Design and Analysis of a Novel Modular-Stator Tubular Permanent-Magnet Vernier Motor

Tian Yao, Wenxiang Zhao, Fangfang Bian, Liyang Chen, Xuhui Zhu

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

Presented at the MT-25
RAI-Amsterdam
Session number: Mon-Af-Po1.04-35 [65]
Program I.D. number: 784
2017 Aug. 28 (Mon) 13:15

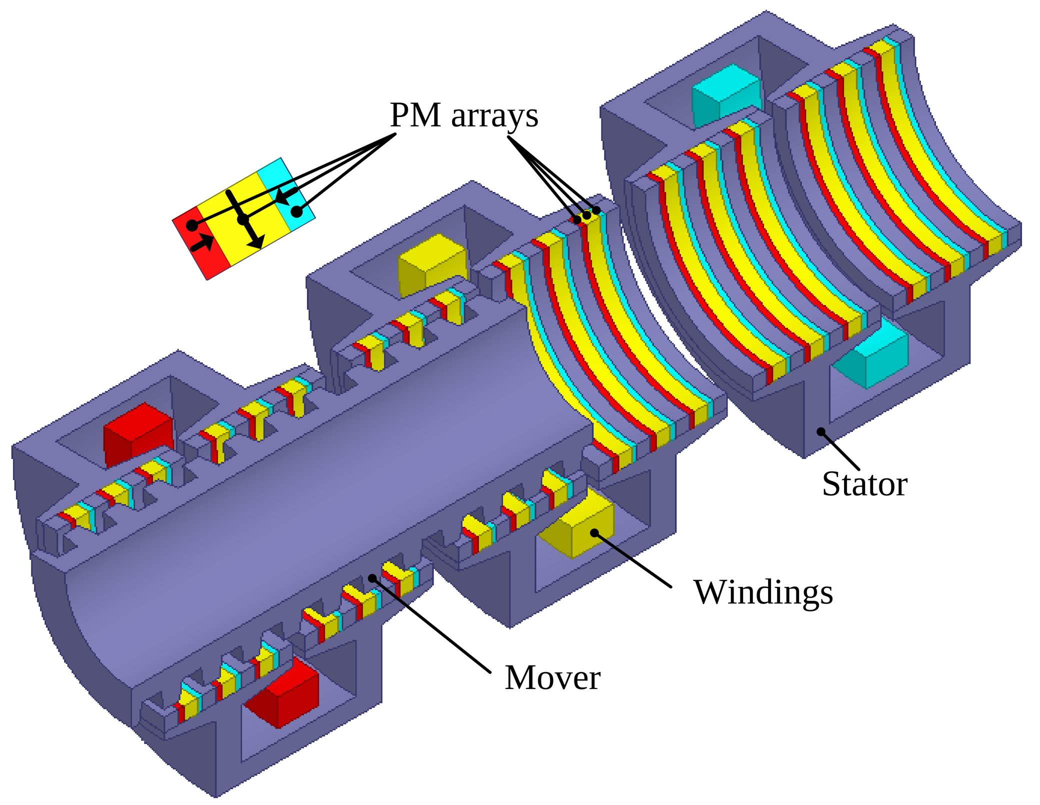
Summary

This paper proposes a new modular-stator tubular permanent-magnet (PM) vernier (MST-PMV) motor, possessing good fault-tolerant capability and improved force performance, suitable for active vehicle suspension. The proposed motor artfully integrates tubular motors and PM vernier motors together, offering zero net radial force between the armature and mover, robust mover structure and high thrust force. Meanwhile, the modular complementary stator structure is designed to decouple the adjacent phase windings, hence offering the desired fault-tolerant capability. Moreover, The PMs with two magnetized directions are adopted, namely radially and axially. One is used to produce the main flux, while another can reduce fringing leakage flux, hence increasing the thrust force. The electromagnetic performances are analyzed by using the finite-element method, verifying the effectiveness of the theoretical analysis.

Conclusion

- A new MST-PMV motor with good fault-tolerant capability and improved force performance has been proposed and analyzed.
- By artfully integrating tubular motors and PM vernier motors together, the proposed motor can offer zero net radial force between the armature and mover, robust mover structure and high thrust force.
- Due to the adoption of the PM arrays and modular complementary stator structure, this motor offers the advantages of reduced PM volume, high thrust force, low detent force and good fault-tolerant capability

Topology



The proposed MST-PMV motor has a simple mover only consisting of iron to transmit high thrust force. Meanwhile, its armature windings have no end-windings, offering low copper loss. Besides, the modular complementary stator structure and PM arrays with two magnetized directions are adopted to provide good fault-tolerant capability and improved force performance.

Operation principle

The proposed MST-PMV motor operates on the so-called flux modulation operation principle. That is to say, the relationship among PM pole pairs P_{pm}, armature windings pole pairs P_w and the number of active teeth on the mover N_s can be expressed as

$$P_w = \left| P_{pm} - N_s \right|$$

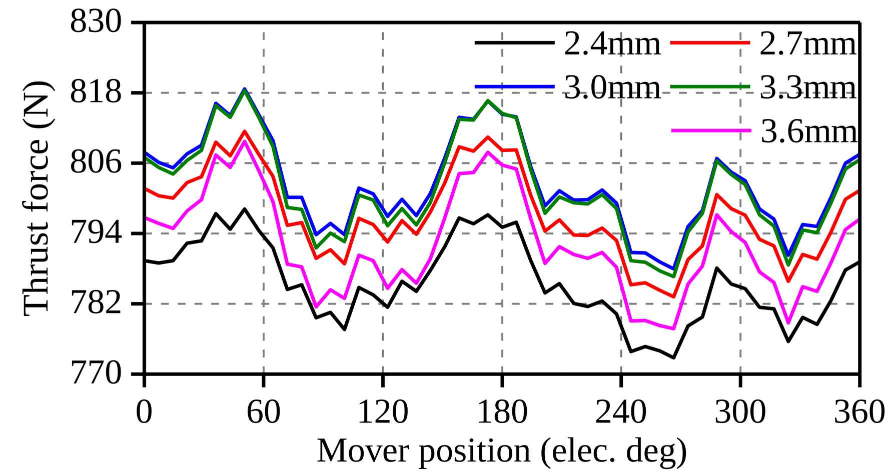
Thus, the speed of the magnetic field produced by the PM v_{pm} and magnetic gear ratio G can be obtained as

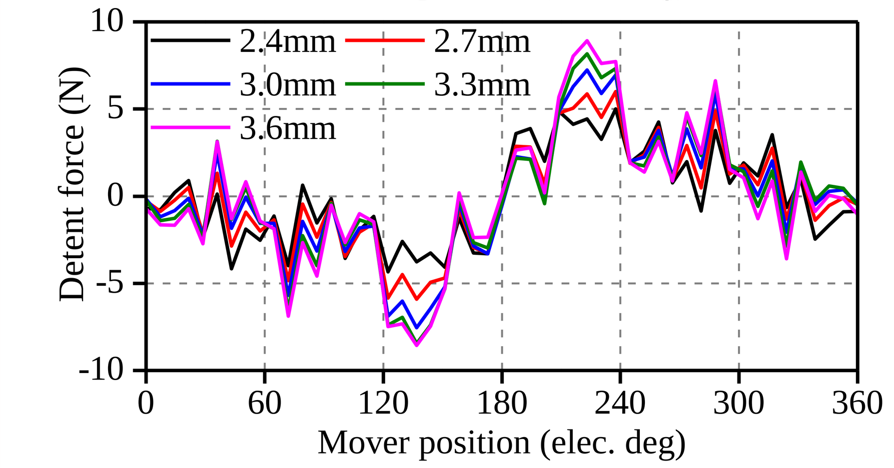
$$v_{pm} = \frac{P_w}{P_{pm}} v$$

$$G = \frac{P_w}{N_s}$$

where v is the linear speed of the mover.

Design



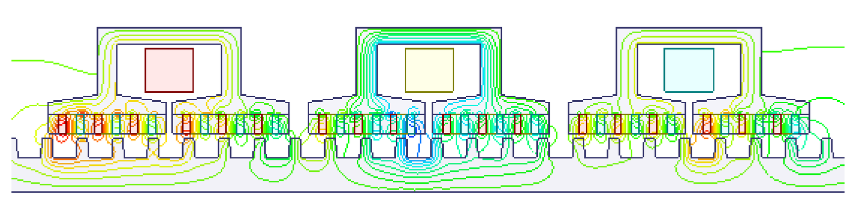


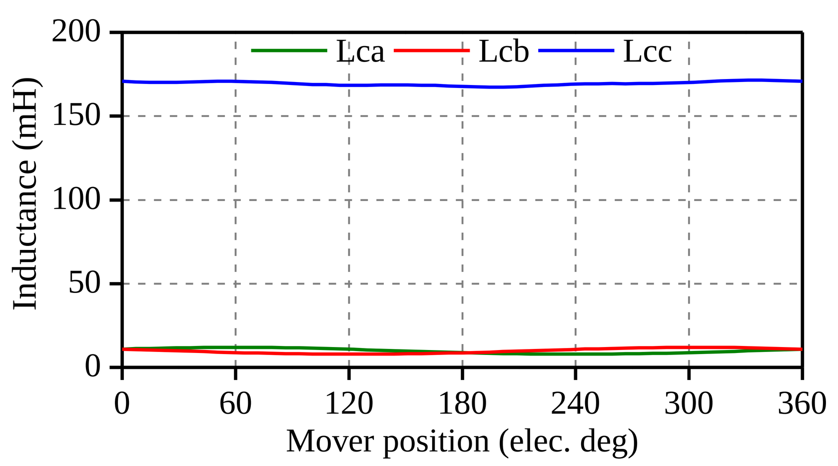
The force performance has a close relationship with many motor parameters, for example, axially magnetized PM axial width w_a, PM thickness t_{PM}, stator teeth width w_{st}, and so on.

By way of example, there is an optimal w_a that yields the maximum thrust force and relatively small detent force.

Electromagnetic performances

Magnetic Field Distributions and Inductances



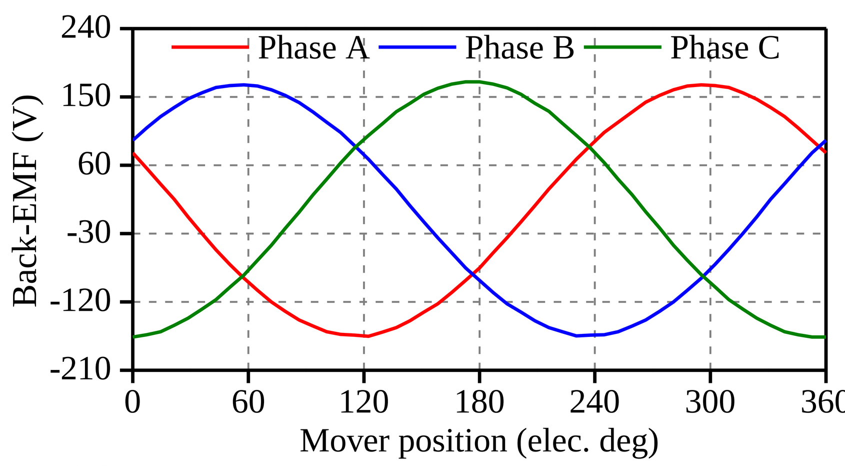


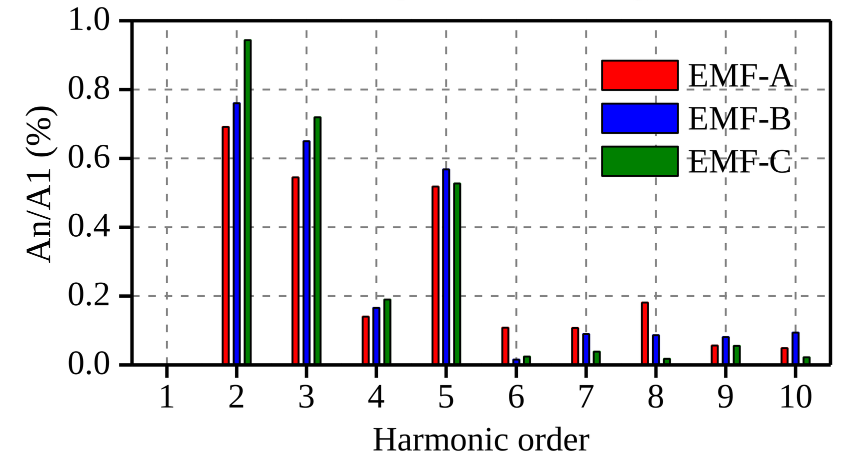
The flux lines of one module pass the stator to the air gap, to the mover, and then back to the ferromagnetic pole or another PM of the module, forming a circle. Thus, the flux lines of three modules are magnetically decoupled due to the designed modular complementary stator structure.

The average self-inductance is 169mH and the average mutual-inductance is 10mH. Then, the ratio of the mutual-inductance to self-inductance is only 6%. Thus, the proposed motor is essentially phases decoupling. Then, the electrical, magnetic, thermal, and physical separations of the various phases are achieved indeed.

Therefore, the proposed motor can provide desired fault-tolerance capability for high reliability operation.

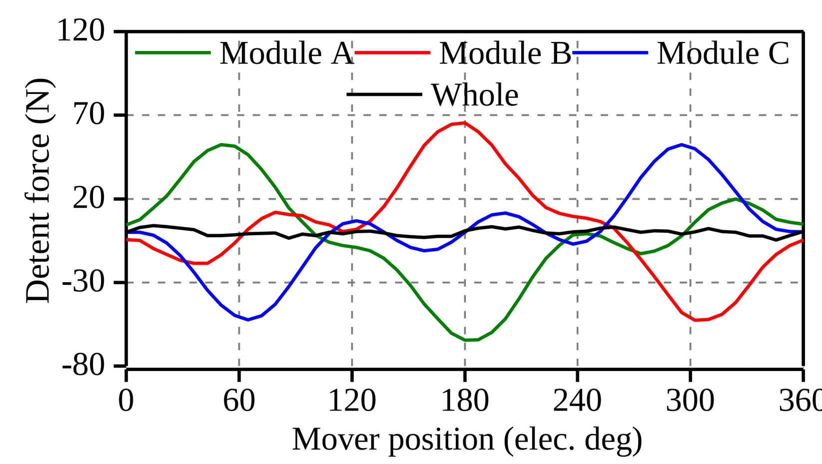
Back-EMF

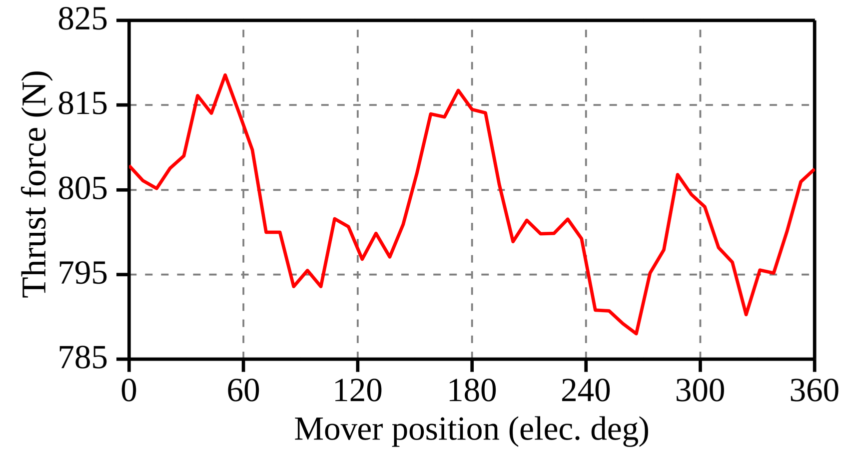




The proposed MST-PMV motor has a nearly ideal symmetrical sinusoidal wave of no-load back electromotive force (back-EMF), thanks to the artful arrangement of three elementary modules.

Force performance





The detent forces of three modules are virtually identical with a 120 ºangle shift along the horizontal axis. There is, however, some small difference in the magnitude of the detent force among three modules. The reason for the phenomena is the fringing effect on Modules A and B. Since, they are located on the two sides while Module C is in the middle. Thus, the detent force of the whole motor is reduced by the offset with the three modules.

The average thrust force of the proposed MST-PMV motor is 802N, while the thrust force ripple factor K_T is only 4%.

Therefore, the proposed motor can offer good force performance.