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Discussion

Comments on "identification of a nonlinear electromagnetic system: An experimental study"

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The writers found the subject of the paper by Chang and Tung [1] interesting. Considering some limitations in their experiments such as saturation of the magnetic material, which is mentioned by the authors, they concluded that the attractive magnetic force cannot have the conventional form of $KI^2/(g_0 - y)^2$, where I is the instantaneous current in the coil. Using the harmonic balance method in their experimental setup they tried to identify a polynomial form for the electromagnetic force. They wrote the general form of equation of motion of the rotor as follows:

$$M\frac{\mathrm{d}^2y}{\mathrm{d}t} + C\frac{\mathrm{d}y}{\mathrm{d}t} + ky = F_m(i, y) + D. \tag{1}$$

Here F_m is the electromagnetic force exerted on the rotor and 'i' is the oscillating current about mean value I_0. In the paper, three polynomial forms of the magnetic force as functions of air gap and coil current with unknown coefficients were proposed. Considering the voltage balance in magnetic bearing, the proposed models are

Case 1:

$$\begin{aligned}&\ddot{y} + a_1\dot{y} + a_2y + a_3y^2 + a_4y^3 + a_5i + a_6i^2 + a_7i^3 + a_0 = 0,\\ &L_0\frac{\mathrm{d}i}{\mathrm{d}t} + iR = K_AA_0\sin(\omega t).\end{aligned} \tag{2}$$

Case 2:

$$\begin{aligned}&\ddot{y} + a_1\dot{y} + a_2y + a_3y^2 + a_4y^3 + a_5i + a_6i^2 + a_7i^3 + a_0 = 0,\\ &L_1(I_0 + i)^{-1}\frac{\mathrm{d}i}{\mathrm{d}t} + iR = K_AA_0\sin(\omega t).\end{aligned} \tag{3}$$

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Case 3:

$$\ddot{y} + b_1\dot{y} + b_2 y + b_3 y^2 + b_4 y^3 + b_5(I_0 + i)^{6/3} + b_6(I_0 + i)^{2/3} + b_7(I_0 + i)^{4/3} + b_0 = 0,$$
$$L_1(I_0 + i)^{-1}\frac{\mathrm{d}i}{\mathrm{d}t} + iR = K_A A_0 \sin(\omega t). \tag{4}$$

Identification results show that none of the coefficients of the terms y, y^2 and y^3 are zero. Comparing Eq. (1) with Eqs. (2) and (3) it can be concluded that the magnetic force is assumed as a sum of two functions, a displacement function (F_{m1}) and a current function (F_{m2}):

$$F_m(i, y) = F_{m1}(y) + F_{m2}(i). \tag{5}$$

Here in cases 1 and 2

$$F_{m1} = M(a'_2 y + a_3 y^2 + a_4 y^3 + a''_0),$$
$$F_{m2} = M(a'_5 i + a_6 i^2 + a_7 i^3 + a'_0) \tag{6}$$

and in case 3

$$F_{m1} = M(b'_2 y + b_3 y^2 + b_4 y^3 + b''_0),$$
$$F_{m2} = M[b_5(I_0 + i)^{6/3} + b_6(I_0 + i)^{2/3} + b_7(I_0 + i)^{4/3} + b''_0). \tag{7}$$

In these equations, a'_2 and b'_2 represent a linear term including magnetic force in addition to the linear mechanical stiffness.

Due to the summation form of Eq. (5) even when the excitation and bias current is zero that portion of the magnetic force which depends on displacement may become nonzero. But in electromagnetic actuators it is obvious that when the coil current is zero, the magnetic force also must be zero. In other words, the authors identified an electromagnetic force which is not zero when the excitation current or coil current is zero. If this nonzero force is due to the inclusion of hystersis effects, according to Hodgdon [2], it must be a function of both current and displacement.

Indeed instead of summation form, the electromagnetic force must be modeled and identified as multiplicative functions of current and displacement, where the vanishing of coil current should result in zero electromagnetic forces. In other words, the identified model must have the following general form:

$$F_m(i, y) = \sum_{\text{finite}} F(y) \times G(i, y^{\alpha} i^{\beta}), \tag{8}$$

where F's and G's are distinct functions, α and β are powers that must be identified. Also the identified model should meet the following condition:

$$i = 0 \rightarrow G(0, 0) = 0 \Rightarrow F_m(0, y) = 0. \tag{9}$$

It must be noted that the coefficients and the powers of the proposed functions have such a dimension that the unit of resulted function is force.

References

[1] S.C. Chang, P.C. Tung, Identification of a non-linear electromagnetic system: an experimental study, *Journal of Sound and Vibration* 214 (5) (1998) 853–871.

[2] M.L. Hodgdon, Mathematical theory and calculations of magnetic hystersis curves, *IEEE Transactions on Magnetics* 24 (6) (1988) 3120–3122.