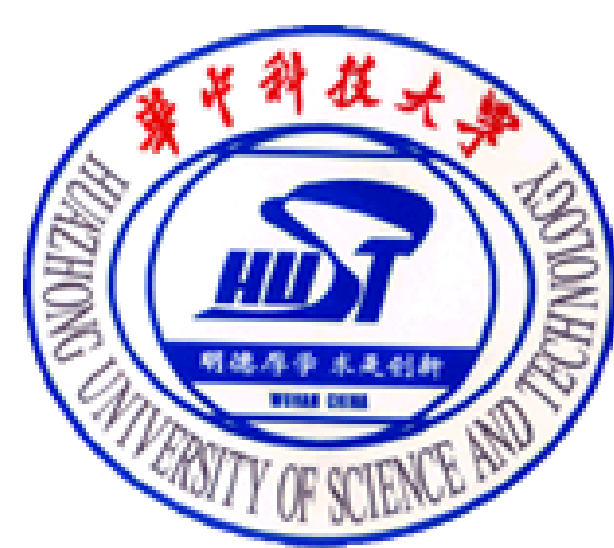


Stator-Magnet Moving-Iron Transversal-Flux Linear Oscillatory Machine with Spoke-Type Magnets in Inner Stator

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Background

Whilst offering the merits of high reliability and robustness, high material utilization ratio, low fabrication cost, conventional stator-magnet moving-iron transversal-flux linear oscillatory machine (CSMTLOM) still suffers from high permanent magnet (PM) temperature rise and demand of rugged resonant spring. In order to reduce the mover weight and prevent magnets away from winding (regarded as the main heat source), one improved inner stator-magnet moving-iron transversal-flux linear oscillatory machine (ISMTLOM) is proposed, with magnets inserted in the inner stator core.

Objectives

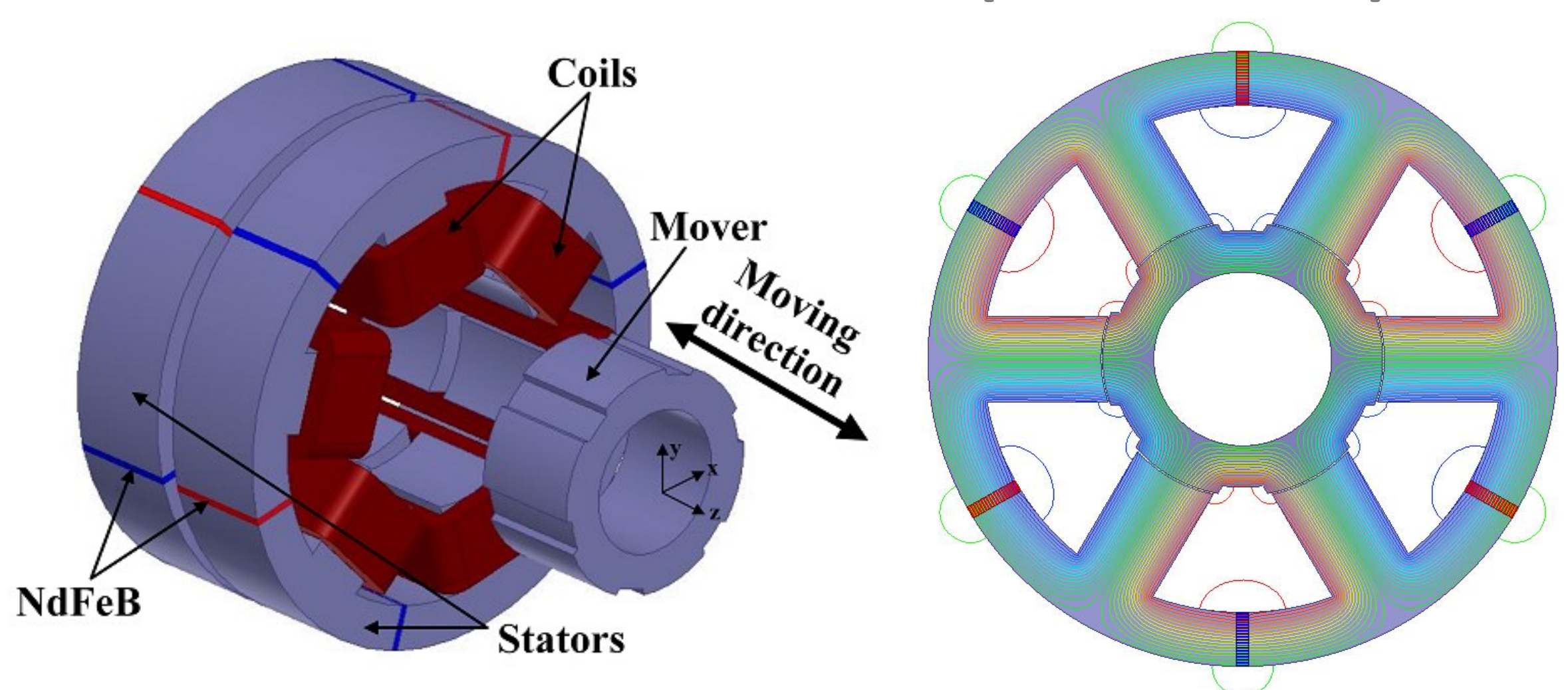
- ❖ Novel inner stator-magnet moving-iron transversal-flux linear oscillatory machine, with magnets inserted in inner stator yoke.
- ❖ Dimension optimization of proposed structure and the comparison with the traditional one from several key indexes, including back EMF, thrust and temperature distribution, etc.

Conclusion

- ❖ One novel ISMTLOM is proposed and fully analyzed by 3D FEM.
- ❖ Under the constraints of same outer diameter and copper loss, the output thrust of ISMTLOM also could reach the same level as that of CSMTLOM.
- ❖ Several key dimension coefficients, especially the split ratio (k_s) and slot open ratio (k_{so}) is investigated to gain the optimal choice of (k_s, k_{so}) for ISMTLOM is (0.35, 0.6).
- ❖ Comparing with the conventional structure, by redesigning mover, its mover weight could be reduced remarkably by about 79 %, and thus the demand of spring stiffness is also reduced by 77%.
- ❖ By placing the winding and magnets on different stators, the temperature of permanent magnets could be reduced by about 6 °C at the rated load condition, thus the temperature margin for magnets is larger.

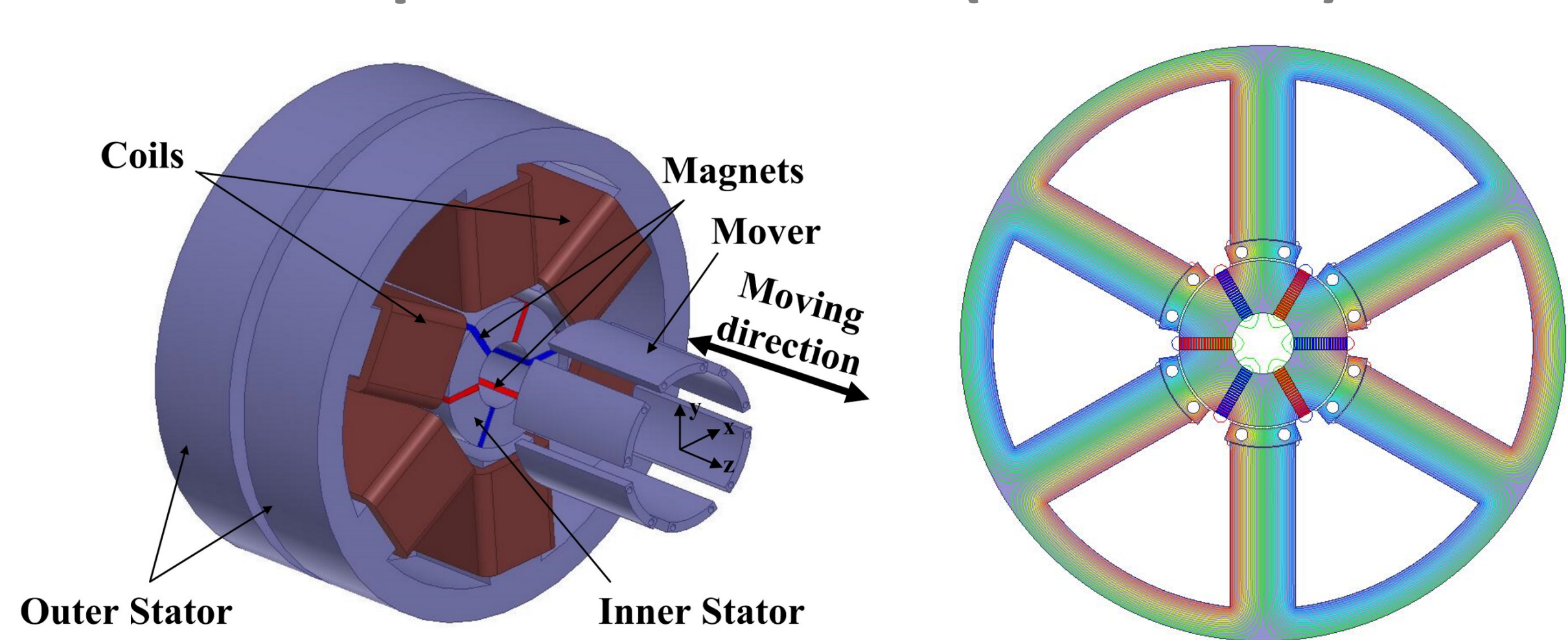
Topologies

Conventional Structure (CSMTLOM)



The stators of CSMTLOM resemble that of switched reluctance machine, with magnets inserted in its yoke, while the mover composes of iron only. The coils are wound on each pair of axial-aligned teeth, and every adjacent coils are connected in reverse series. The flux path is radial, which is perpendicular to the moving direction, i.e. z axis.

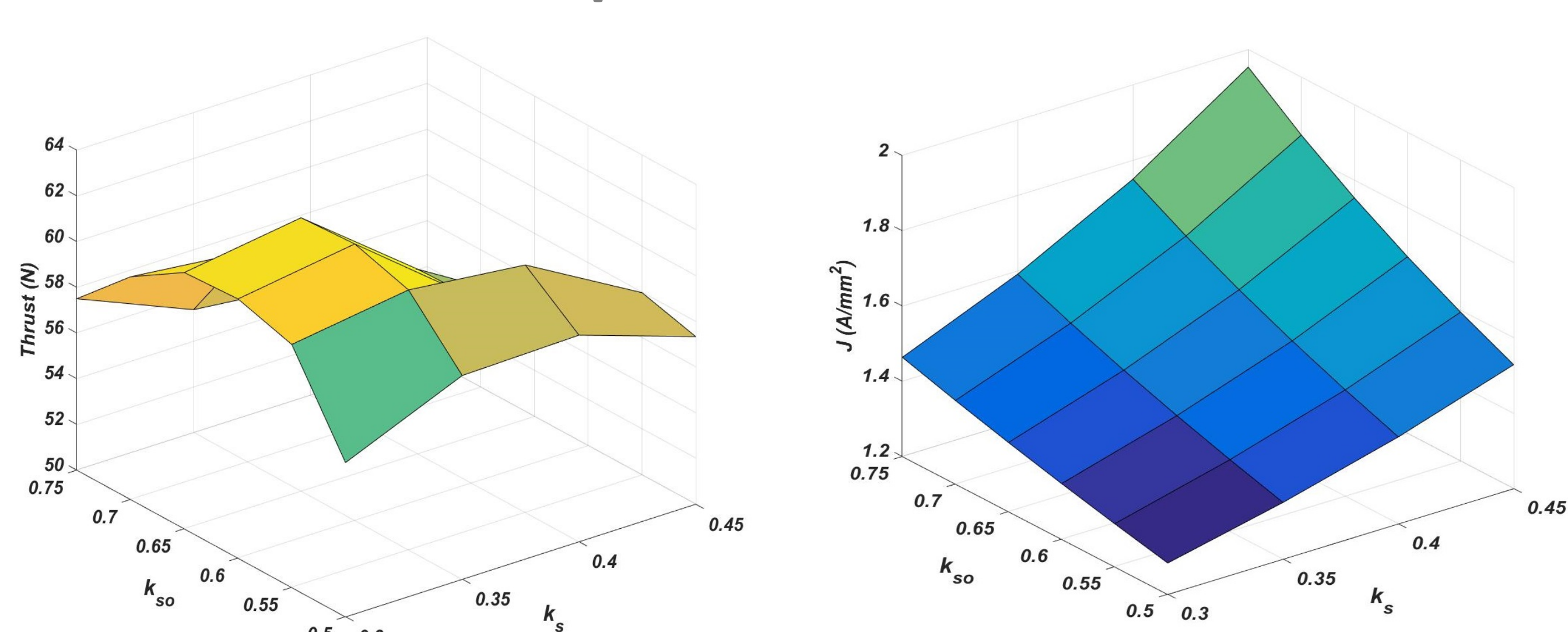
Proposed Structure (ISMTLOM)



Different from CSMTLOM, ISMTLOM's stators contain two parts, i.e. inner and outer ones. The outer stators resemble that of switched reluctance machine, with armature winding on it, while the inner ones are designed as ring type, with spoke-type magnets inserted in it.

Size Parameter

Dimension optimization of ISMTLOM



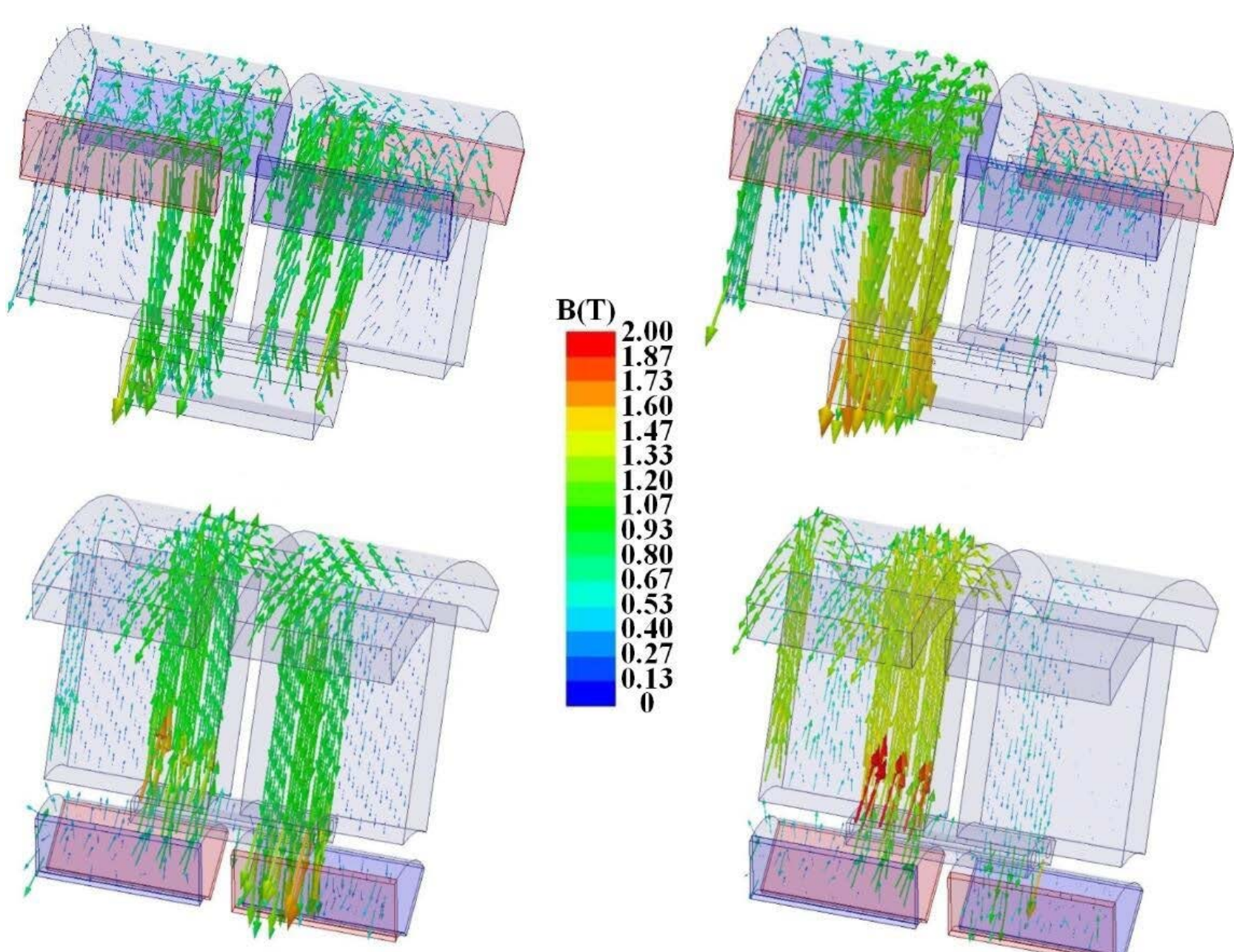
As shown in Figs, the variation of k_s and k_{so} would result in the variation of the current density (J), under the condition of same copper loss and outer diameter. The thrust reaches its peak value at a specific pair of (k_s, k_{so}). It can be concluded from Figs that an optimal choice of (k_s, k_{so}) for ISMTLOM is (0.35, 0.6).

Main Specifications

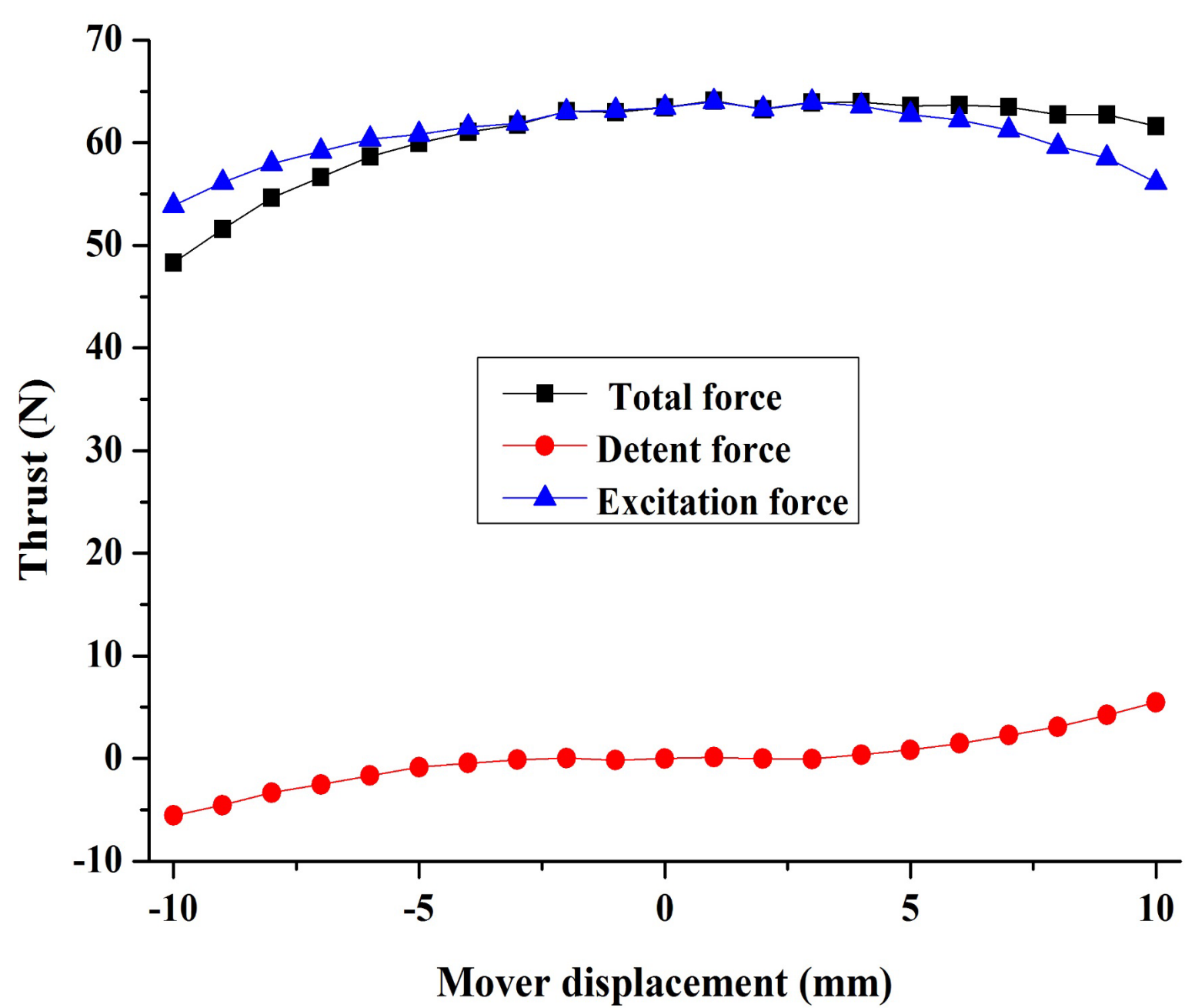
Name	Symbol	CSMTLOM	ISMTLOM	Unit
Output power	P_r	123.2	123.9	W
RMS current density	J	1.72	1.43	A/mm ²
RMS current	I	0.97	1.30	A
Copper loss	P_{cl}	13	13	W
Efficiency	η	90.4	90.5	%
Operation Frequency	f	50	50	Hz
Stator outer diameter	D_{so}	148	148	mm
Stator stack length	L_s	32	30	mm
Mover stack length	L_m	32	33	mm
Stator spacing length	L_b	6	6	mm
Whole axial length	$2L_s + L_b$	70	66	mm
Total air-gap length	g	0.4	0.8	mm
Stroke length	S_l	20	20	mm
Coil turns	N_c	350	350	turns
Split ratio	k_s	0.45	0.35	-
Slot open ratio	k_{so}	0.6	0.6	-
Mover/stator pole ratio	k_{ms}	1.1	1.2	-
Outer/inner air-gap ratio	k_g	-	1/3	-
NdFeB thickness	T_m	3	3	mm

Results

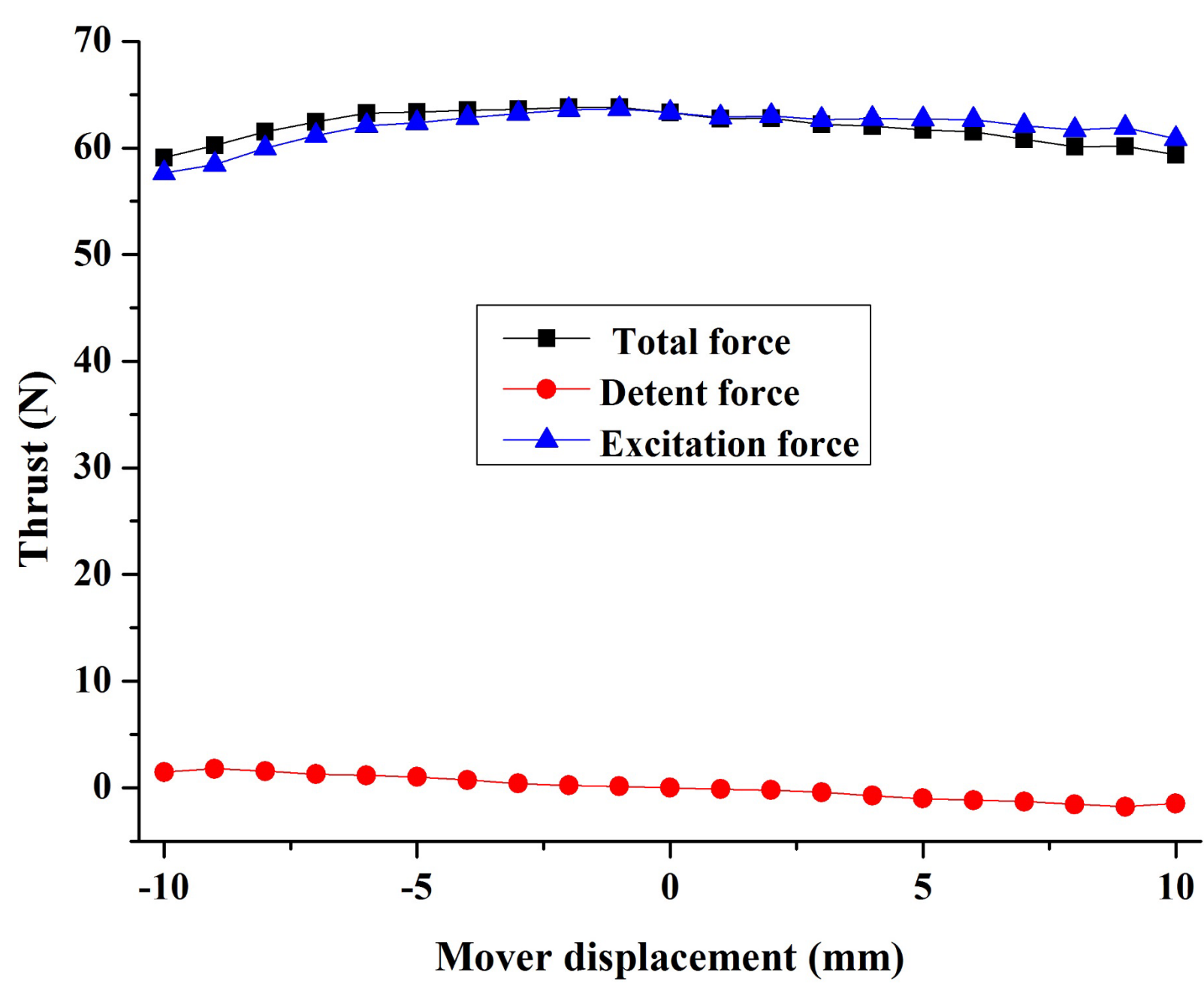
Flux distribution and Thrust characteristic



Figs show the flux distribution at the balance position. While the mover rests at the balance point, for both CSMTLOM and ISMTLOM, the flux distribution in each side of the stator is symmetrical under the no-load condition, while asymmetrical under the rated one. Thereof, the mover would be driven towards the flux-strengthened side.



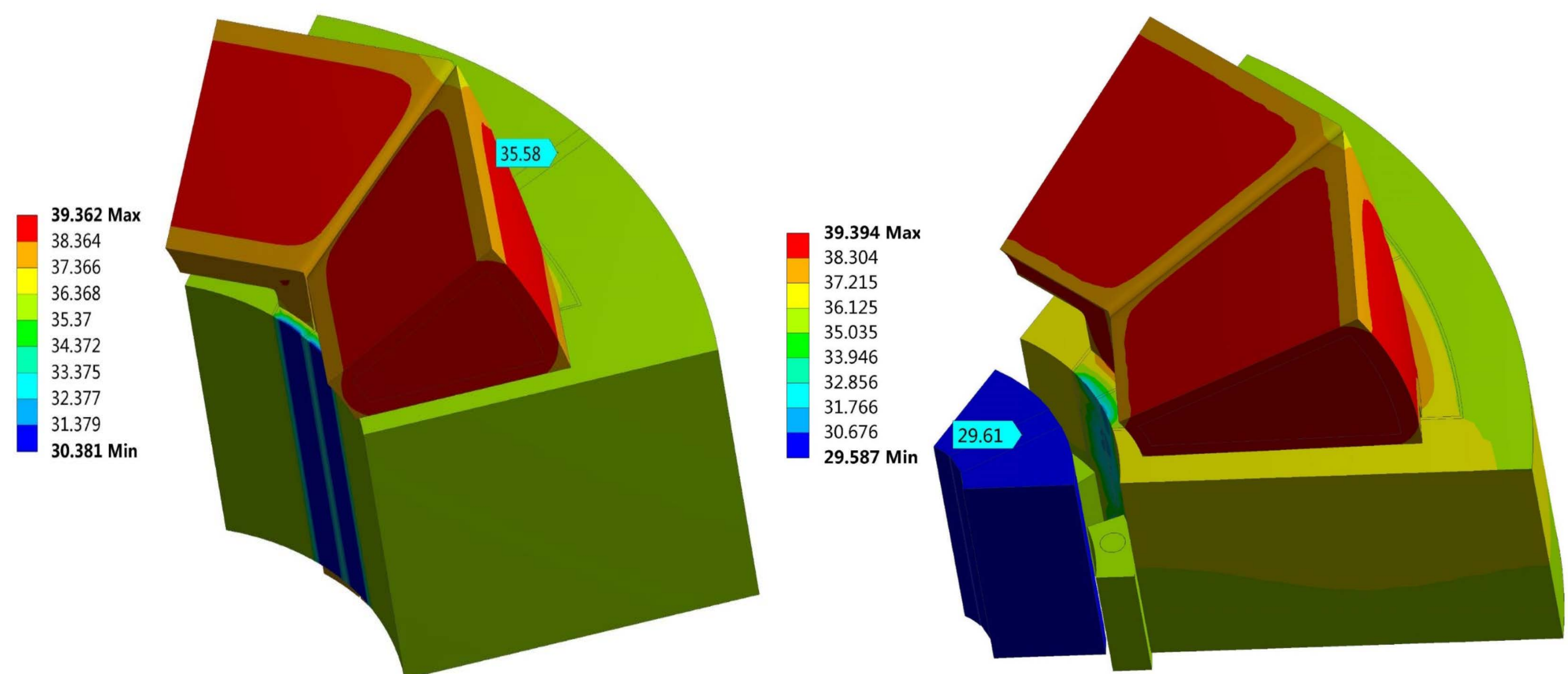
CSMTLOM



ISMTLOM

As shown in Figs, the average output thrust of ISMTLOM and CSMTLOM is nearly the same, with values of 61.9 and 61.6 N, respectively. But the peak to peak value of detent force of ISMTLOM is only 3 N, which is about 70 % lower than that of CSMTLOM.

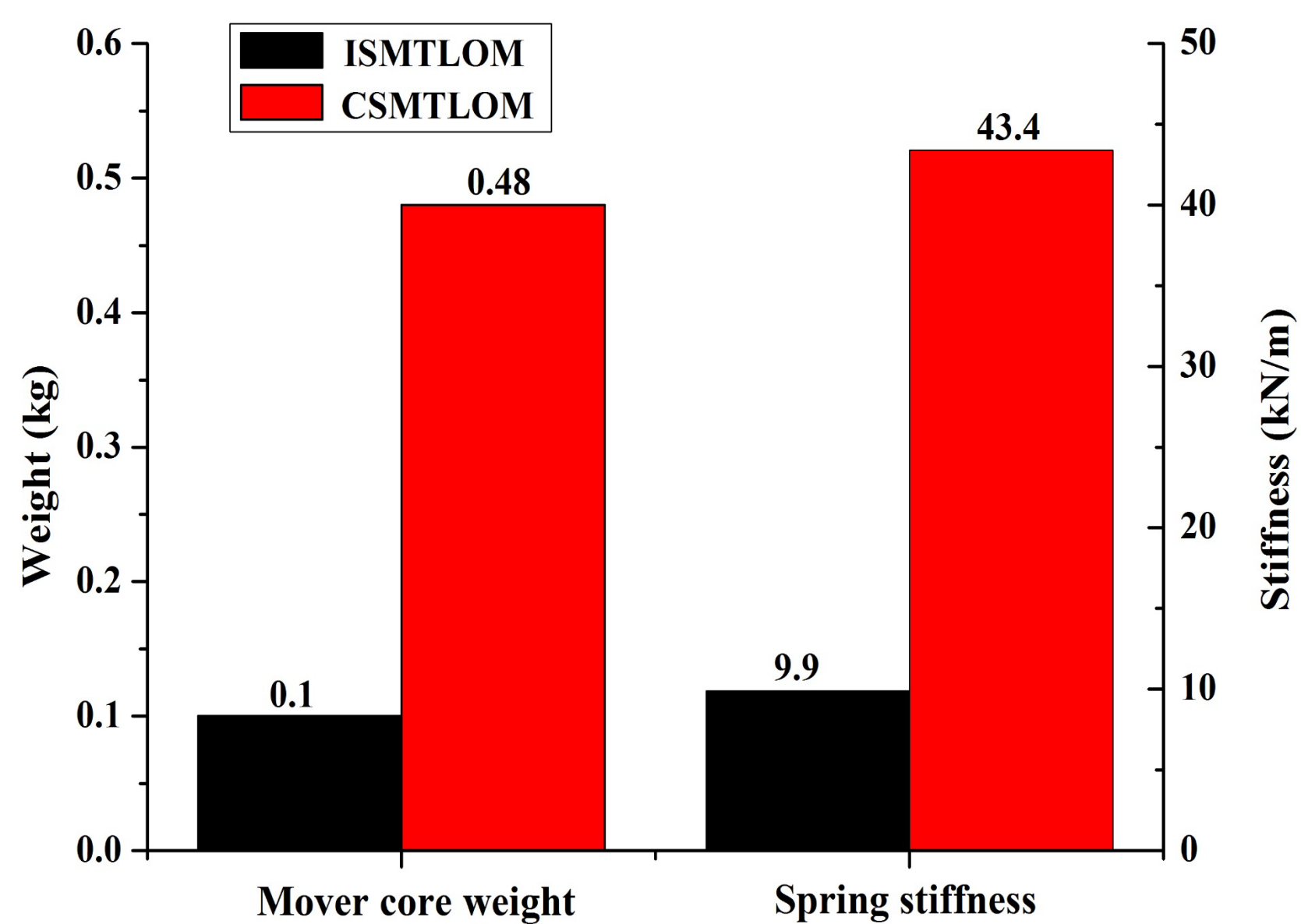
Thermal Distribution and Spring Stiffness



CSMTLOM

ISMTLOM

It could be concluded from Figs that with magnets inserted into inner stator yoke, the PM temperature of ISMTLOM is about 6 °C lower than that of CSMTLOM, owing to the relative far distance between PMs and stator winding (regarded as main heat source). It means more temperature margin for ISMTLOM and thus high reliability for its PMs.



While reaching the same oscillatory frequency of 50 Hz, as shown in Fig, it is obvious that the mover weight could be reduced a lot in the proposed topology, and hence, the demand for spring stiffness also could be reduced markedly, which further indicates lower cost, or in other word, higher operation frequency.