Analysis and Performance Evaluation of a Novel High Reliability Linear Switch Reluctance Machine for Low Cost Conveyor Applications

Daohan Wang[1], Xiuhe Wang[1] and Sang-Yong Jung[2], *Member*, *IEEE*
[1]School of Electrical Engineering, Shandong University, Jinan 250061, China
[2]School of Electronic and Electrical Engineering, Sungkyunkwan University, Suwon 440-746, Korea
wangdh@mail.sdu.edu.cn

***Abstract*—This paper presents a novel linear switch reluctance machine (LSRM) with segmental stator. The presented machine incorporates a simple concentric winding and concrete segmentations, which feature high reliability and low cost. The performances of the machine in terms of inductance characteristics, statistic torque profile and normal force are evaluated and compared to the well-known teethed type linear switch reluctance machines. The results demonstrate that the presented machine has gained superiority in terms of higher propulsion force density and low cost.**

I. Introduction

In recent years, there has been an increasing demand for employing direct drive linear applications instead of the gear transfer devices. In fact, permanent magnet linear machine (PMLM) has been a very attractive candidate for these applications. However, PMLMs are facing some obstacles in linear applications with a mechanical guide of quite long distance, such as skyscrapers elevator and urban rail transit system due to the dramatic growth of magnetic material cost [1]-[2].

Linear switch reluctance machine (LSRM) has been an attractive alternative solution for these linear transmission applications. Existing literatures have presented various kinds of linear switch reluctance machines, which include many different structure topologies and their combinations such as single stator-single translator [2]-[3], twin stators-back-to-back translator [3] and non-yoke translator [3]. All the existing LSRMs in the literatures have the same teethed-type stator, so they feature similar magnetic circuit and operation principle for torque production. LSRM exhibits a relatively low force density and efficiency. Even though optimization process can be performed in machine design to improve the operating performance, it is almost impossible to significantly increase the propulsion force density to be satisfactory degree in LSRM if remaining the traditional teeth-typed magnetic circuit in LSRM unchanged.

The purpose of this paper is to investigate a novel linear switch reluctance machine, named segmental stator linear switch reluctance machine (SSLSRM). In this machine, a segmental stator consisting of series of isolated segmentation take the place of the traditional teeth type stator. The segmentations in stator are embedded in the stator base which is made of non-magnetic material. The principle and characteristics of the machine are presented and compared to the traditional teeth-type LSRM.

II. Topology of the Presented Machine

The SSLSRM presented in this paper is shown in Fig. 1 and the traditional teeth-type LSRM is shown in Fig. 2, both of machines have three phases winding, with 6-pole-translator and 4-pole-stator. Concentric pattern windings are used in both machines to reduce the length of end-windings as well as the copper mass and loss.

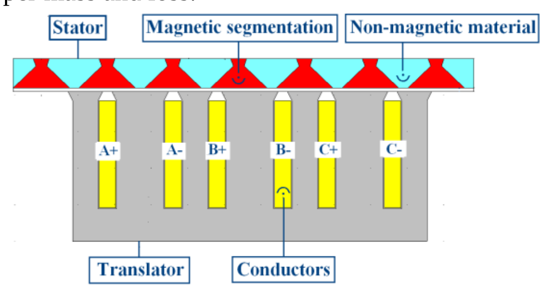


Fig.1 Sketch of SSLSRM presented

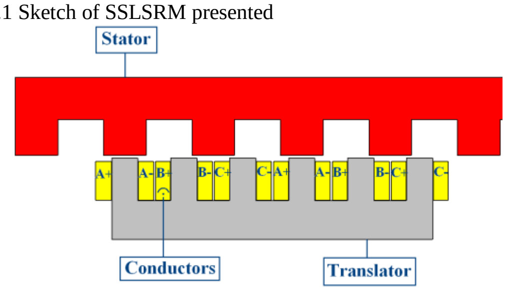


Fig.2 Sketch of teeth type LSRM

As shown in Fig.1, the presented machine incorporates one single stator and translator. But the translator features different width of tooth tip and body which is used to facilitate the concentric pattern winding. In this configuration, the larger tooth is centering on two adjoining smaller teeth. The larger tooth is wrapped around by the windings whist the smaller teeth remain unwrapped. So each slot only is filled in by conductors of the same phase, thus no phase-isolation measures in the slots are needed.

To demonstrate the unique characteristic and principle of the presented SSLSRM, the traditional teeth type LSRM, as shown in Fig.2, are designed and fairly compared to SSLSRM. For fair comparison, the teeth type LSRM is designed to have the same dimensions as the SSLSRM. The dimensions of the machines are detailed in Table. Ⅰ and Fig.3.

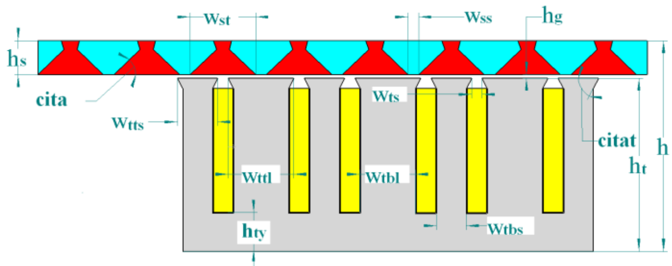


Fig.3 Dimensions of the presented SSLSRM

Note that the SSLSRM and teeth type LSRM are designed following the common design criteria for SRM, demanding that the flux flows through the magnetic circuit evenly but not give rise to critical saturation. It can be seen from Table. Ⅰ that the presented SSLSRM requires much less iron core material per unit in stator, which gains a superiority to be used in long transit rail over the traditional teeth type LSRM.

TABLE Ⅰ MACHINE DIMENSIONS

Machines	SSLSRM	Teeth type LSRM
No. of stator poles	4	
No. of translator poles	6	
Air-gap length, h_g	0.8	
Total height, h	50 mm	
Stack length, l_s	50 mm	
Translator height, h_t	41 mm	25.2 mm
Stator height, h_s	8.2 mm	24 mm
Stator pole width, w_{st}	15.5 mm	13 mm
Translator slot width, w_{ts}	2.5 mm	10 mm
Stator slot width, w_{ss}	2.5 mm	14 mm
Translator pole width, w_{tts} and w_{ttl}	9.5/15.5 mm	8 mm
Translator length, l_t	103.5 mm	102 mm
Height of stator yoke	*No* exist	13 mm
Height of translator yoke, h_{ty}	9.2 mm	12 mm
Mass of stator core (one unit)	0.056 kg	0.191 kg
Length of winding coil per phase	Approximately 17497 mm	Approximately 16084 mm
Mass of translator core	0.875 kg	0.727 kg
Turns of winding per phase	104	104
Mass of winding coil	0.385 kg	0.354 kg
Rated current	DC 12A	DC 12A
Coil resistance per phase	0.367 Ω	0.338 Ω

III. STATIC PERFORMANCE EVALUATION AND COMPARISON

Fig.4 shows the flux-MMF curves at aligned and unaligned position, while Fig.5 gives the results of mean force.

It can be seen that in SSLSRM, the windings per turn link more flux than the teeth type LSRM. The linked flux in SSLSRM at unaligned position is also more than the teeth type LSRM, but totally the generated mean force in SSLSRM is higher than teeth-type LSRM.

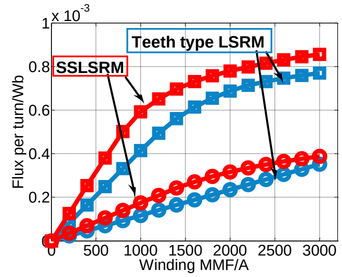


Fig.4 Profile of MMF to Flux

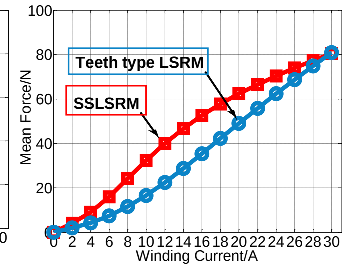
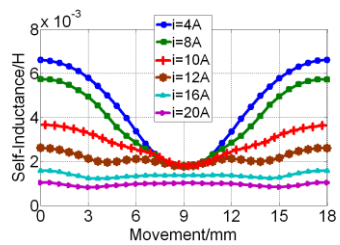


Fig. 5 Profile of mean force

This is mainly because the average force in SRM is proportional to the area enclosed between the aligned and unaligned magnetized curves, which can be shown in (1)

$$F_{avg} \propto \int_0^{\phi} [MMF_{aligned}] d\phi - \int_0^{\phi} [MMF_{unaligned}] d\phi \quad (1)$$

Where F_{avg} is the average thrust force, ϕ the flux linkage, $MMF_{aligned}$ and $MMF_{unaligned}$ the winding magnetic motive force corresponding to ϕ at the aligned and unaligned position, thus $\int_0^{\phi} [MMF_{aligned}] d\phi$ and $\int_0^{\phi} [MMF_{unaligned}] d\phi$ denote the co-energy of machine at aligned and unaligned position, the variation of which generates propulsion force.



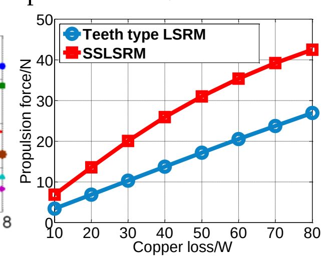


Fig. 6 Inductance profile of SSLSRM with different current

Fig.7 Propulsion force at different copper loss

Besides, Fig. 6 gives the inductance profile in SSLSRM with different winding current excitation. Fig.7 gives the comparison of propulsion force with different copper loss, which demonstrates the virtual force density of the two machines foregoing. It is found that the presented machine exhibit higher force density than teeth-type LSRM.

IV. CONCLUSION

In this paper, a novel linear switch reluctance machine with segmental stator is presented. The principle of the machine is demonstrated and fairly compared to the well-known teeth type LSRM which demonstrated that the presented machine exhibits substantial higher propulsion force density than teeth type LSRM.

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