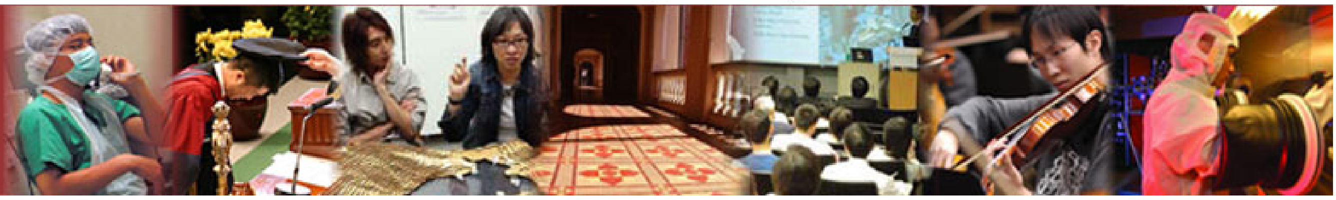

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DESIGN OF PERMANENT MAGNETS TO AVOID CHAOS IN PM SYNCHRONOUS MACHINES

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Purpose

The permanent-magnet synchronous machine (PMSM) is becoming more and more attractive for both industrial and electric vehicle applications [1] because of its inherent advantages of high power density and high efficiency. However, the investigation onto its chaos has been surprisingly little. Even so [2], the discussion was based on ac-hoc computer simulation, whereas the actual effect of PMs on the chaos in PMSMs was unexplored. In this paper, the relationship between the sizing of PMs and the chaos in PMSMs will be revealed. Both computer simulation and experimental results will be given to support the design criteria.

Chaos

As shown in Fig. 1, a PMSM coupled with an induction motor (IM) is used for exemplification. The PMSM is modeled in d-q frame as given by (1). Under the conditions that the stator windings are short-circuited and the mechanical torque is equal to the PM torque, the PMSM model can be transformed into a dimensionless form as given by (2). Consequently, it can be deduced that the PM flux ψ_a exhibits an important effect on the system behavior: namely, normal stable operation is *guaranteed only when ψ_a is lower than a critical value; otherwise, chaos may occur.* This finding illustrates that the sizing of PMs is crucial to avoid chaos in PMSMs.

$$\begin{cases} L_{ds}\dfrac{di_{ds}}{dt} = -u_{ds} - R_s i_{ds} + \dfrac{P}{2}\omega_r L_{qs} i_{qs} \\ L_{qs}\dfrac{di_{qs}}{dt} = -u_{qs} - R i_{qs} - \dfrac{P}{2}\omega_r L_{ds} i_{ds} + \dfrac{P}{2}\psi_a \omega_r \\ J\dfrac{d\omega_r}{dt} = T_m - \dfrac{3}{2}\dfrac{P}{2}\psi_a i_{qs} + \dfrac{3}{2}\dfrac{P}{2}(L_{ds} - L_{qs}) i_{ds} i_{qs} - B\omega_r \end{cases} \quad (1)$$

$$\begin{cases} \dfrac{dx}{dt} = -bx + yz \\ \dfrac{dy}{dt} = -y - xz + cz \\ \dfrac{dz}{dt} = xy - az \end{cases} \quad (2)$$

Results

As shown in Fig. 2, the bifurcation diagram of the rotor speed ω_r with respect to ψ_a can be obtained from (2). *It indicates that the critical value of ψ_a is* 0.0634 Wb. When ψ_a =0.117 Wb, chaos occur. Fig. 3 shows the corresponding chaotic waveforms of i_{ds}, i_{qs} and ω_r in time-domain as well as the trajectories on the $i_{ds} - i_{qs}$, $i_{ds} - \omega_r$ and $i_{qs} - \omega_r$ planes. It can be found that the waveforms exhibit a well-known property of chaos (namely, random-like but bounded), while the trajectories resemble a butterfly (namely, the Lorenz attractors). Detailed simulation and experimental results will be included in the full version.

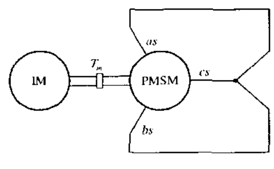

Fig. 1. The PMSM system.

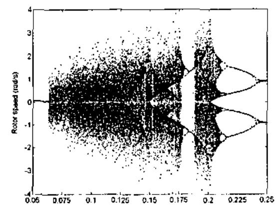

Fig. 2. Rotor speed bifurcation diagram via PM flux.

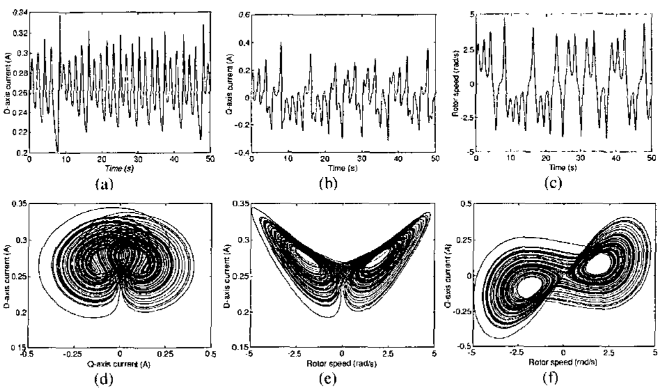

Fig. 3. Chaotic waveforms and trajectories of the PMSM.

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