High starting Torque LSPM Motor for wide range of Industrial applications

Paper # 56

Abstract

In contrast with typical design of Linear Start Permanent Magnet (LSPM) new patented dual rotor construction LSPM motor is able to develop high starting torque and able to handle high inertial loads practically equivalent to D-design AC Induction Industrial motors. New LSPM design is also able to significantly reduce Total Harmonic Distortion (THD) of the motor current draw. Presentation will discuss FEA and test results of a prototype motor delivering IE7 efficiency, high starting torque and ability to drive high inertia loads.

I. Traditional LSPM and its performance shortcomings

Line-Start Permanent-Magnet motors (LSPM) have been proposed several decades ago [1, 2] but only recently have drawn more attention as a candidate technology to be capable deliver IE4 and higher requirements [2, 3]. In fact some authors conclude that LSPM is the only valuable candidate to deliver IE4 efficiency requirements for a line driven industrial motors [3].

LSPM technology is now commercially available, but still is not able to become a truly common Industrial application motor. LSPM short fallings are well known and accepted.

Here are the main performance issues slowing use of LSPM:

1. Inability to synchronize load with high inertia. According to some the maximum load inertia for LSPM is between 25 to 30 times the motor rotor own inertia.
2. The initial “kick” torque is quite violent, and often can cause damage in the coupled load or coupling itself.
3. Line current draw harmonic are often far greater than comparable Squirrel Cage Induction Motors (SCIM)
4. Risk of permanent magnet demagnetization during start in cases with high load inertia
5. High power factor of LSPM at full load drops quickly at partial loads that causes higher current draw and I^2R losses, and eventually diminishes savings is case LSPM running lower than full load [4].

The reason behind offering new Dual Rotor LSPM is to significantly improve listed above weak characteristics of traditional LSPM designs.

II. Dual Rotor LSPM Construction

Construction of a four pole Dual rotor LSPM can be seen on the Fig. 1. This motor has two rotors, but only one of them is mechanically coupled with the motor shaft . Dual rotor LSPM shaft is coupled only with the Inner Rotor. The Outer Rotor is not coupled with the motor shaft, and it has ability to rotate around the inner rotor and its shaft on the set of additional bearings.
This construction was proposed and described in US Patent [8].

As shown on the Fig.1 Inner Rotor carries a squirrel cage and slot cuts creating distinct d/q reluctance structure similar to rotor of synchronous reluctance motor. Outer Rotor also has a squirrel cage and permanent magnets installed on its inner surface. Stamped in the outer rotor lamination Flux barriers are made to reduce magnet flux leakage. In presented example both Outer Rotor and Inner Rotor Cages have the same number of slots and bars.

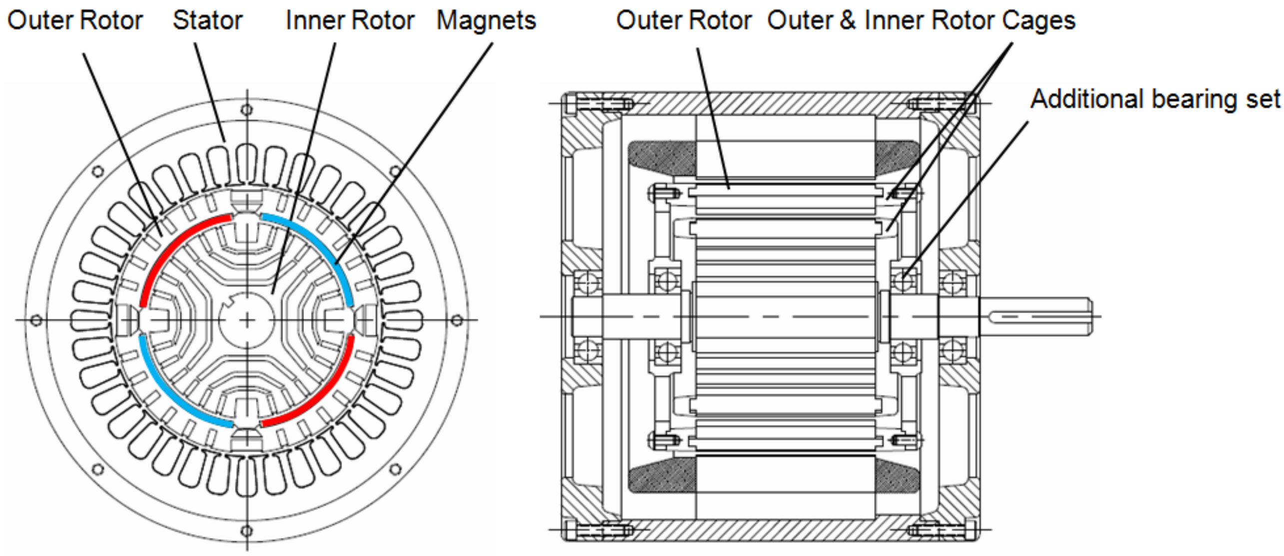

Fig.1. Dual Rotor LSPM Construction

Permanent magnets of the Outer Rotor have electromagnetic coupling with both, asynchronous and synchronous coupling with Stator , and also asynchronous and synchronous interaction with Inner Rotor. The absence of the hard mechanical coupling of the rotor with permanent magnets enables successful synchronization of high inertia loads, much higher than traditional single rotor LSPM.

III. Analysis of Torque in Dual Rotor LSPM

To optimize electromagnetic design of the proof of concept Dual Rotor LSPM we used FEA Flux2D. Fig. 2 shows flux distribution in the motor for two cases, (a)- aligned inner rotor (zero load), and (b) – inner rotor is misaligned by load torque relative to outer rotor magnets.

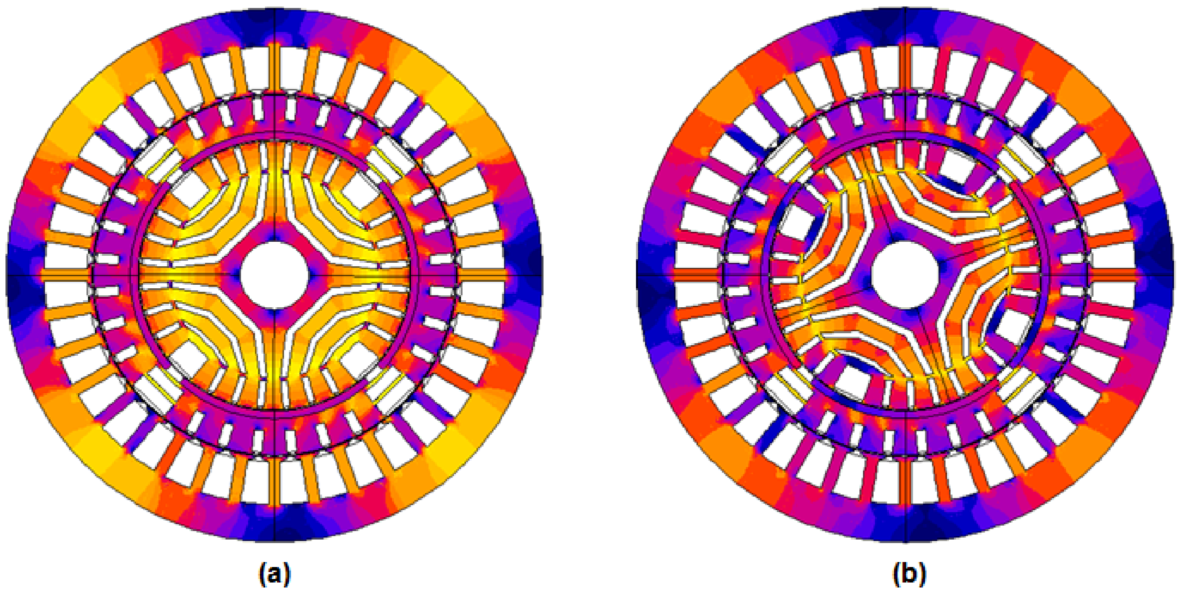

Fig.2. Flux distribution in Dual Rotor LSPM

The synchronous torques calculated with FEA are shown on Fig. 3. The analysis was conducted in two stages. At first, we evaluated the reluctance torque between Outer Rotor magnets and the inner rotor (blue curve) is done on for various static positions between the Inner Rotor and Outer Rotor (blue curve), with no stator MMF present. At second stage we left Inner rotor in fully aligned position and rotated Outer Rotor relative to stator with rated current MMF (red curve). These two torques have to be is certain relationship to achieve optimum operation of the motor. The fact that Inner Rotor torque (due to its reluctance nature) has period two times shorter than synchronous torque between the stator MMF and permanent magnets of the Outer Rotor is helping to reduce transient load torque spikes, one of the concerns/limitations with traditional LSPM.

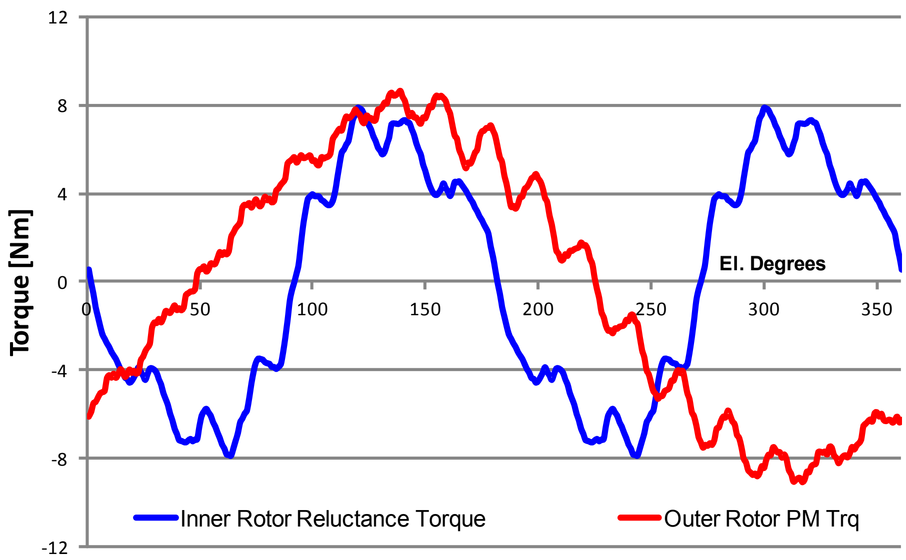

Fig.3. Dual Rotor LSPM Synchronous Torques

In order to validate the concept we have built a three phase test motor with the following parameters: Rated power =0.75kW; OD=172 mm; Lst=76mm; Rated voltage =220V. The sketch of the motor construction is presented on the Fig. 1.

IV. Dual Rotor LSPM Startup Test

Since one of the main aspects of any LSPM motor is its startup performances, i.e. ability to synchronize in presence of load torque and inertia, we built a special test bench where both parameters can be adjusted, see Fig.5. Inertia of the one disk plate is 0.0534 kgm^2 that about 27 times greater than inertia of the Internal Rotor, and we have tested up to 4 plates at the time.

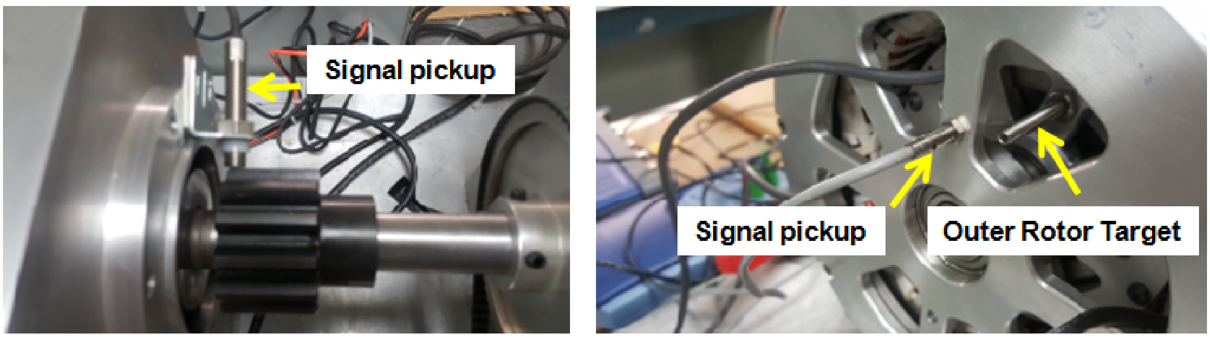

Fig.4. Rotors RPM measurement

Both rotors of the motor were equipped with magnetic RPM counters based on magnetic proximity sensors, see Fig. 4. Pulses of these sensors during startup tests were recorded and converted to RPM.

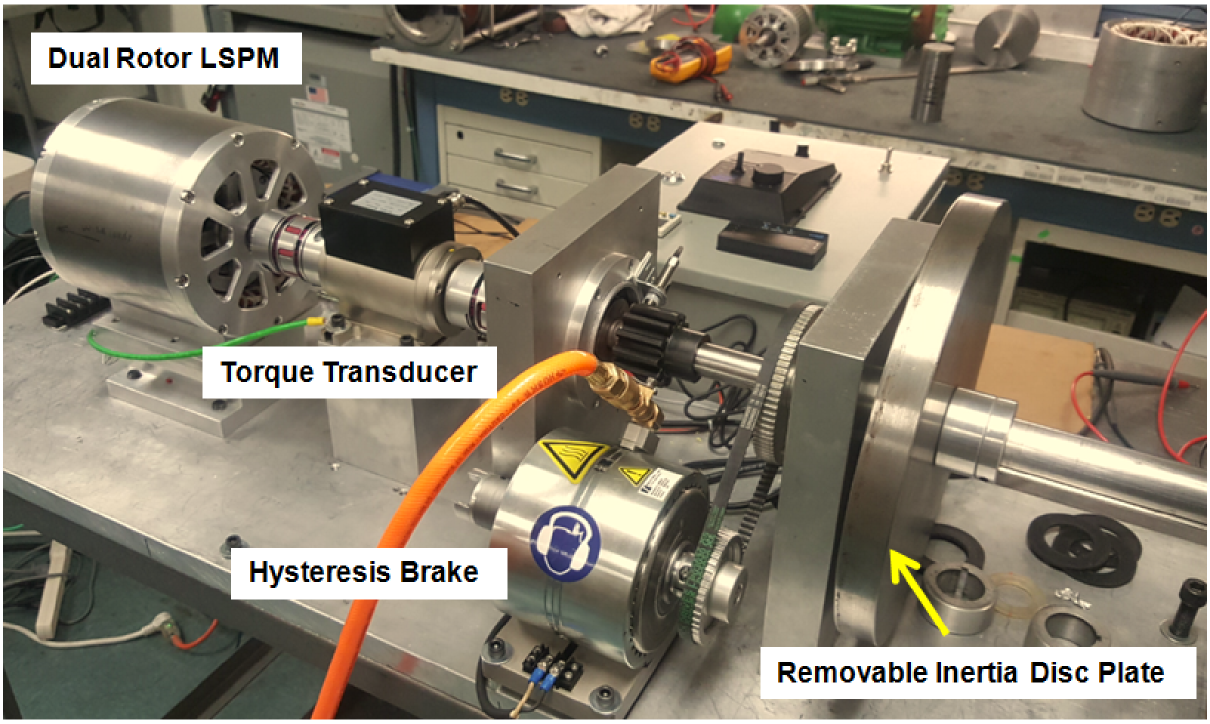

Fig.5. Dual Rotor LSPM Test Bench

Load torque was adjusted prior to startup recording. On the Fig. 6 below are recording of the startup with one inertia disk plate and 4Nm load torque corresponding to 0.75 kW nominal load.

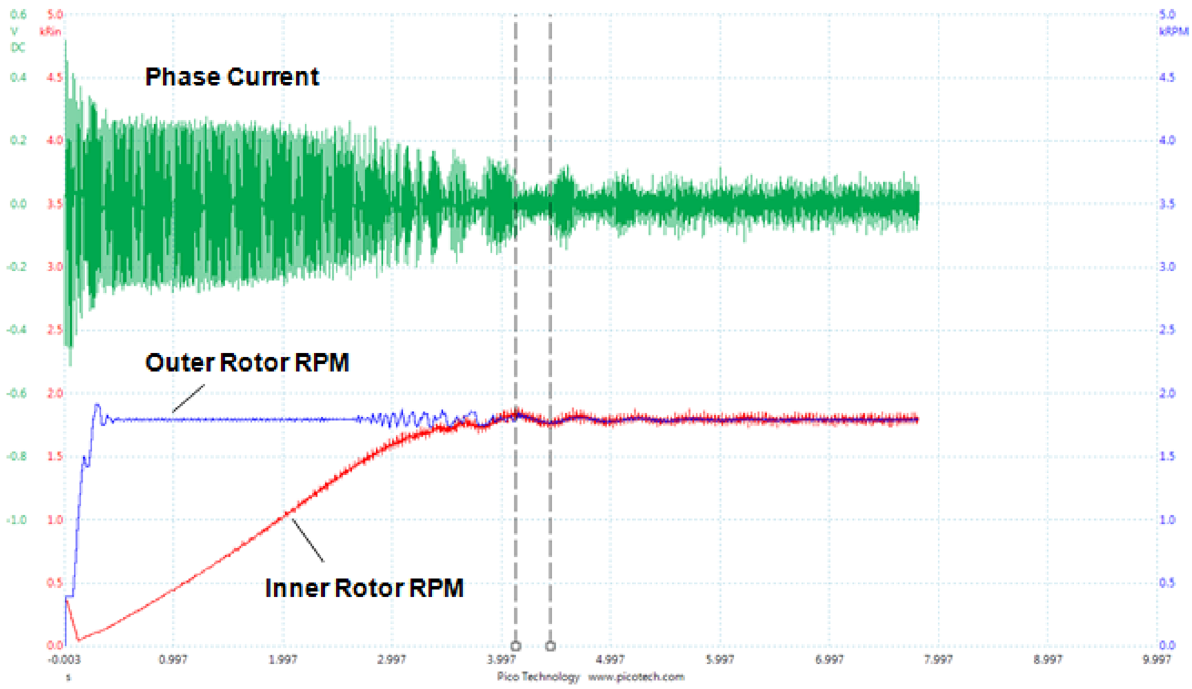

Fig.6. Dual Rotor LSPM Startup with 4 Nm load with 27 times higher than motor inertia

To find out full potential in ability to synchronize grater inertia, we have tested and successfully synchronized at nominal load torque up to 3.5 inertia disks, that is 94 times greater than motor own inertia. Startup recording for the 3.5 inertia plates is shown on Fig. 7.

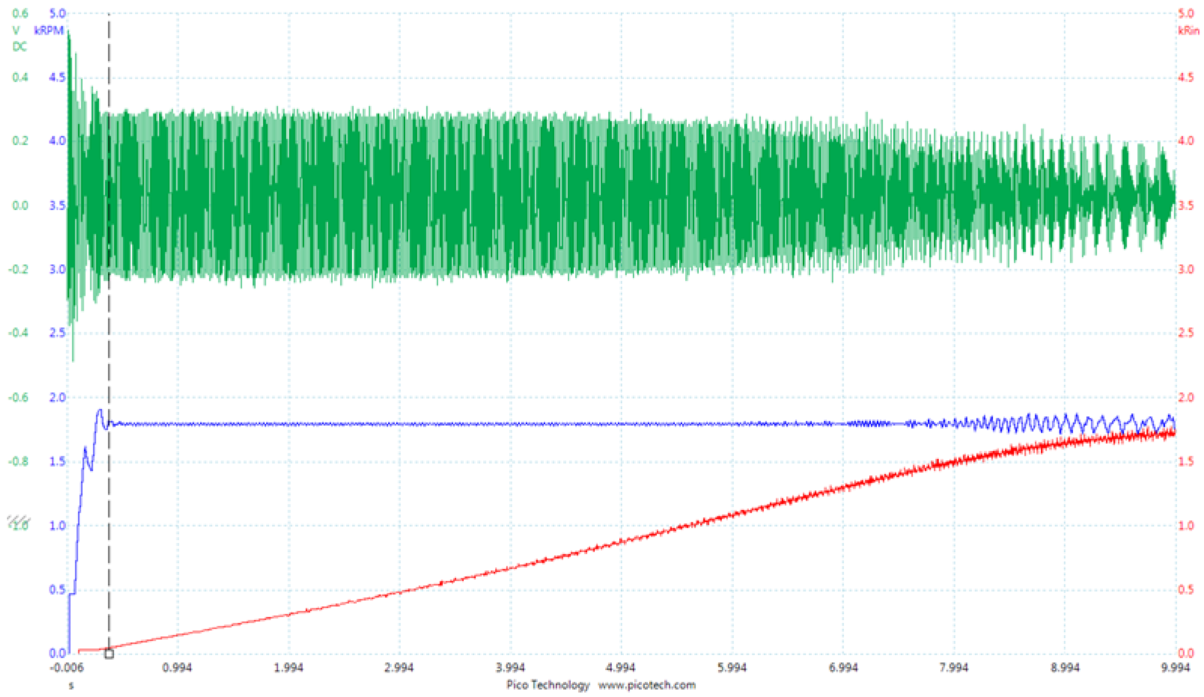

Fig.7. Dual Rotor LSPM Startup with 4 Nm load with 94 times higher than motor inertia

V. Dual Rotor LSPM Startup Observations

The first obvious difference between new design and traditional LSPM is the Load inertia that can be successfully synchronized. The maximum load inertia of LSPM is stated in several publications as 25 to 30 times the motor own inertia [4,6]. The Dual Rotor LSPM test results proof ability to successfully synchronize the load with at least 94 times higher inertia than motor own.

The second important observation is a very smooth load acceleration or in other words absence of the so called LSPM starting “kick” that in some cases can lead premature wear of the load gears and bearings [4]. According to our startup data analysis the maximum dynamic torque applied to load is about 50% of the load torque. In contrast, even optimized traditional LSPM design [2] has achieved reduction of this startup “kick” from 1700% to 700%.

As a result of a smooth motor acceleration Dual Rotor LSPM startup does not produce so much noise and vibration vs. typical traditional design LSPM. This fact should open to LSPM benefits many additional industrial applications.

The reason for a high starting torque “kick” and “violent” oscillation of load torque [4] during synchronization is laying in the fact that in majority practical situation motor load cannot be brought to synchronous speed in the quarter of supplied voltage cycle, that means that in some moments the EMF from rotor magnets will cause negative torques, and high current spikes. And the longer it takes to get to synchronous RPM, the longer is potentially harmful load torque oscillation will exist.

In the presented design, the Outer Rotor carrying magnets accelerates and reaches synchronous rpm in fraction of second, practically independent of the load inertia. As can be seen from the two startup recordings, Outer Rotor is reaching synchronous RPM in about 300 milliseconds in both cases. And the load is being accelerated at the rate according to its inertia and load torque. It takes longer for high inertia load to reach synchronous RPM.

VI. Dual Rotor LSPM Lock Rotor Test

Lock rotor performance is important part of characteristics of any industrial application motor. Lock rotor test recording for our proof of concept Dual Rotor LSPM is shown of Fig.8.

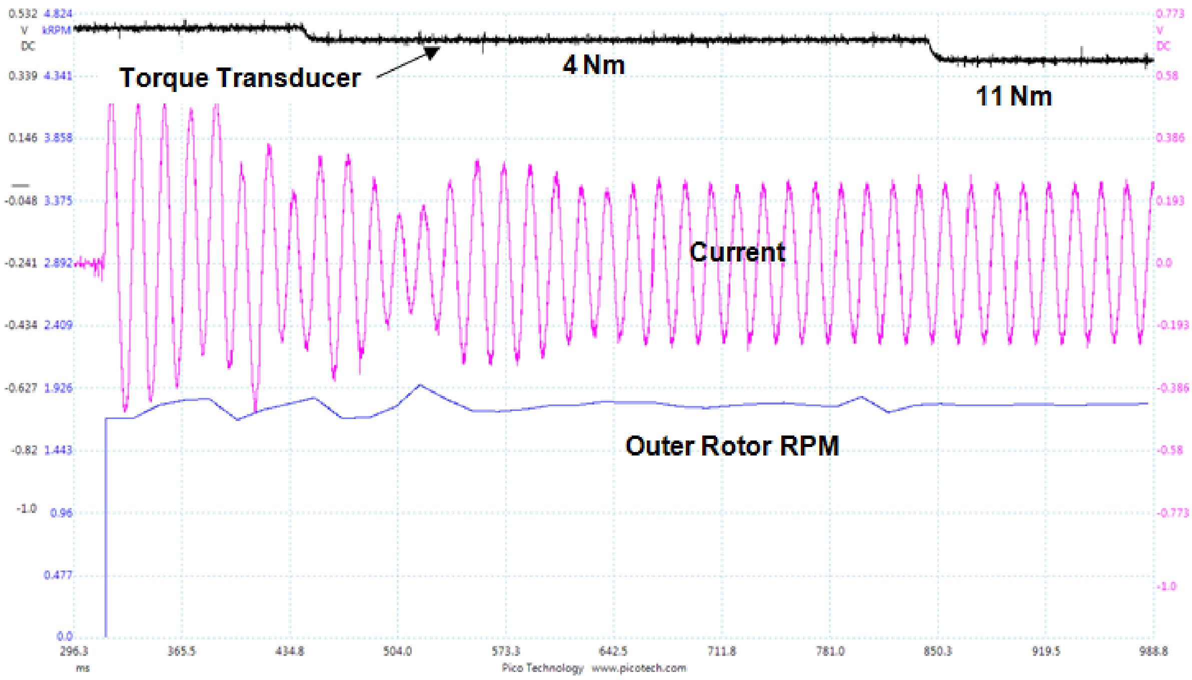

Fig.8. Dual Rotor LSPM Lock Rotor Test

The proof of concept Dual Rotor LSPM produces 11 Nm of torque at lock rotor which is 2.8 times the rated torque, at 850% of current draw which on par with AC Induction Super Premium Efficiency Motors [7]. The corresponding parameters for the 1HP motor in [7] are LRT = 2.6 and Lock Rotor current is 840%.

The Outer Rotor of Dual Rotor LSPM at Lock output shaft did synchronize in similar fashion as in startup recordings described earlier.

We do not have a good explanation at the moment regarding the curve of the torque transducer, why it developed an intermittent 4 Nm torque plateau before stabilizing at 11 Nm.

VII. Dual Rotor LSPM Efficiency and Power Factor

Superior efficiency of LSPM is available due to presence of permanent magnet, that provides near unity power factor and very low rotor losses, this is commonly accepted among electric machine specialists. Adding additional rotor and air gap in Dual Rotor LSPM does not create any significant loss of the flux linkage with stator winding. Larger effective air gab in fact even can help to reduce parasitic eddy current losses in the LSPM cage bars.

LSPM motor Efficiency test procedure is not formalized yet, but most experts agree that input-output or direct method is the most applicable at the moment. This is how we have conducted our motor efficiency of our motor. The results are shown in the Table 1.

Table1. Dual Rotor LSPM Steady State Performance

DR_LSPM Operating Point	Load Torque	RPM	RMS Current	Power Factor	Input Power	Output Power	Efficiency
	Nm	rpm	A	PF	Wt	Wt	%
@ No load	0	1800	0.56	0.87	187.6	0.0	0.0
@ 3/4hp	2.97	1800	1.61	0.98	601.9	559.9	93.0
@ 1hp	3.96	1800	2.06	0.99	779.4	746.5	95.8
@ 1.5 hp	4.95	1800	2.62	0.99	991.6	933.1	94.1

As can be seen the motor prototype rated load efficiency is far exceeding the IE4 level, it is probably close to IE7. Another worth mentioning fact is that power factor even at no load is still 6% higher than corresponding power IE4 AC IM in WEG catalogue [7].

VIII. Conclusions

New Dual Rotor LSPM has been presented. This new type LSPM is able to overcome some major problems with use of line-start motors for general industrial applications. The starting LSPM torque "kick" and load inertia limitation have been practically eliminated. These improvements can widen up the range of use LSPM for IE4, IE5 applications, well behind traditionally accepted 10-15 kW.
The new design is exhibiting excellent Efficiency and power factor even at low load level.

References

[1] Rahman M. A. and Osheiba A.M. *Performance of Large Line-Start Permanent Magnet Synchronous Motors*. IEEE Transaction on Energy Conversion, Vol. 5, No.1, March 1990, pp. 211-217

[2] Doppelbauer M. *Line-Start Permanent Magnet Motors and Their Use in Typical Industrial Applications*. 7th Energy Efficiency in Motor Drive Systems (EEMODS'11) Alexandria, USA, 2011

[3] Rajarm T.U., Bhalchandra N.C. and Ashutosh P. *Overview of research evolution in the field of line start permanent magnet synchronous motors*. IET Electr. Power Applications, 2014, Vol.8, Iss. 4, pp.141-154

[4] De Almedia A., Feeeira F. and Quintino A. *Technical Economical Conciderations on Super High-Efficiency Three-Phase Motors*. Industrial & Commercial Power Systems Technical Conference (I&CPS), 2012 IEEE/IAS 48th

[5] De Almedia A., Feeeira F. and Baoming G. *Beyond Induction Motors - Technology Trends to Move up Efficiency*. IEEE Transactions on Industry Applications, Vol. 50, No. 3, May/June 2014

[6] Bork B.C., Martins C.E.G. *Performance evaluation a Line-Start Permanent Magnet Motors using finite element analysis and experimental tests*. 7th Energy Efficiency in Motor Drive Systems (EEMODS'11) Alexandria, USA, 2011

[7] WEG Motor Catalogue, *"WQuattro Super Premium Efficiency Motor",* 2011

[8] US Patent 9484794 Finkle L.J. *Hubrid Induction Motor with Self Aligning Permanent Magnet Inner Rotor*