Rotor Displacement Self-sensing Method for Six-pole Radial Hybrid Magnetic Bearing Using Mixed-kernel Fuzzy Support Vector Machine

Tiantian Liu, Huangqiu Zhu, Mengyao Wu, and Weiyu Zhang

School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu, China

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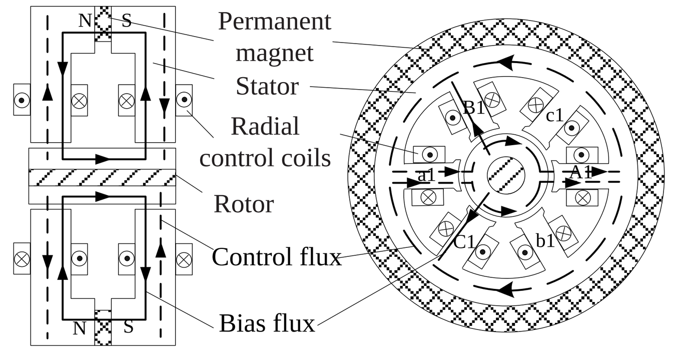
Background

The rotor of a magnetic bearing is suspended in the air gap by using permanent magnet or currents in the coils to generate magnetic force, which has the advantages of no friction, long life, high speed and high precision and so on. So magnetic bearings have been widely used in aerospace, medical instruments, rail transit and other fields. In traditional magnetic bearings, displacement sensors are often used to detect rotor displacements, which provide some problems such as high price, occupying space and increasing system structural complexity. To solve above problems, the self-sensing method is proposed to predict rotor displacements.

Six-pole radial Hybrid Magnetic Bearing

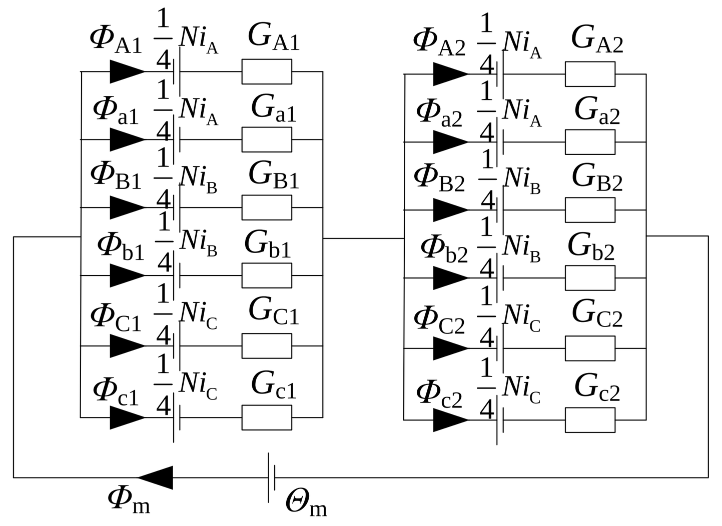
Operation Principle

- The six-pole radial hybrid magnetic bearing is mainly composed of a permanent magnet, two pieces of stator, radial control coils and rotor.



- Radial control coils on the corresponding two magnetic poles are connected in series and the winding directions are opposite, so that the six control coils can be driven by a three-phase inverter.
- The magnetic flux consists of bias flux and control flux, which are generated by the permanent magnet and the electrification of the control coils, respectively.

Mathematical Model



To simplify the calculation, the influence of magnetic resistance and eddy current can be neglected.

Radial suspension forces can be expressed as follows:

$$\begin{cases} F_x = \sqrt{\dfrac{3}{2}}\dfrac{\mu_0 S_r \Theta_m N}{\delta_r^2}\cdot i_x + \dfrac{3\mu_0 S_r \Theta_m^2}{2\delta_r^3}\cdot x \\ F_y = \sqrt{\dfrac{3}{2}}\dfrac{\mu_0 S_r \Theta_m N}{\delta_r^2}\cdot i_y + \dfrac{3\mu_0 S_r \Theta_m^2}{2\delta_r^3}\cdot y \end{cases}$$

The equation of motion is shown as

$$\begin{cases} m\ddot{x} = F_x \\ m\ddot{y} = F_y - mg \end{cases}$$

In the vicinity of the equilibrium position, the suspension forces in the *x*- and *y*-direction of the six-pole radial HMB are only linearly related to the control current and displacement.

Displacement Prediction Model

FSVM

According to KTT condition and the Mercer condition, the prediction model of the SVM can be expressed as follows:

$$y(x) = \sum_{k=1}^{N} \alpha_k K(x_k, x) + b$$

Kernel fuzzy clustering (KFC) algorithm is used to blur the input training samples. And the objective function expression of KFC algorithm in high dimensional space is as follows:

$$J_m(\boldsymbol{I}, \boldsymbol{U}, \boldsymbol{V}) = \sum_{j=1}^{N}\sum_{k=1}^{N} \mu_{jk}^{\ m} dis^2(i_k, v_j)$$

Mixed-kernel Function

$$K_m = \lambda K_l + (1-\lambda)K_g$$

where K_l is the radial basis kernel function, K_l=exp(-||x-x_i||/2s^2), K_g is the polynomial kernel function, K_g=((x,x_i)+1)^3, λ is the mixing coefficient, 0<λ<1.

Self-sensing Modeling

1) Acquisition and preprocessing of sample data for input and output variables.

2) Initialize parameters.

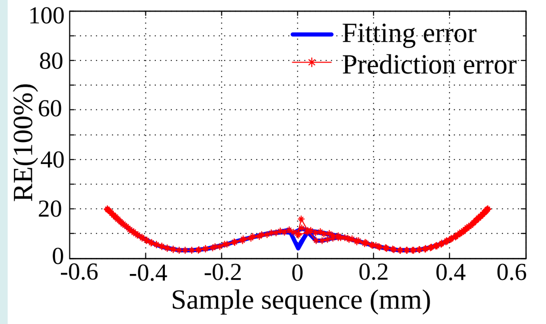
3) Determine if the particles meet the requirements.

4) Produce the next generation population.

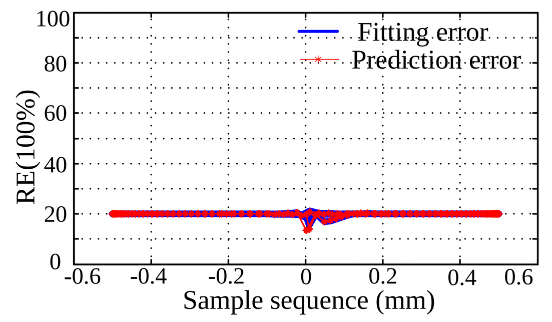
5) Retrain and test the FSVM model.

6) Output the predicted values.

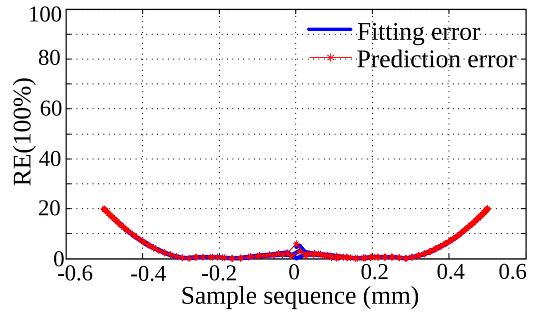
Simulations



(a) Radial basis kernel function



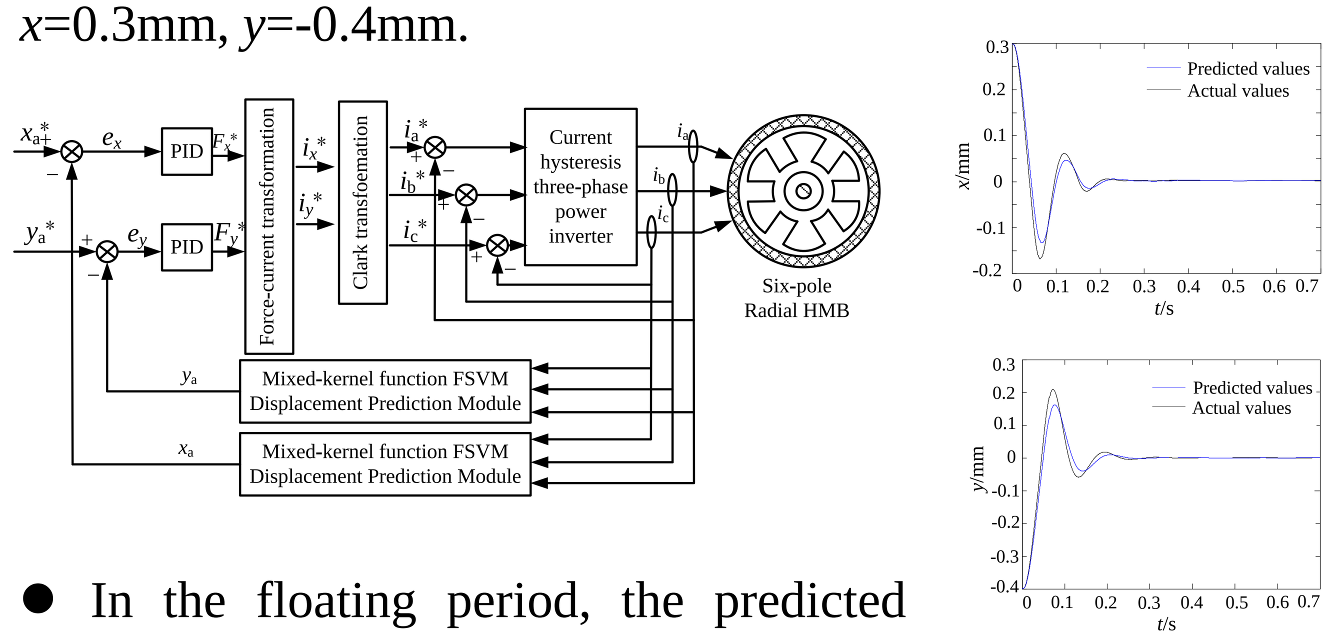
(b) Polynomial kernel function



(c) Mixed-kernel function

- The mixed-kernel function FSVM method combines the advantages of polynomial kernel function and radial basis kernel function, and can effectively improve the prediction accuracy and fitting ability of the model.

The initial displacements of magnetic bearing rotor is x=0.3mm, y=-0.4mm.



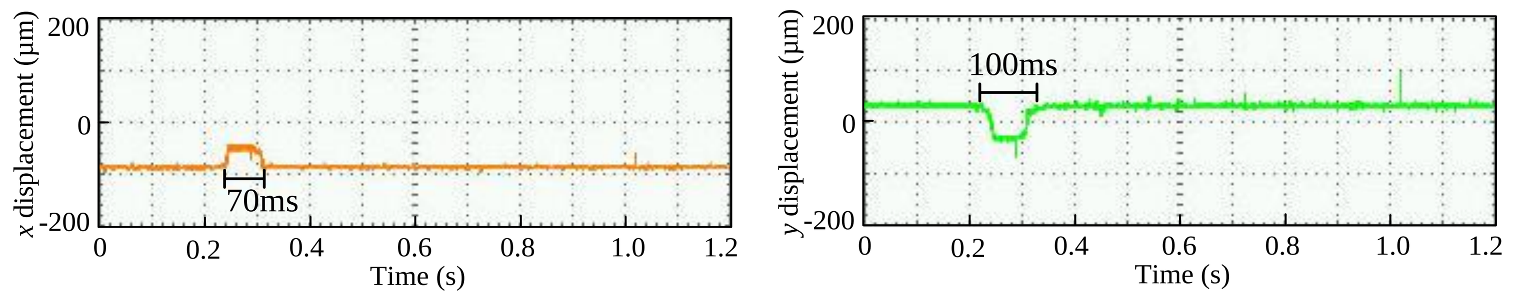
- In the floating period, the predicted values is closer to the actual values.
- So the prediction performance of the method proposed in this paper is good .

Experiments

Main paramenters of six-pole radial HMB:

Parameters	Values
Air gap length d_0	0.5 mm
Saturation induction density B_s	0.8 T
Radial magnetic pole area S_r	260 mm^2
Maximum ampere-turns of a radial coil $(N_r i_r)_{max}$	160 At
Magnetomotive force of permanent magnet Θ_m	320 At
Width of magnetic poles W_{HrP}	16 mm
Axial width of permanent magnet W_m	3 mm
Magnetic bearing length	25 mm

When the system is in a stable state, a 50 N disturbance force is added to the rotor.



- The rotor can quickly return to the equilibrium position, and the system has good anti-interference performance, which verifies the feasibility of the method proposed in this paper.

Conclusions

- A self-sensing method using the mixed-kernel function FSVM is proposed to establish the rotor displacement prediction model of six-pole radial HMB.
- The prediction model between the currents of the control coil and the displacement of the rotor is established, which realizes the self-sensing control of the rotor.
- The predicted values are nearly equal to the actual values, which proves that the method can accurately detect the displacements of the rotor and realize the stable suspension of the magnetic bearing system.