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# DESIGN OF PERMANENT MAGNETS TO CHAOIZE PM SYNCHRONOUS MOTORS FOR INDUSTRIAL MIXERS

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## Purpose

Industrial mixers are among the most expensive and ineffective equipments. The industrialists and academics in the USA have estimated that the cost of ineffective industrial mixing is of the order of US$ 1 to 10 billion per annum [1]. Thus, the improvement of mixing is highly desirable and justifiable.

In recent years, chaotic mixing has been proposed to improve the energy efficiency and the degree of homogeneity by using either mechanical [2] or electrical means [3]. Compared with those mechanical means which are essentially based on geometrically asymmetric design of the mixer to produce a practical chaotic motion, the electrical means not only produces the desired chaotic mixing, but also offers the advantages of high flexibility and high controllability. A chaotic DC motor has ever been adopted as the agitator in [3]. However, the indispensable commutator and brushes cause many shortcomings, limiting its widespread application to industrial mixers. In this paper, the permanent magnet synchronous motor (PMSM) will be used as the agitator because of its inherent advantages of high power density, high efficiency and maintenance-free operation. The effect of PM sizing on the performance of the chaotic motion of PMSM will be discussed. Simulation as well as experimental results of the proposed mixer will be presented to verify the effectiveness.

## System Modeling and Simulation

Based on field orientation control, a surface mounted PMSM can be represented by

$$J\frac{d\omega}{dt} = -B\omega + K_T i_q - T_l \quad (1)$$

$$L\frac{di_q}{dt} = -Ri_q - K_E\omega + u_q \quad (2)$$

where $B$ is the viscous damping coefficient, $i_q$ is the $q$-axis current, $J$ is the load inertia, $K_E$ is the EMF constant, $K_T$ is the torque constant, $L$ is the armature inductance, $R$ is the armature resistance, $T_l$ is the load torque, $u_q$ is the $q$-axis voltage, $\omega$ is the rotor speed. The key to chaoize the motor is to employ time-delay feedback control based on the feedback law

$$T_e^* = \mu\xi B\, f\left(\frac{\omega(t-\tau)}{\xi}\right) \quad (3)$$

where $T_e^*$ is the electromagnetic torque command, $\mu$ is the torque parameter, $\xi$ is the speed parameter, $\tau$ is the time-delay parameter, and a sine function is chosen as the integrable bounded function $f(\cdot)$ that serves to limit the required torque to the motor torque capability.

Realistic system parameters are adopted, which will be presented in full paper. The speed bifurcation diagram with respect to PM sizing is presented in Fig. 1, which illustrates how the system behavior is affected by varying the PM sizing, namely the PM flux. It can be seen that the motor initially operates at a fixed point with a large value of PM sizing. With the decrease of PM sizing, the motor bifurcates to chaotic motion. Fig. 2 shows the corresponding speed when the motor runs in the chaotic mode at its manufactured flux.

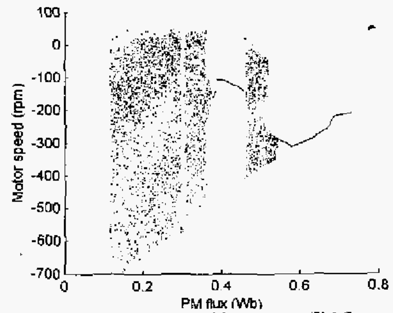



**Fig. 1** Motor speed with respect to PM flux.

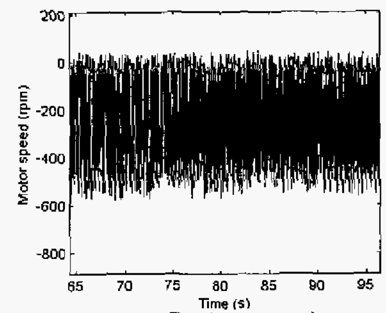
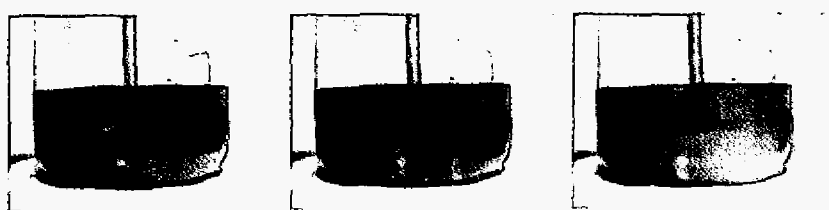



**Fig. 2** Chaotic motor speed.

## Experimental Results

The mixing apparatus consists of a tank and an impeller spun by a digitally-controlled drive mounted vertically on a stand. The task is to mix the acidic mixture (200 ml light corn syrup; 5 ml pH indicator; 5 ml 1 N HCl) with the basic mixture (100 ml light corn syrup; 2.5 ml pH indicator; 2.5 ml 1 N NaOH). Although the overall solution is acidic (red in color) as there is twice as much acid as base, there are basic regions (green in color) due to diffusion limitations caused by the highly viscous solvent (light corn syrup). Fig. 3 shows the system colorations after 0 s, 30 s and 90 s of chaotic mixing, respectively. A segregated region, which exists in constant speed mixing and costs a lot of energy to be destroyed, is not visible in chaotic mixing.



(a) (b) (c)

**Fig. 3** Colorations during chaotic speed mixing. (a) 0 s. (b) 30 s. (c) 90 s.

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