MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Comparative Study of Permanent Magnet Assisted Linear Switched Reluctance Motor and Linear Flux Switching Permanent Magnet Motor for Railway Transportation

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Abstract

Linear switched reluctance motor (LSRM) has been investigated and is supposed as a good candidate in railway system. Permanent magnet assisted switched reluctance motor (PMA-SRM) has attracted extensive attention because of the high torque, robust structure and low cost. However, all these researches focus on the application of small air gaps. How does PMA-SRM perform in large air gap? As we know, there are many similarities be-tween linear flux switching permanent magnet (LFSPM) motor and permanent magnet assisted linear switched reluctance motor (PMA-LSRM) such as similar primary iron, winding structure, robust secondary and a small amount of permanent magnets. In this case, what are the differences between these two motors? This paper will compare them based on the volume of rail transit.

Topology and operation principle

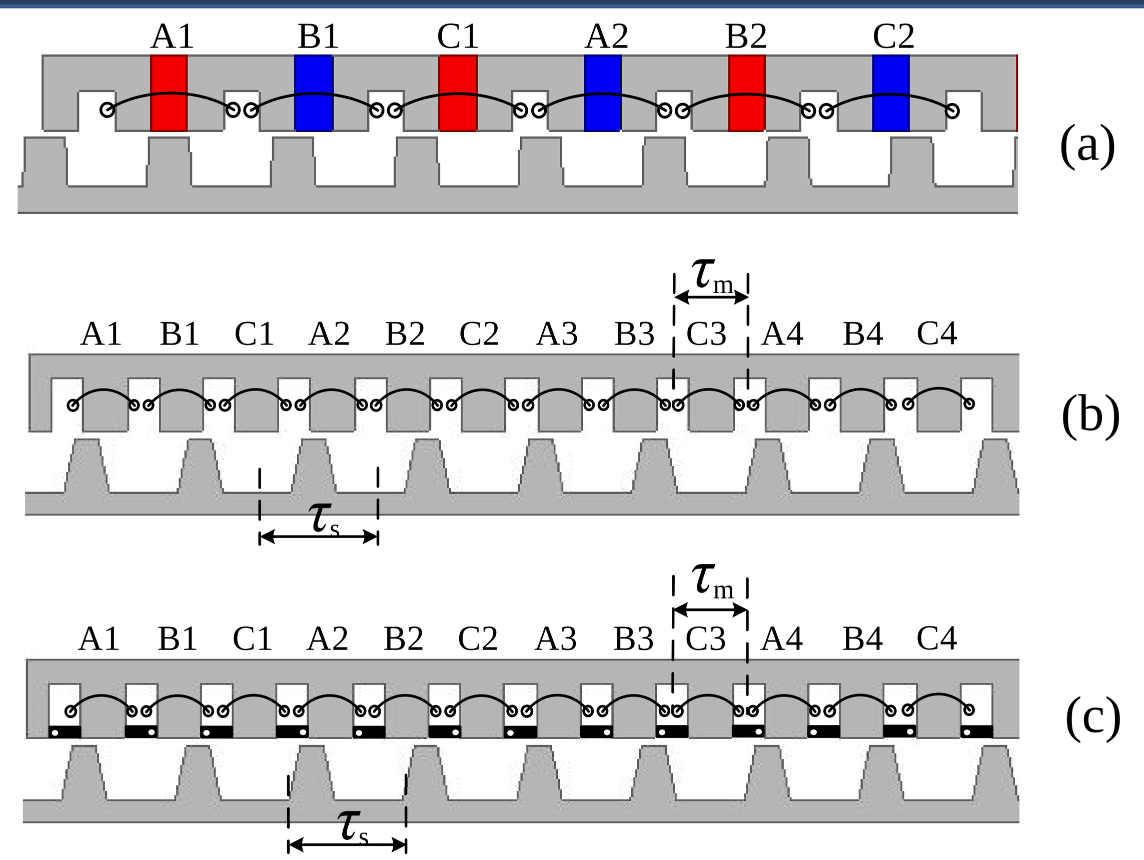

Fig.1 Topologies of (a) LFSPM motor (M I) , (b) LSRM (M II) and (c) PMA-LSRM (M III)

- **Topology**:

Fig.1(a) shows the structure of LFSPM as the object of comparison, named as M I. Fig. 1 (b) and (c) show the topologies of LSRM and PMA-LSRM, named M II and M III respectively. For three motors, the windings are all located at the primary teeth and the secondary is only made of iron core. M III is changed from M II and its permanent magnets are located at the opening of the mover slot, where the circle represents the north pole of the permanent magnets. Adjacent permanent magnets have the opposite magnetization direction.

- **Working principle**:

LSRM works on the principle of minimum reluctance. When a certain phase winding is excited, the magnetic flux always tends to the path with the smallest magnetic resistance when selecting a closed path. Therefore, tangential magnetic pulling force will be generated between the stator and the mover of the motor. As can be seen from Fig.2, the working area of PMA-LSRM is larger than the conventional LSRM. Fig.3 shows the magnetic circuits of the LSRM and PMA-LSRM. The flux produced by excited coils and the flux produced by the PM are added together. It can be expected that this will lead to an increase in the thrust of the motor.

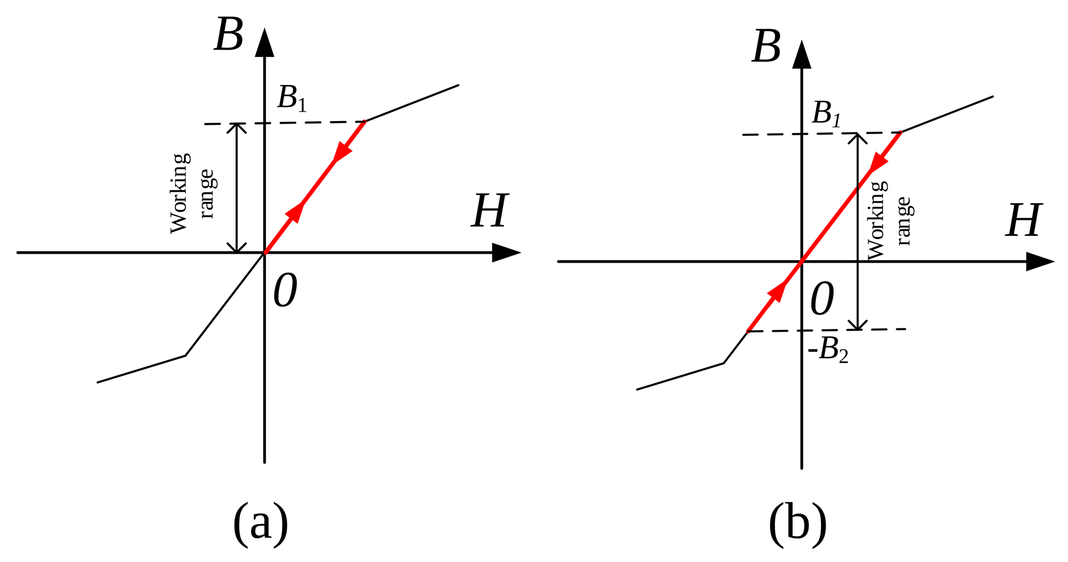

Fig.2 Working range of the LSRMs
(a) LSRM and (b) PMA-LSRM

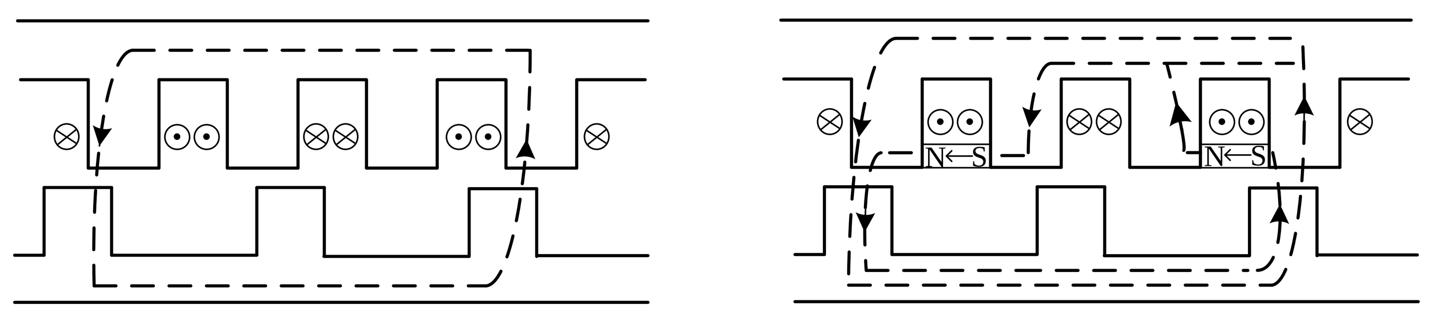

Fig. 3. Magnetic circuits of (a) LSRM and (b) PMA-LSRM

Optimization of the LSRM

Table I. Optimal Parameters

Name and Unit	LFSPM	LSRM
Primary height [cm]	10	10
Primary pole pitch [cm]	19.42	9.92
Primary tooth width[cm]	4.85	3.97
Primary yoke height [cm]	4.85	3
Primary length [cm]	248	248
Secondary height [cm]	10	10
Air gap length [cm]	1	1
Secondary yoke height [cm]	3.5	4
Current density [A/mm2]	4.68	4.68
Turns of coils per slot	14	28
Stack length [cm]	28	28
Speed [m/s]	15.68	15.68

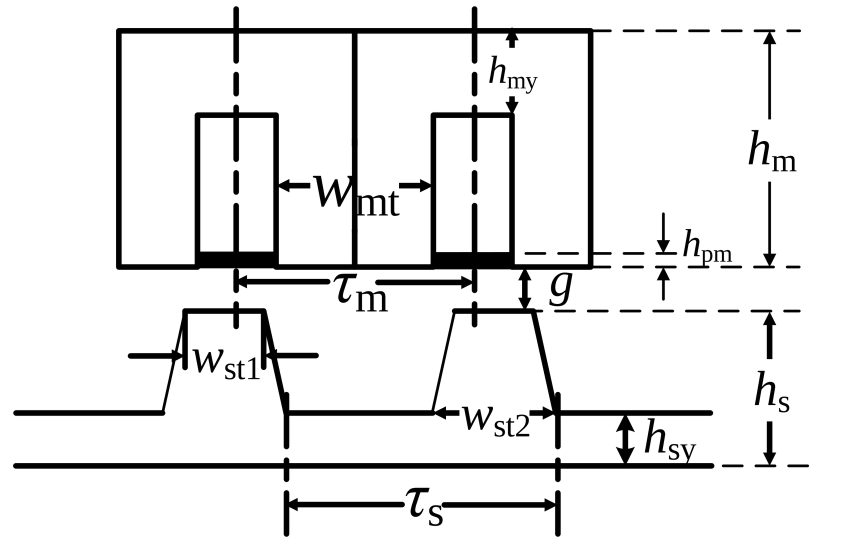

Fig.4 Parameters of PMA-LSRM.

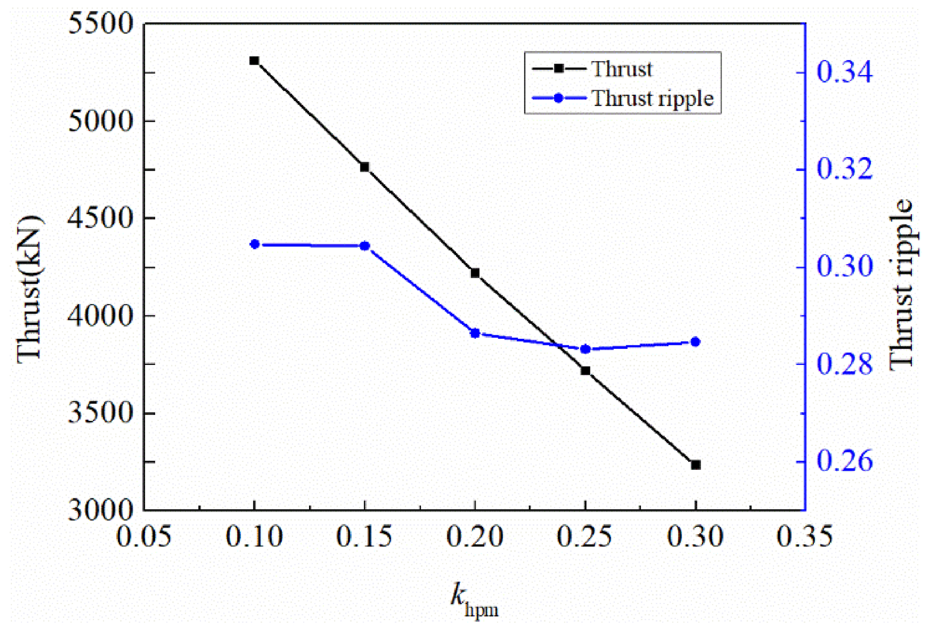

Fig.5 Thrust waveforms of PMA-LSRM.

- **Motor parameters:**

The parameters of LSRMs are designed and optimized according to the practical application of rail transit system.

- **Optimization:**

The optimization objectives are to maximize the thrust and to minimize the ripple at the given dimensions and the rated condition. To improve the thrust force, thrust force ripple and efficiency, the secondary height (h_s) and secondary yoke height (h_{sy}), the tooth width of the secondary (k_{wst}), the primary yoke height (k_{hmy}) and the width of the primary tooth (k_{tooth}) are optimized by 2D finite element analysis method. The parameters are shown in Fig.4 and the optimal values are listed in Table I.

Fig. 5 illustrates the thrust and ripple of the motor show a downward trend with the increase of permanent magnet usage. Therefore, LSRM without permanent magnets are selected for comparison with LFSPM motor.

Electromagnetic characteristics

Table II. Electromagnetic Characteristics of LFSPM motor and LSRM

Name and Unit	LFSPM motor	LSRM
Thrust force [kN]	13.2	6.19
Thrust force ripple [%]	9.6	41.2
Normal force [kN]	94.4	43.2
Copper loss [kW]	2.92	8.03
Efficiency [%]	98.4	92.4

Field distribution

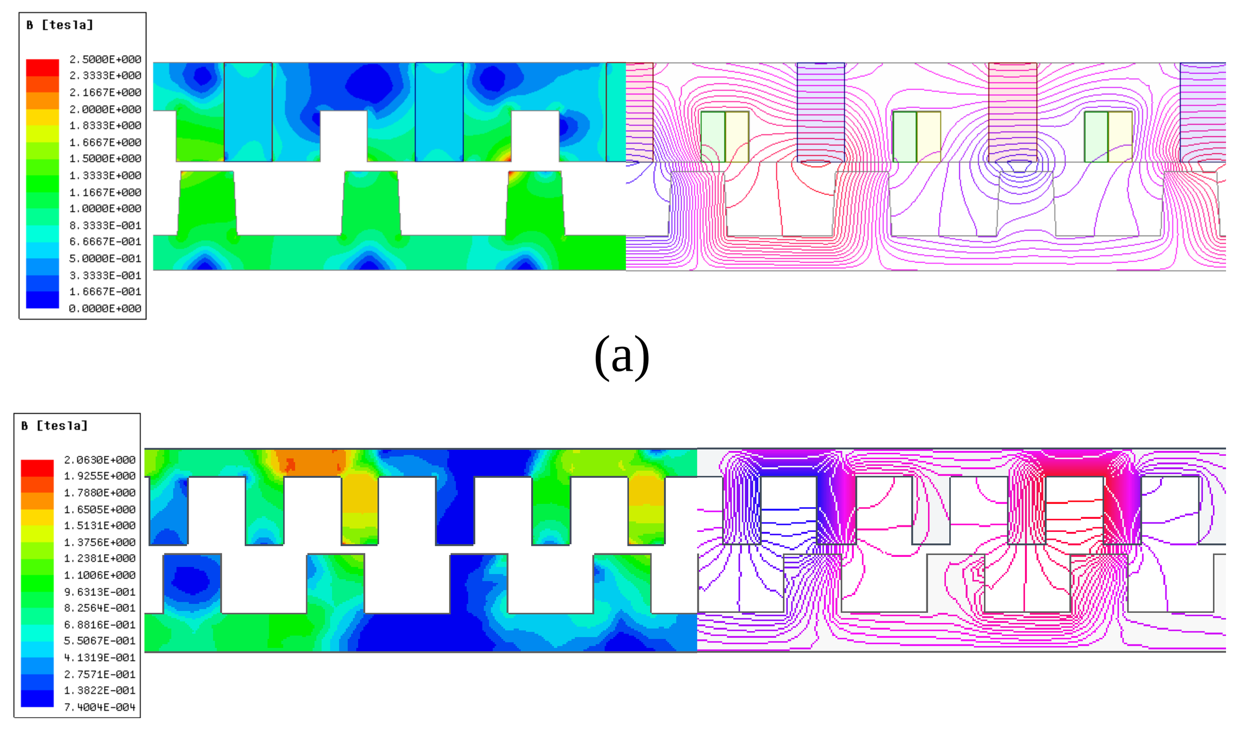

Fig.6 Flux distribution of (a) LFSPM (b) LSRM

Conclusions

- The thrust, ripple and efficiency of LFSPM motor are superior to LSRM motor but normal force. Although the two motors have similar topological structures, their performances under the large air gap differ greatly due to the differences in their working principles and loading methods.
- When LSRM works in the state of large air gap and large current, permanent magnets cannot improve the thrust of the motor.
- The application prospect of this type of motor for railway transportation field is not optimistic.