A Dual-Stator HTS Modular Linear Vernier Motor for Long Stroke Applications

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Motivation

With the absence of the mechanisms converting the rotation to linear motion as well as mechanical gearboxes, linear direct drive motors (LDDMs) have attracted more and more attention in transportation such as rail transit and ropeless elevator. Among the existing LDDMs, linear permanent magnet (PM) vernier motors (LPMVMs) based on the "magnetic gearing effect", are the most powerful competitor, because they have the advantages of large thrust force density. However, due to the presence of PMs, LPMVMs might suffer from high cost, irreversible demagnetization, eddy current loss and installation difficulty. HTS coils carrying exceptionally high current density can produce large magnetic field, which can be comparable to PM excitation. With the rapid development of HTS material, HTS coils with DC instead of PM excitation for electric machines is a good alternative, such as double-sided HTS linear flux-switching PM motors (LFSPMs), doubly fed doubly salient HTS linear motors (DFDS-HTSLMs). However, since the HTS windings and armature windings are in the same slot, the double-sided HTS LFSPM suffers from the conflict of slot space. For the DFDS-HTSLM, how to in-stall the cooling Dewar on the stator may be a big challenge. So, combining the advantages of vernier motors, DC HTS coil excitation and ease in installation, the motivation of this work is to propose a dual-stator HTS modular linear vernier motor (DS-HTS-MLVM) which is very suitable for long stroke application.

Proposed DS-HTS-MLVM

Figs. 1 and 2 show the structure of the proposed DS-HTS-MLVM. The dual stators only consist of laminated iron-cores with stator teeth, thus resulting in a simple and rugged structure. And the dual stators are staggered by half of the stator pole-pitch (τs). The mover adopts a modular structure (Fig. 3), which is composed of some H-shaped supporters. And each two adjacent cores and a non-magnetic beam constitute an H-shaped supporter for the accommodation of the HTS windings and the copper armature windings. The HTS windings and the copper windings are located in different slots, and perpendicular to each other. From another perspective, the HTS windings are sandwiched between the upper and lower copper windings.

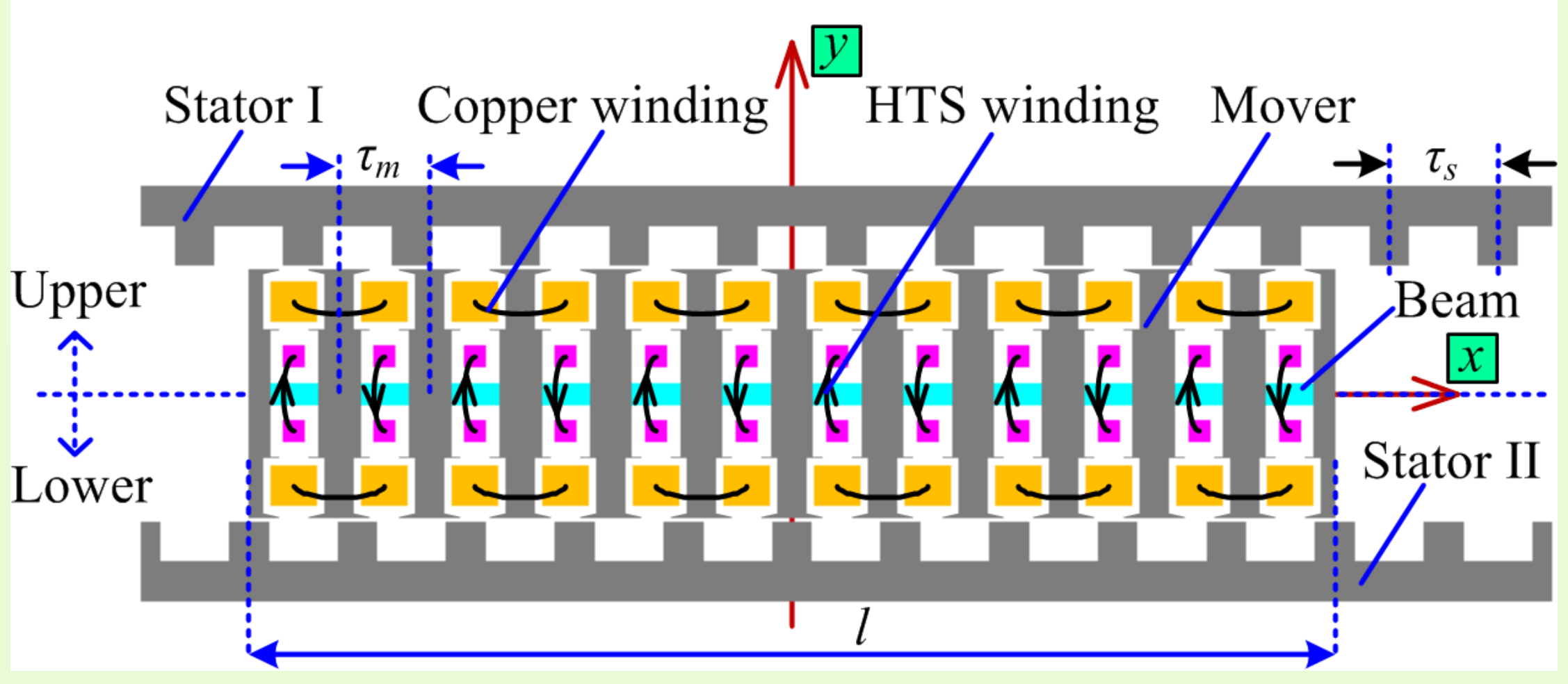

Fig. 1. Structure of the proposed DS-HTS-MLVM (M1)

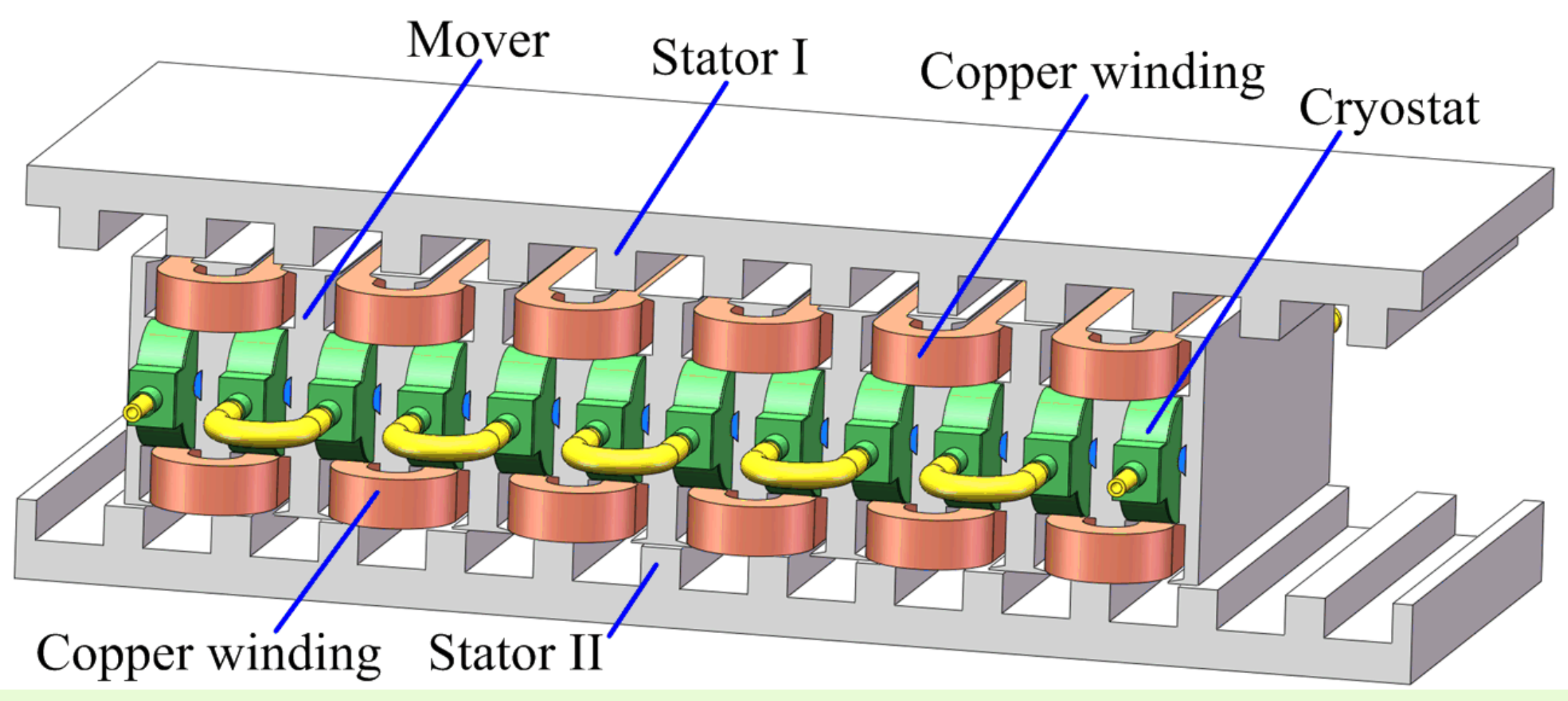

Fig. 2. 3D assembly drawing

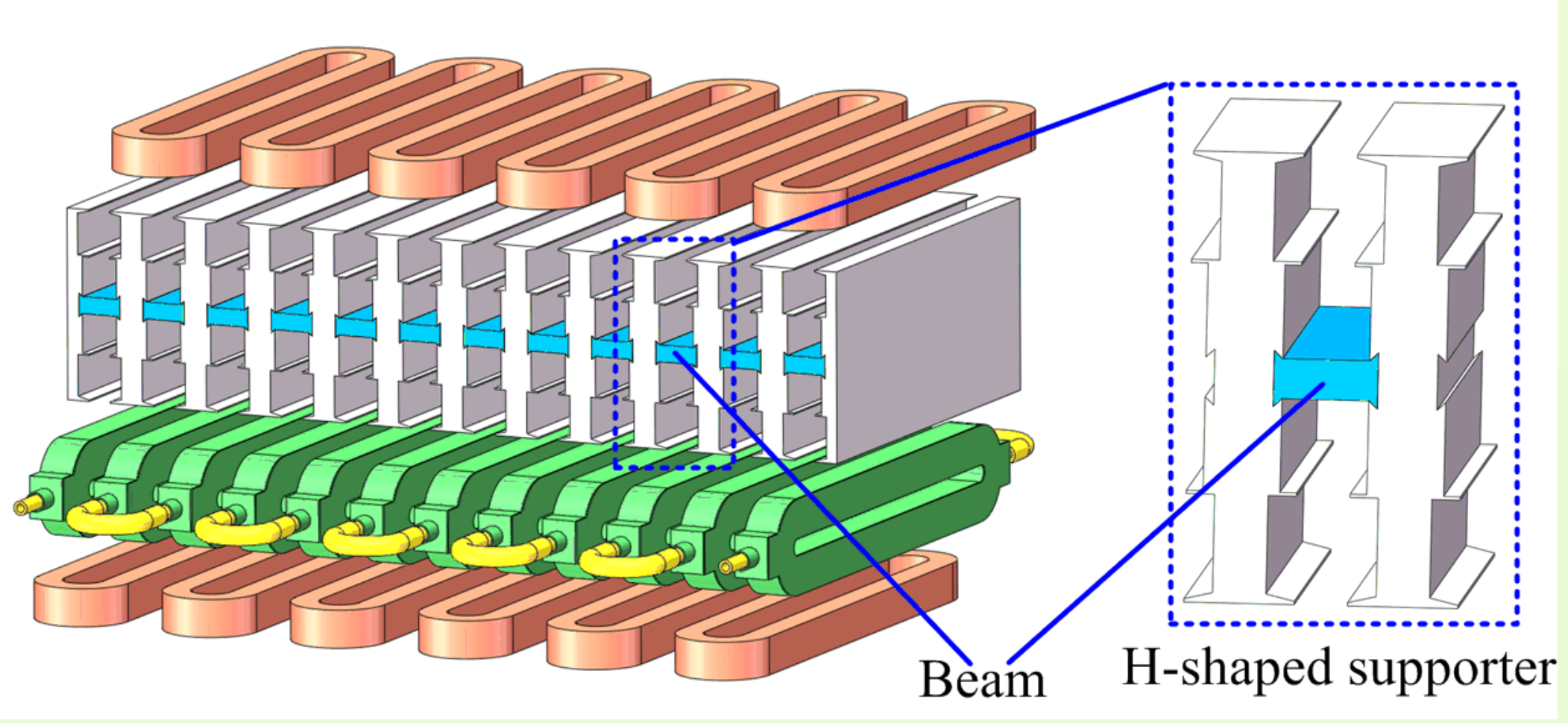

Fig. 3. Exploded view of the modular mover

Performance Analysis and Comparison

The proposed motor belongs to venier motor and also follows the "magnetic gearing effect". So, the choice of slot-pole combination is very flexible. For simplicity, We keep Nm=12 and change Ns to analyze the influence. As can be seen from Fig. 4, with the increase of Ns, back-EMF and thrust force increase at first and then decrease. When Ns=10, the proposed motor outputs maximum thrust force. So the 12/10 (Nm/Ns) motor is selected for analysis in this paper. Fig. 5 shows the results of field analysis when the 12/10 motor works at no load. From Fig. 5(b), the dominant harmonics are in accordance with the results from derived equations. From Fig. 5(c), one can find that harmonics with PPN=6 in upper and lower air-gaps are 180 degrees apart, while harmonics with PPN=4 or 16 in upper and lower air-gaps have the same phase angle (180°), which is also consistent with the results from derived equations.

M2 is a machine that obtained by aligning the dual stators of M1. Figs. 6 to 7 display the comparative results between M1 and M2. It can be seen from Fig.6, two stators staggered 0.5τs can increase air-gap flux density. From Fig. 7(a), M1 can offer larger back-EMF than M2. This also indicates that two stators staggered 0.5τs is helpful to increase back-EMF. From Fig.7(b), M1 can obviously output larger thrust force than M2 under the same electric load. The average force of M1 and M2 is 144.41 N and 42.97 N, respectively. Apparently, the thrust force of M1 is three times higher than M2. Moreover, the force ripple of M1 (27.51%) is much lower than that of M2 (184.11%). It means that two stators staggered 0.5τs can significantly suppress force ripple.

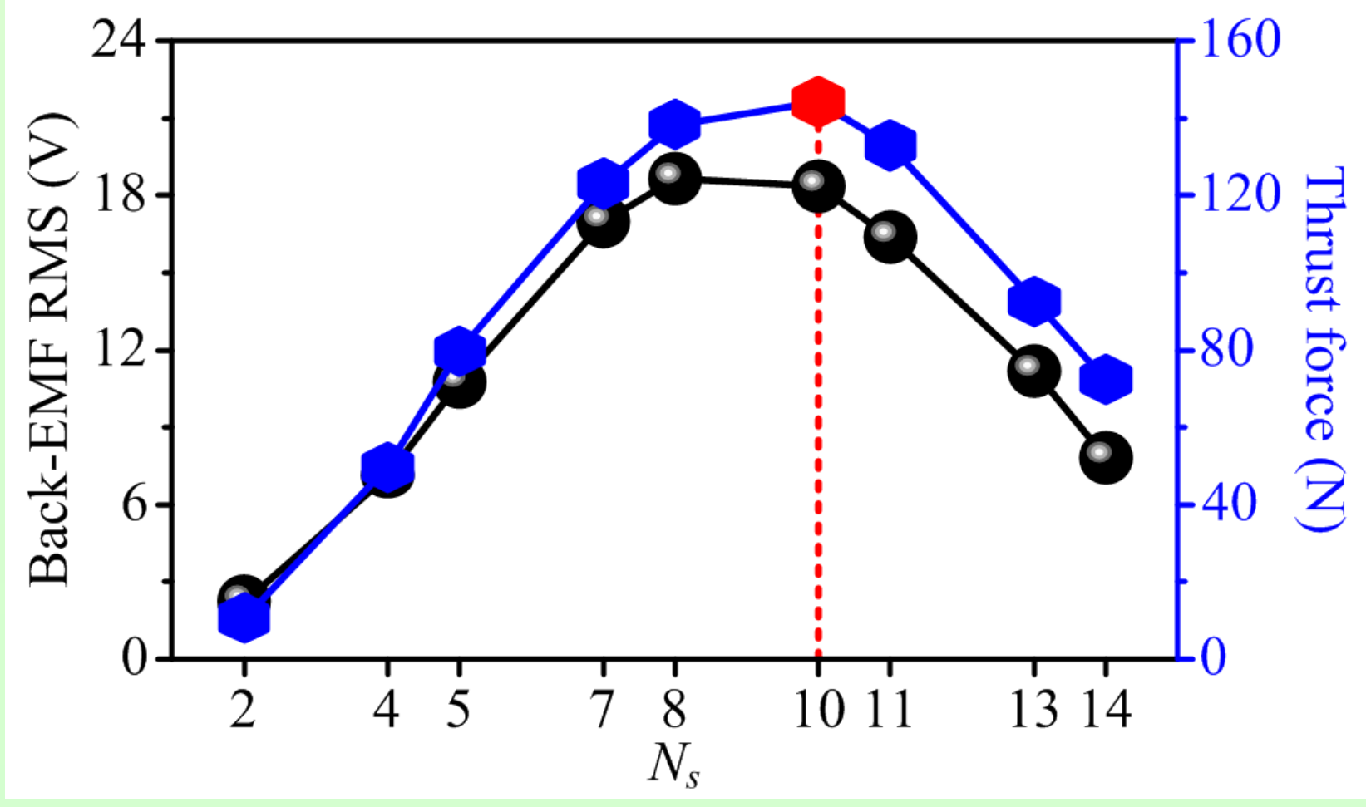

Fig. 4. Influence of slot-pole combinations

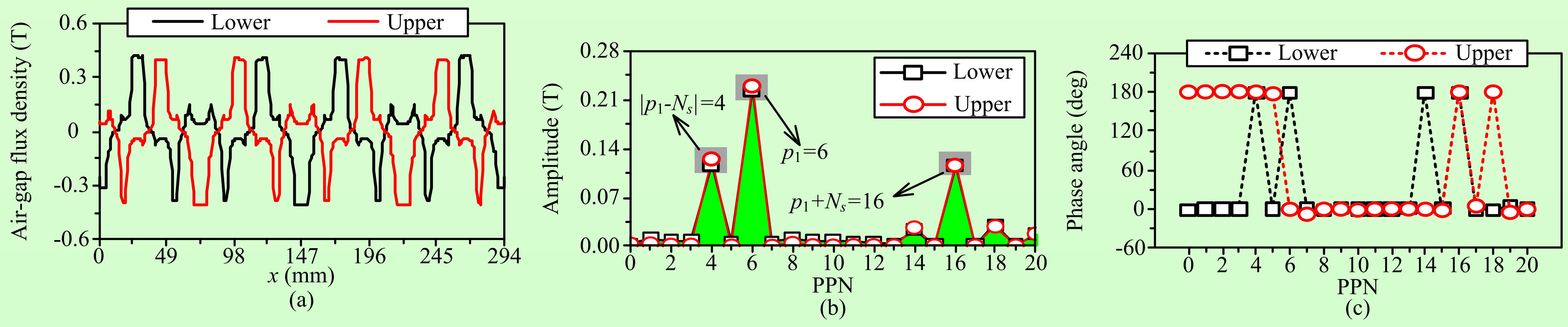

Fig. 5. Field analysis at no load. (a) Waveform of flux density in upper and lower air-gaps. (b) Amplitude of harmonics. (c) Phase angle of harmonics

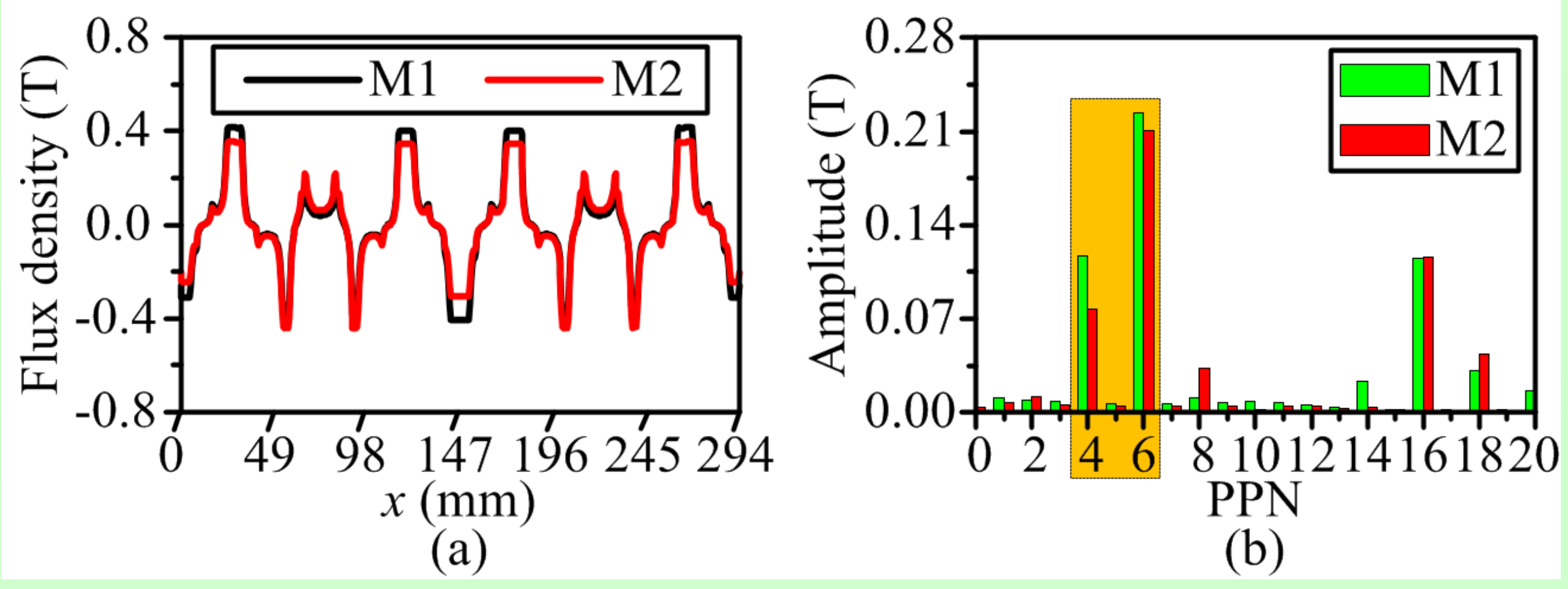

Fig. 6. Field comparison at no load. (a) Waveform of flux density in lower air-gap. (b) Amplitude of harmonics

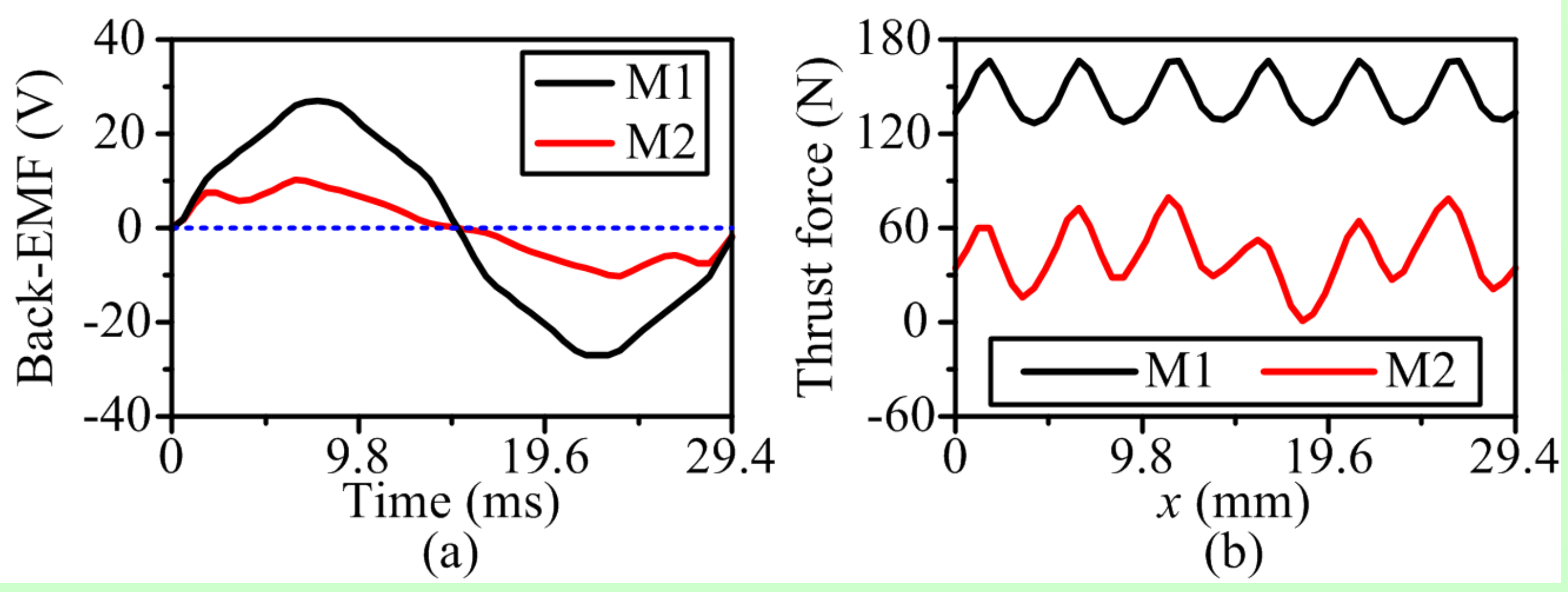

Fig. 7. Performance comparison. (a) Back-EMF (v=1 m/s). (b) Thrust force