On heat dissipation control of linear variable reluctance motors

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1 Introduction

Many material properties are temperature dependant. That is why the force actuators used in high-precision motion systems are required, besides the high force predictability, to have predictable behavior with respect to heat dissipation. We investigate strategies on how to control heat dissipation of variable reluctance linear motors with flux feedback control.

2 Physical principles

A typical layout of a linear variable reluctance motor is shown in Fig. 1. If the magnetic cores are assumed to be made of a linear laminated ferromagnetic material, i.e. $B = \mu H$, then the total induction losses per unit volume of the material are given by [1]:

$$P_{\text{tot}} \left( \frac{d\Phi}{dt} \right) = P_{cl} + P_{ex} = \frac{\sigma d^2}{12A_g^2} \left( \frac{d\Phi_1}{dt} \right)^2 + \frac{C\sqrt{\sigma d}}{A_g^{3/2}} \left| \frac{d\Phi}{dt} \right|^2,$$

(1)

where $P_{cl}$ are classical eddy current losses, $P_{ex}$ are excess losses, $d$ is the lamination thickness, $\sigma$ is the electric conductivity of the material, and $C$ is a constant dependant on the material type. The hysteresis losses are neglected.

Furthermore, the dynamics of the mass suspended by two variable reluctance actuators (Fig. 1) can be modeled as [2]:

$$m\ddot{g} = F + F_d = \frac{1}{\mu_0 A_g} \left( \Phi_1^2 - \Phi_2^2 \right) + F_d,$$

(2)

where $m$ is the total mass of the translator, $F$ is the net force on the translator, $F_d$ is the disturbance force, and $\Phi_1$ and $\Phi_2$ are air gap magnetic fluxes entering the translator at the actuating direction. It is assumed that a high bandwidth, e.g. 10 kHz, flux feedback control loop is implemented for both actuators together with the measurements of $\frac{d\Phi}{dt}$ (e.g. sensing coil) and $\Phi$ (e.g. hall probe, observer).

3 Control design

The heat dissipation in the translator is of interest. Since these actuators are primary used for tracking control and disturbance rejection, there will always be some heat dissipation which depends on the desired force profile and can be accurately calculated using available flux measurements and (1). The idea is to introduce additional dissipation in order to meet temperature distribution objectives. Two approaches are investigated:

- The heat dissipation is controlled by adding high-frequent sinusoidal components to the flux reference signals, i.e. $\Phi_1^{\text{ref}}(t) = \Phi_1^{\text{ref}} + A_{\Phi_1}\sin(\omega t)$ and $\Phi_2^{\text{ref}}(t) = \Phi_2^{\text{ref}} + A_{\Phi_2}\sin(\omega t)$, where $\omega$ is an order of magnitude larger then the motion control bandwidth, and $A_{\Phi_1}$ and $A_{\Phi_2}$ are additional control signals of relatively small amplitudes used for dissipation control. The inertia of the mass will further attenuate these components by -40 dB, so they will be neglectable in the motion control, but can create problems for the power electronics since the available voltage swing will be reduced.

- By investigating (2) it can be seen that there are infinitely many possible $\Phi_1$ and $\Phi_2$ that generate the same net force on the translator. The controller has to choose the signals $\Phi_1^{\text{ref}}$ and $\Phi_2^{\text{ref}}$, so that equalities $(\Phi_1^{\text{ref}} - \Phi_2^{\text{ref}}) = \mu_0 A_g F_{\text{desired}}$ and $P_{\text{tot}} \left( \frac{d\Phi_1^{\text{ref}}}{dt} + \frac{d\Phi_2^{\text{ref}}}{dt} \right) = P_{\text{desired}}$ hold. This approach requires no high-frequent components in the control signal and is therefore preferred.

The applications of the introduced schemes include start-up transient temperature control and steady-state temperature fluctuation reduction in electromechanical machines.

References
