AXIAL–GAP ELECTROSTATIC WOBBLE MICROMOTOR

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The torque–versus–angle mechanical characteristic of an axial gap electrostatic wobble motor is computed by an analytical method.

INTRODUCTION

Microdevices and micromotors are a subject of increasing interest due to their multiple applications in industry, medicine, military, and many other fields. The structure of microdevices is generally subjected to certain restrictions derived from the manufacturing process which uses integrated circuit technology. Electrostatic motors appear then to be more convenient than motors of a classical type, based on electromagnetic forces. Unavoidable manufacturing errors have a strong influence on the device structure at such a small scale, and may result in an unacceptable dispersion of the performance figures. The wobble motors, [1,2,3,4], which integrate as an operation principle the very variation of the motor airgap, present themselves as a promising alternative.

The design of micromotors starts from a preliminary performance evaluation, with a view to establish the range of the proper design and manufacturing requirements. In this respect, the evaluation of the mechanic characteristic of the micromotor, i.e., the dependence of the active torque on the rotation angle of the rotor, is of foremost importance for both the overall performance evaluation and the design of appropriate driving procedures. The present paper aims at the computation of an approximate mechanic characteristic of the radial–gap wobble motor, obtained under some reasonable simplifying assumptions.

DEVICE MODEL AND SIMPLIFYING ASSUMPTIONS

The stator of the micromotor under study [1,2,5] consists in equal sectors of an annular conductor deposited on an insulator substrate and covered by a thin insulating film, and the rotor is a conducting disk that can rotate around the support point at the basis of its shaft, with the circumference touching the stator plane at a single point. (fig. 1).

The operation of the wobble motor is quite simple: The conducting rotor disk is permanently maintained at null potential by the contact at the support point of its shaft, while appropriate sector pairs of the fragmented stator (stator poles) are successively placed at a driving potential V. An energized stator pole sector attracts the rotor disk, tending to reduce the average rotor–stator distance between them, and thus makes the rotor roll until the contact point C of the rotor and the stator plane is at the middle I of the energized structure. By energizing successive pairs of stator poles, the contact point C rolls on the stator plane and the rotor wobbles around the stator axis.

The stator is considered split into 6 equal sectors of radii a and $b = 2a$, covered by an insulating film of thickness e and relative permittivity ε_r. The rotor radius is R, its shaft height is h, and the clearance of the inferior rotor face above the superior stator face, when these are parallel, is d $(d < h)$. Moreover, the rotor radius and the outer stator radius are such that the instantaneous contact point C of the rotor with the stator plane is distanced at a radius $R_C = b$ from the stator axis.

Some simplifying hypotheses are supposed to apply:

1°. The shaft length h and the rotor–stator clearance d are very small as compared with the rotor radius R.

2°. The stator insulator thickness is negligible with respect to the shaft length and the rotor–stator clearance;

3°. The insulating gaps between successive stator sectors (poles) are considered to be extremely narrow.

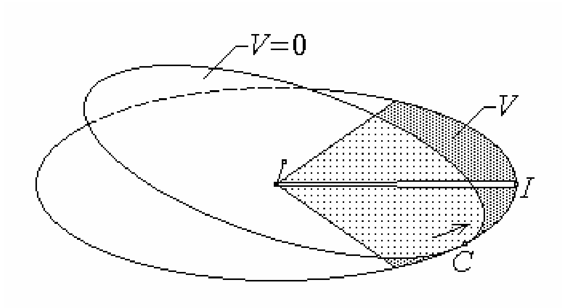

Fig. 1. Operating principle of micromotor

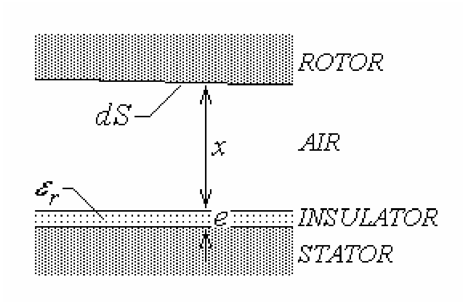

Fig. 2. Local structure

The symmetry of the structure makes it sufficient to compute the mechanic characteristic corresponding to the rotor–stator contact point C travelling along the circumference of a single energized stator pole, when the pair of energized stator sectors is at the driving potential V and all other stator sectors are at a null potential. The geometry of the structure under study corresponds to a rather complex three–dimensional field problem. However, since, according to the simplifying hypotheses, the angle θ between the rotor and stator faces is very small, a simplified approach may assume a two–dimensional electric field problem, where the electric field lines are locally normal to the stator pole faces.

The active electric torque is computed as [6,7,8]

$$T = \frac{\partial W^*}{\partial \alpha} = \frac{\partial}{\partial \alpha} \frac{C V^2}{2}\bigg|_{V=\mathrm{ct.}} = \frac{V^2}{2} \frac{\partial C(\alpha)}{\partial \alpha} \quad ,$$

where W^* is the electric co–energy, α is rotor position angle, i.e., the angle between the radii of the rotor–stator contact point C and the border point I separating the energized stator sectors, and $C(\alpha)$ is the rotor–stator capacitance.

COMPUTATION OF THE ELECTRIC CAPACITANCE

The computation of the electric torque is reduced to the computation of the electric capacitance associated to the rotor and the energized stator sectors [9],

$$C(\alpha) = \int_{\text{energized sectors}} dC = \int_{\text{energized sectors}} \frac{\varepsilon_0 \, dS}{x(r,\psi) + e/\varepsilon_r} \quad ,$$

where r is the distance of the current point on the energized stator sector to the stator axis, ψ

is the angle between the position vector of the same current point and the position vector of the rotor–stator contact point C, and x is the local airgap (fig. 2).

Using the notations appearing in fig. 3, which represents an axial cross section of the motor passing through the rotor–stator contact point C, two equations hold as

$$R_C = R\cos\theta + h\sin\theta \quad , \quad h\cos\theta = R\sin\theta + (h-d) \quad .$$

Under the simplifying hypotheses, the second equation gives

$$\tan\frac{\theta}{2} = \frac{\sqrt{R^2 + d\,(2h-d)} - R}{2h-d} \cong \frac{d.}{2R} \quad \Rightarrow \quad \tan\theta \cong \sin\theta \cong \theta \cong \frac{d}{R} \quad ,$$

so that

$$R_C \cong R\left[1 + \frac{d\,(h-d)}{R^2}\right] \quad , \quad H = R_C\tan\theta \cong Rd\left[1 + \frac{d\,(h-d)}{R^2}\right] \quad .$$

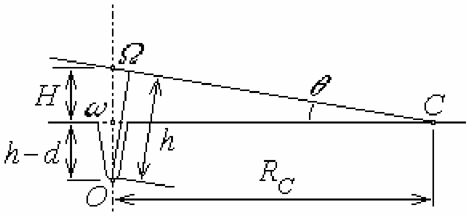

Fig. 3. Axial cross section

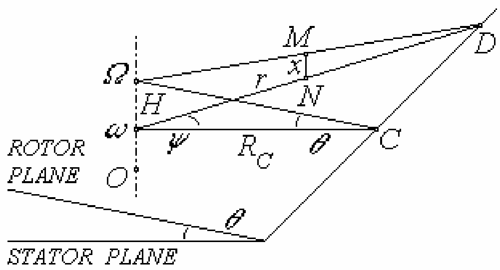

Fig. 4. Airgap evaluation

According with the notations appearing in fig. 4, one can readily obtain that

$$x = H\left(1 - \frac{r\cos\psi}{R_C}\right) \cong d\left[1 + \frac{d\,(h-d)}{R^2} - \frac{r}{R}\cos\psi\right] \quad ,$$

and, consequently, the capacitance results as represented in fig. 5 [10],

$$C(\alpha) = \varepsilon_0 \int_{-\pi/3-\alpha}^{+\pi/3-\alpha} d\psi \int_a^b \frac{r\,dr}{d + d^2(h-d)/R^2 + e/\varepsilon_r - (d/R)\,r\cos\psi} =$$
$$= C_1(b,\psi_2) - C_1(a,\psi_2) - C_1(b,\psi_1) + C_1(a,\psi_1) +$$
$$- C_2(b,\psi_2) + C_2(a,\psi_2) + C_2(b,\psi_1) - C_2(a,\psi_1) \quad ,$$

where

$$C_1(r,\psi) = \frac{2A\tan\psi/2}{B^2\left(\tan^2\psi/2 - 1\right)} \ln\left|\,(A + Br)\tan^2\psi/2 + (A - Br)\,\right| \quad ,$$

$$C_2(r,\psi)=\frac{2\sqrt{A^2-B^2r^2}}{B^2}\arctan\left(\sqrt{\frac{A+Br}{A-Br}}\tan\frac{\psi}{2}\right)\quad ,$$

$$\psi_1=-\frac{\pi}{3}-\alpha \quad , \quad \psi_2=+\frac{\pi}{3}-\alpha \quad , \quad A=d\left[1+\frac{d\,(h-d)}{R^2}\right]+\frac{e}{\varepsilon_r} \quad , \quad B=\frac{d}{R} \quad .$$

COMPUTATION OF THE APPROXIMATE MECHANIC CHARACTERISTIC

The approximate mechanic characteristic torque–versus–rotation angle,

$$T=\frac{V^2}{2}\frac{\partial C(\alpha)}{\partial\alpha}=\frac{\varepsilon_0 V^2}{2}\frac{\partial}{\partial\alpha}\varepsilon_0\int_{-\pi/3-\alpha}^{+\pi/3-\alpha}d\psi\int_a^b\frac{r\,dr}{d+d^2(h-d)/R^2+e/\varepsilon_r-(d/R)r\cos\psi}\quad ,$$

is computed as the derivative of a parameter–dependent integral [11] as

$$T(\alpha)=\frac{\varepsilon_0 V^2}{2}\left[\int_a^b\frac{r\,dr}{A-B\,r\cos(\alpha+\pi/3)}-\int_a^b\frac{r\,dr}{A-B\,r\cos(\alpha-\pi/3)}\right]=$$

$$=\frac{\varepsilon_0 V^2}{2}\left[\frac{b-a}{B\cos\varphi}+\frac{A}{B^2\cos^2\varphi}\ln\frac{A-B\,b\cos\varphi}{A-B\,a\cos\varphi}\right]_{\varphi=\alpha+\pi/3}^{\varphi=\alpha-\pi/3}\quad .$$

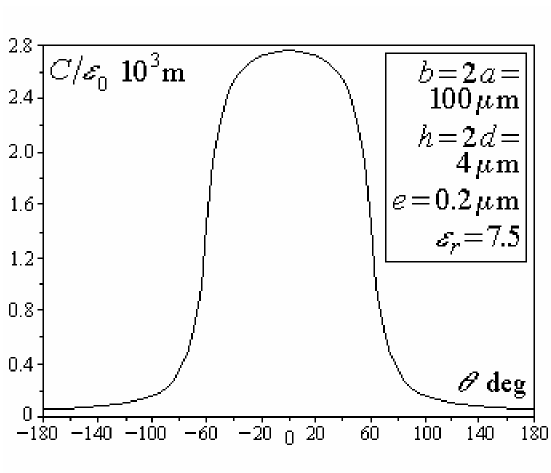

Fig. 5. Rotor–stator capacitance

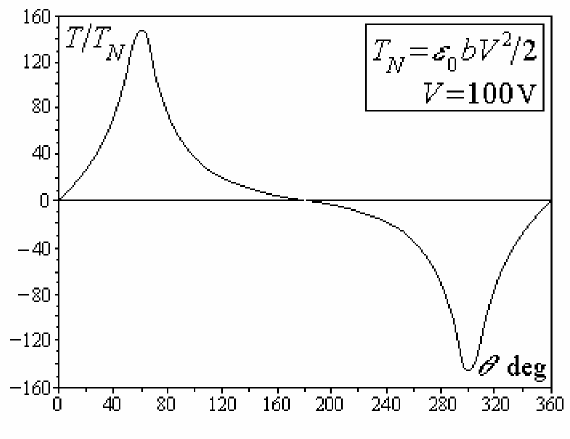

Fig. 6. Mechanic characteristic

The operation of the micromotor supposes the transfer of the energizing potential V to successive stator pole pairs. This way the overall mechanic characteristic of the motor can be derived as the periodic repetition of the above one pole pair mechanic characteristic, , as represented in fig. 6, with the period done by the pole pitch of $\pi/3$.

The usual mechanic characteristic torque–versus–revolving speed can then be derived with reference to a particular driving procedure, aiming at relating the revolving speed with the switching rate of the energized pole pairs.

CONCLUSIONS

The approximate mechanic characteristic of an axial–gap electrostatic wobble motor was computed, under reasonable simplifying hypotheses, for data compatible with current actual realizations. Moreover, the formulae obtained for the rotor–stator capacitance could be used in the computation of the torque–versus–current driving characteristic of the wobble motor.

It is worth mentioning that the numerical results obtained following the simplified analytical procedure exposed above compares successfully with other published results, [1].

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