Journal of Zhejiang University-SCIENCE A

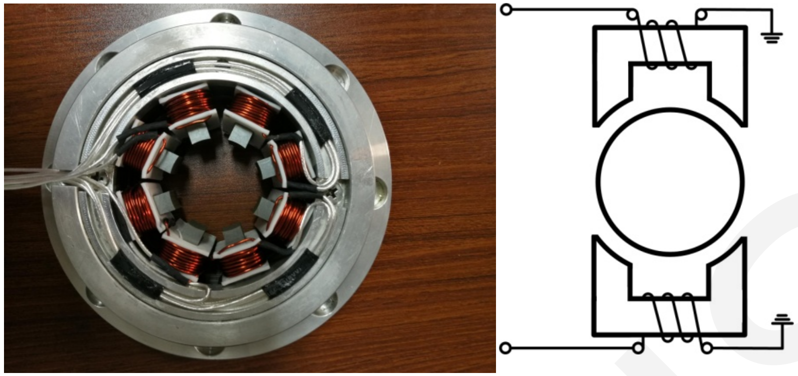
A synchronous sampling-based direct current estimation method for self-sensing active magnetic bearings

Xiong-xin HU

Coll. Mech. Eng., Zhejiang Univ. Technol.

Cite this as: Xiong-xin Hu, Fang Xu, Da-peng Tan, 2020. A synchronous sampling-based direct current estimation method for self-sensing active magnetic bearings. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(5): 401-405. https://doi.org/10.1631/jzus.A2000067

Magnetic bearings and instances

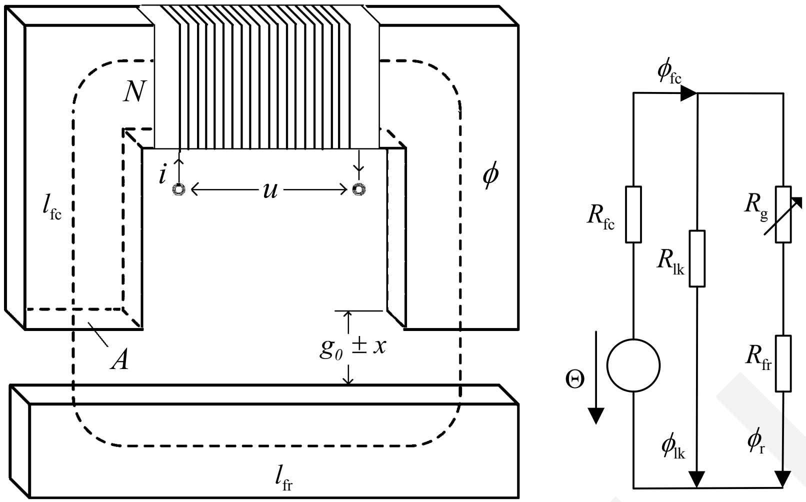


(**a**) Magnetic levitation systems enable a frictionless suspension of object. The close-loop system of active magnetic bearings (AMBs) is implemented by the **position sensor** which makes **AMBs relatively expensive** and causes problem in the **failure** cases

(**b**) Position sensor: eddy current sensor and laser sensor etc.

(**c**) Magnetic bearings in some industrial applications, such as **turbine machine**, **air-blast, flywheel** and **haulage motor** .

Self-sensing AMBs and model



Position sensor is replaced by an estimator which makes use the voltage and current of coil, and the self-sensing AMBs is developed.

$$R_{\mathrm{m}} = R_{\mathrm{fc}} + R_{\mathrm{g}} + R_{\mathrm{fr}}$$
$$= \frac{1}{\mu_0 A}\left[2(g_0 \pm x) + (l_{\mathrm{fc}} + l_{\mathrm{fr}})/\mu_{\mathrm{r}}\right]$$

Reluctance model of magnetic bearings

The switching current of the power amplifier is controlled by a duty-cycle

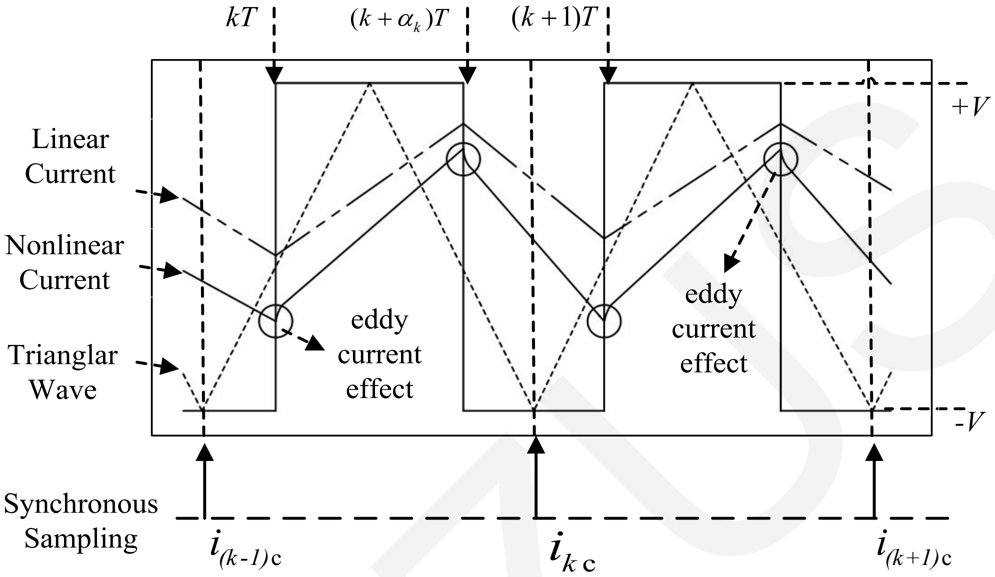
$$i_k(t) = \frac{V(2\alpha_0 - 1)}{R} + \frac{2\alpha_{mk} V \cos(\omega_c t)}{R + j\omega_c L} + \sum_{n=1}^{\infty} \frac{4V}{n\pi} \frac{\left|\sin(n\pi\alpha_k)\right|}{jn\omega_s L} \cos(n\omega_s t - n\pi\alpha_k)$$

the fundamental ripple of the coil current $i_{1\mathrm{d}}$ and voltage $u_{1\mathrm{d}}$ obtained by **DFAdM**.

$$x_{\mathrm{ge}} = \frac{\pi\omega_s K_{\mathrm{N}}}{2V} \frac{i_{1\mathrm{d}}}{u_{1\mathrm{d}}}.$$

Synchronous sampling DCE(SS-DCE)

In the DFAdM estimator, the self-sensing path is so complex that the phase shift is larger than the traditional position sensor.

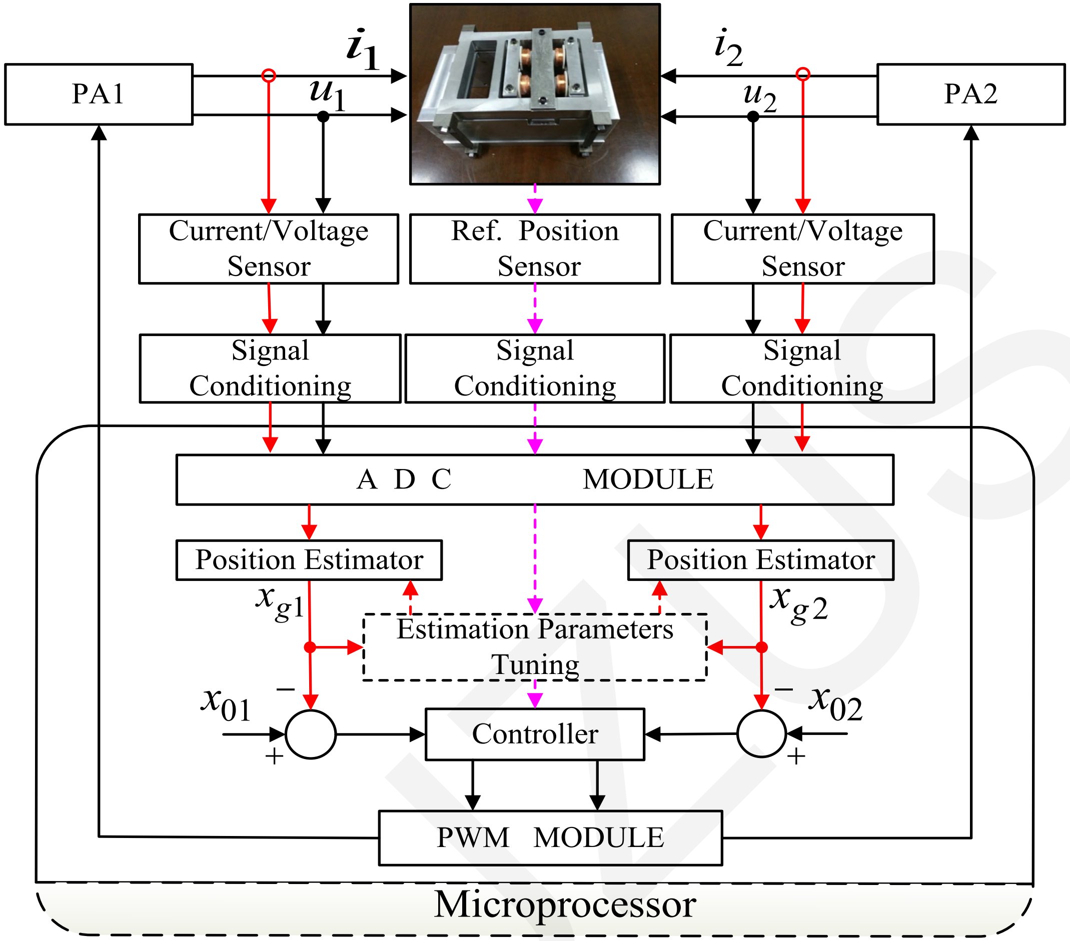


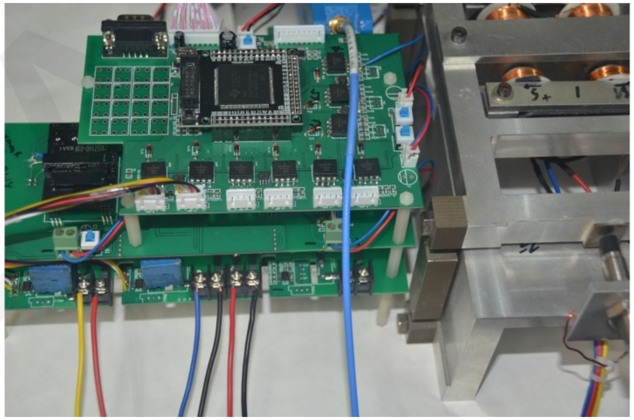
$$t_{kc} = \pi(1+\alpha_k)/\omega_s$$

if synchronous sampling occurs at t_{kc} , **SS-DCE** is developed as a novel method of position estimation which owns a short self-sensing path. And its estimation algorithm can be depicted as:

$$x_g = \frac{\omega_s K_N}{V} \frac{i_{kc} - i_{(k-1)c}}{2\alpha_k - 1}.$$

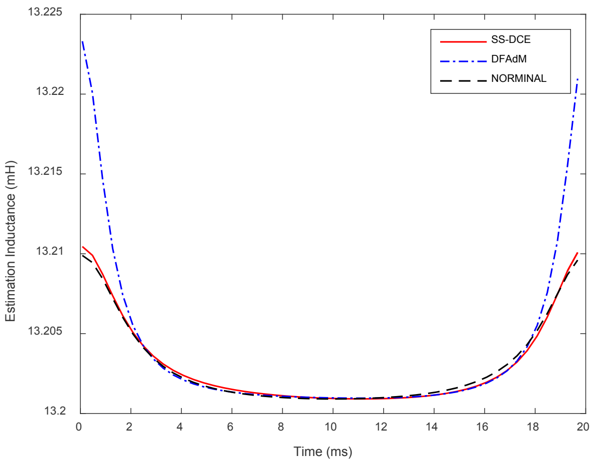
SS-DCE experimental platform



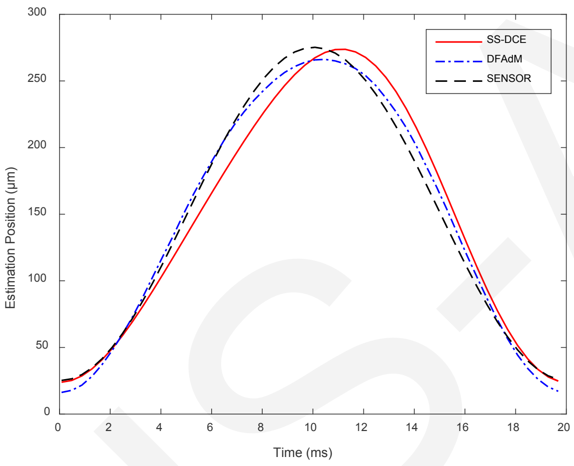


The SS-DCE experimental platform with reference position sensor is set up, and the position estimators' performance are measured in simulation and experimental test.

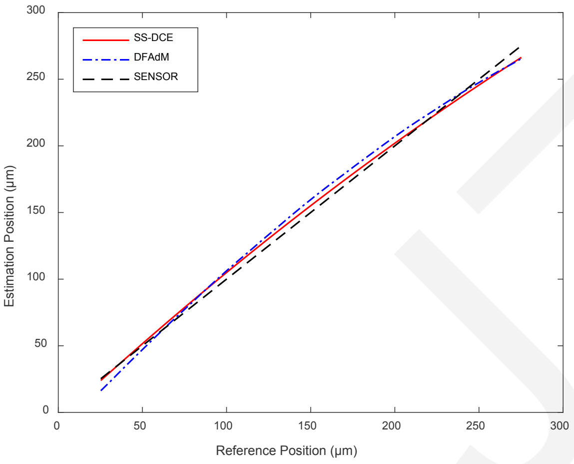
Simulation results



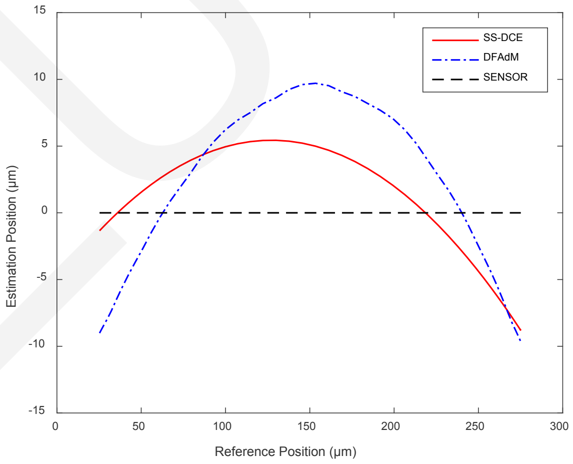
(a)



(b)



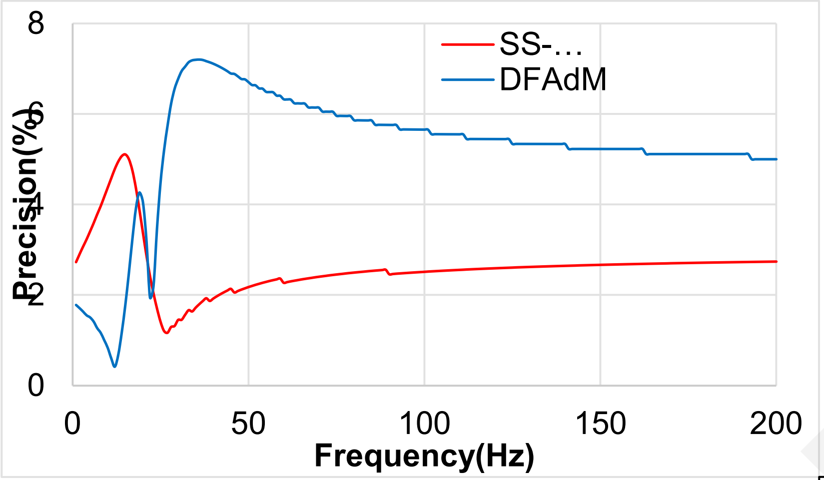
(c)



(d)

(a)-(d) The numerical instances for static performances (position, inductance, linearity, error) are established, in which the switching frequency and synchronous sampling frequency are 2kHz, the control frequency is 50 Hz, the sampling frequency of DFAdM is 100 kHz, the bias current is 3 A, the nominal inductance 13.2 mH.

Simulation results

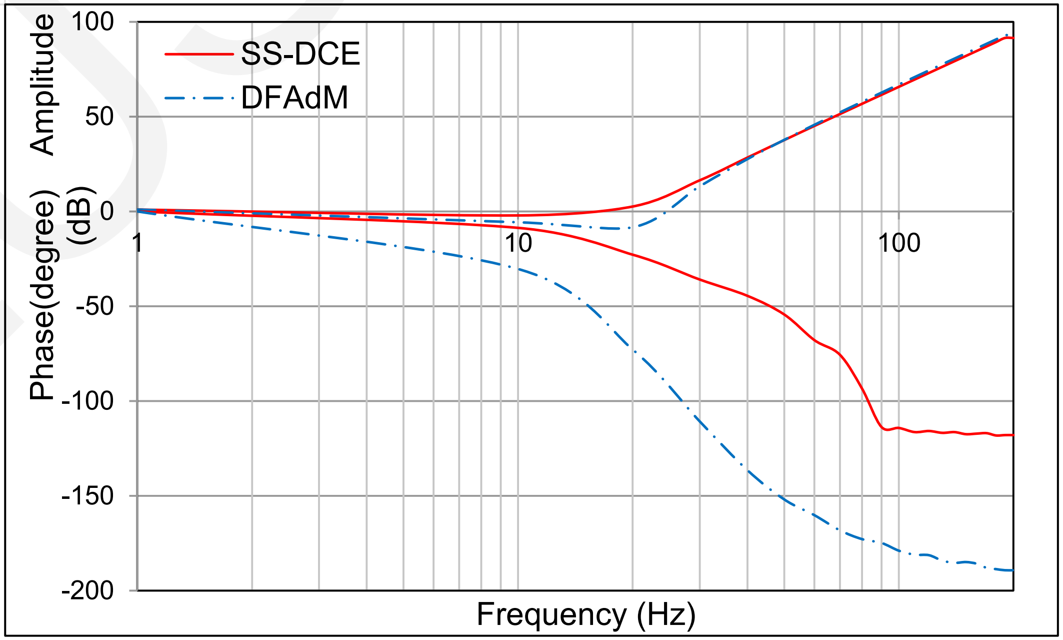


(e) The precision of these estimators ranges from 0.1 Hz to 200 Hz. SS-DCE can perform with higher estimation precision.

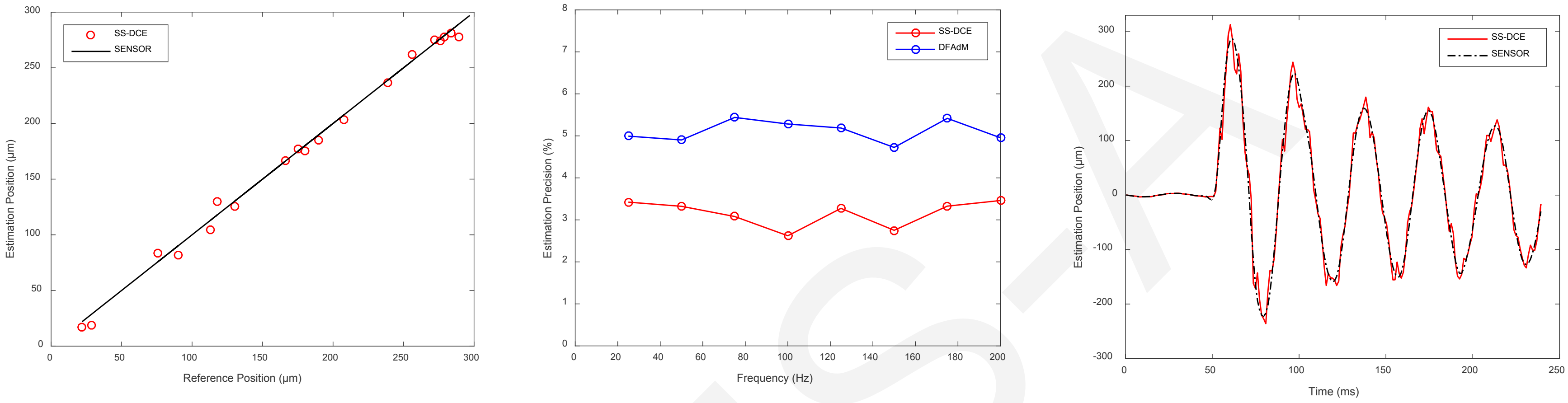
(f) The gain and phase response of the self-sensing system is denoted as

$$G(\omega)=20\log\left(X_{est}(\omega)/X_{sen}(\omega)\right)$$

The phase lag of SS-DCE is around 22^{o} at the eigen frequency: 19.3Hz, but it has 82^{o} phase margin when the rotor operates at 200 Hz.



Experimental results



(g) **(h)** **(i)**

(g)-(h) Within 50~250 μm, the experimental results are shown and the maximum precision of SS-DCE is about 3.64% when the test frequency is 50Hz. The precision test results can prove that SS-DCE has a better estimation precision than DFAdM within 25~200Hz

(i) Meanwhile we can see that the system retains good stability under force disturbance, and has rapid convergence and acceptable overshoot.

Conclusions

- The self-sensing path is determined by filter number, algorithm complexity and phase lag. The rotor displacement is a nonlinear function about the voltage/current. This can be linearized by the switch amplifier ripples to reduce the self-sensing path.
- The estimation error is a function of frequency and position. The SS-DCE method can obtain better static performance (position, inductance, linearity, error).
- A self-sensing AMB experimental platform is established, and the results prove that the SS-DCE method can restrain the phase shift, and with better rising-speed response, rapid convergence and ac-ceptable overshoot.