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Discussion

Author's reply

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We would like to thank Dr. Shabani and others for their comments on our paper. The experimental set-up of the electromagnetic system displays in Fig. 2 of Ref. [1] and the model of the rotor is governed by

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

where y is the oscillating displacement of the rotor about a reference point. Constant parameters C, K, and D denote the equivalent damping, stiffness and dc gain of the electromechanical system, respectively. F_m is the magnetic force of the electromagnet: it is a function of the current and the air gap. It is noted that the term of dc gain is generated due to the origin of the chosen coordinate which may be different from the actual equilibrium point and the spring preload. In general, the calculation of this force is based on the field energy. If we neglect the iron loses and assume the electromagnet to be unsaturated, theoretically, this force is quadratically dependent on the current and inversely quadratically dependent on the air gap. However, if the iron of the electromagnet is operated beyond or close to saturation point with high flux densities (as in our case), we must consider the nonlinear characteristics of the magnetization curve. Then, to determine exactly the motion of the rotor in magnetic field requires the simultaneous solution to the full set of Maxwell equations coupled with the kinetic equation for the rotor. It is indeed a very difficult task. Thus, the nonlinear magnetic force is approximated by an approximate form of polynomial in our study. The authors agree that if the coil current is zero, the magnetic force also must be zero. The fact displays in Fig. 10 of Ref. [1] which is the magnetic force–current characteristics for experimental measurement. Having the experimental data for magnetic force at hand, we perform the curve fitting procedures to obtain two polynomials representing the force–current (fixed air gap) relationship as follows:

$$F_m(I) = C_1 I^{2/3} + C_2 I^{4/3} + C_3 I^{6/3} + C_0, \quad \text{with air gap fixed}, \tag{2}$$

where I is the total current including the biased current. In Eq. (2), the constant C_0 can approach to zero since $I = 0$ (coil current) when $F_m = 0$ (magnetic force). In Ref. [1], we do not consider the hysteresis effect in the

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magnetic force. But if the identified model of electromagnetic system has the spring preload, the dc gain must exist in this model.

Reference

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