vec{x})$ and for finding the admissible point for which the constraints of the problem at the respective stage of the solution are satisfied. For this purpose the functional is minimized:

$$T(\vec{x}) = \Big[\sum_{i=1}^{m} h_1^2(\vec{x}) + \sum_{i=m+1}^{p} U_i g_i^2(\vec{x})\Big]^{\frac{1}{2}}, \tag{7}$$

where $U_i = 0$ at $g_i(\vec{x}) \geq 0$ and $U_i = 1$ at $g(\vec{x}) < 0$.

To avoid a possible arithmetic interrupt of the programme operation because of physical incompatibility of the established admissible point and the designed object, the objective function and the constraints are substituted by global square approximations of the kind

$$\tilde{Y} = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} x_i x_j + \sum_{i=1}^{n} b_{ii} x_i^2 \tag{8}$$

which are obtained simultaneously on the basis of rotatable central compositional plan in agreement with experiment planning theory. The independent variables in the problem of micromotor optimal synthesis are represented in coded form

$$x_i = \frac{X_1 - X_{i0}}{I_i}, \tag{9}$$

where X_i is the ith variable value in the plan centre; I_i is the one-sided variation interval of this variable. Therefore the approximations are valid at $\mid x_i \mid \leq 1$, $i = \overline{1, n}$.

In correspondence with the stated above, the optimal synthesis of the synchronous hysteresis micromotor with shaded poles is specified as follows:

Find the minimum of the function

$$f(\vec{x}) = -\tilde{Y}_1, \quad \vec{x} \in E^6, \tag{10}$$

with the following inequality constraints:

$$\begin{aligned}
g_1(\vec{x}) &= 1 - \mid x_1 \mid \geq 0,\\
g_2(\vec{x}) &= 1 - \mid x_2 \mid \geq 0,\\
g_3(\vec{x}) &= 1 - \mid x_3 \mid \geq 0,\\
g_4(\vec{x}) &= 1 - \mid x_4 \mid \geq 0,\\
g_5(\vec{x}) &= 1 - \mid x_5 \mid \geq 0,\\
g_6(\vec{x}) &= 1 - \mid x_6 \mid \geq 0,\\
g_7(\vec{x}) &= 1 - \frac{\tilde{Y}_2}{50} \geq 0,\\
g_8(\vec{x}) &= 1 - \frac{\tilde{Y}_3}{1.625 \cdot 10^{-3}} \geq 0.
\end{aligned} \tag{11}$$

The variable parameter vector is

$$\vec{x} = [B_{dm}\ \beta_1\ \beta_2\ \Delta_e\ R_{1e} J]^T, \tag{12}$$

where B_{dm} is the magnetic induction amplitude of the forward magnetic field in the rotor active layer; β_1 is the unshaded pole width in parts of the pole pitch; β_2 is the shaded pole width in parts of the pole pitch; Δ_e is the shade thickness; R_{1e} is the inner shade radius; J is the current density in the winding.

The objective function is assumed to be the electromotive torque - micromotor volume relation

$$Y_1 = \frac{M}{V} \tag{13}$$

with a minus sign.

Approximating expressions are found for the function Y_1, the excitation winding overheating Y_2 and the distance between two adjacent poles Y_3.

In case that the optimum vector $\vec{x}^*$ proves to be at the domain boundary for which the approximating expressions are valid, a new cycle is realized with a plan centre at the point corresponding to the established local minimum of the objective function.

4. Experimental verification

An experimental specimen of a synchronous hysteresis micromotor with shaded poles has been constructed based on the results obtained from the optimal synthesis. Table 1 gives comparative data on the micromotor. For this type of motor where parameter dispersion as a result of inevitable technological deviations from specifications is of the order of $10 - 15\%$, the obtained accuracy can be accepted as satisfactory from a practical point of view.

Table 1

Quantity	Calculation	Experiment	Error, %
Rated voltage $[V]$	220	220	-
Rated current $[A]$	$20.44 \cdot 10^{-3}$	$20 \cdot 10^{-3}$	2.20
Consumed power $[W]$	2.72	3	-9.33
Pull-out torque $[Nm]$	$11.48 \cdot 10^{-4}$	$11 \cdot 10^{-4}$	4.36

5. Conclusion

The paper presents an optimal synthesis of a synchronous hysteresis micromotor with shaded poles based on nonlinear mathematical programming.

The substitution of the objective function and the constraints by full polynomials of the second power provides a successful operation of the programme system and allows the obtaining of complete information for the sensitivity of the approimated functions of variable parameters. By applying an improved design, considerably better technical indices have been obtained compared to other micromotors of this type.

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