Jalal A, Baker NJ, Wu D.

Design of tubular moving magnet linear alternator for use with an external combustion - free piston engine.

In: 8th IET International Conference on Power Electronics, Machines and Drives (PEMD 2016).

19-21 April 2016, Glasgow, UK: Institute of Engineering and Technology (IET).

DOI link to published paper:

http://dx.doi.org/10.1049/cp.2016.0273

Date deposited:

27/07/2016

Design of Tubular Surface Mounted Permanent Magnet Linear Alternator for use with an External Combustion - Free Piston Engine

A.Sa. Jalal*, N.J. Baker, D.W. Wu

a.jalal@newcastle.ac.uk Electrical Power Group, School of Electrical Engineering, Newcastle University, NE17RU

Abstract:
The work presents a design methodology for a Surface Mounted Permanent Magnet Linear Alternator (SMPMLA) for use with an External Combustion - Free Piston Engine (EC-FPE). This topic has attracted research interest in the past (2-3) decades as an alternative to the conventional rotary engine in special applications, such as range extender for hybrid vehicles, combined heat power generation into the grid, generation on board spacecraft or use as a standalone power supply.

In the literature, individual topologies have been considered throughout research groups worldwide [1, 2], from which the tubular geometry dominates over other geometries due to its axisymmetric properties, manufacturability and compactness assuring higher power densities. In this paper, the design of three alternative tubular surface mounted permanent magnet linear machines with modular windings is investigated for use with an EC-FPE. In the literature, these three topologies have not been specifically compared for the same force capability. The key optimisable parameters, common to all topologies, are shown in figure (1).

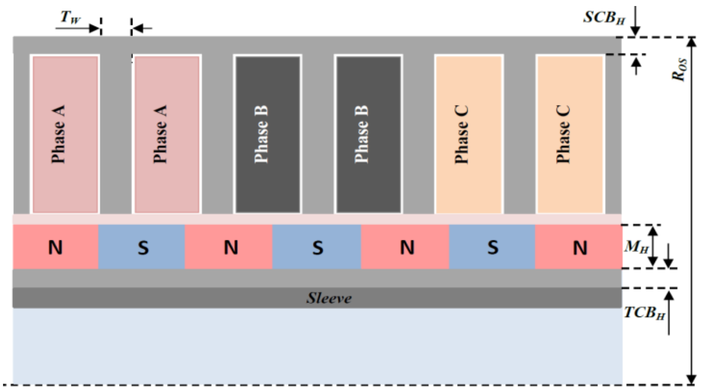
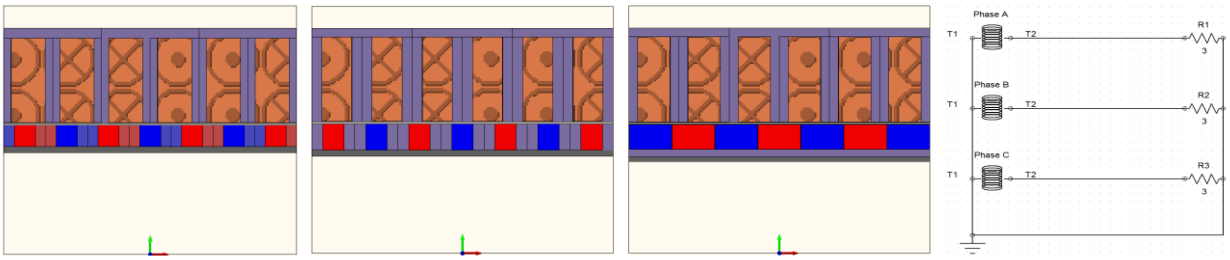


Figure (1): Longitudinal half - section through SMPMLA

Each of the three topologies considered has the permanent magnets mounted on the translator magnetised as Quais-Halbach, Axial and Radial as shown in figures (2 – a), (2 – b) and (2 – c) respectively. All the machines were designed under the same operating speed, air gap length, active length and with a simple resistive load connected across phase terminals as shown in figure (2 – d).



(a) (b) (c) (d)

Figure (2): Machine under investigation

(a)Halbach; (b) Axial; (c) Radial; (d) Machines resistive loading

An initial preliminary design has been performed based on classic design theory [3] to obtain the basic machine dimensions. Using geometric constraints from the EC-FPE, the geometry of each topology has been investigated and manually optimised for a specific peak force using 2D FEA software. The optimisation procedure is shown in figure (3). For each topology, 5 parameters have been optimised individually to clarify their effect on the active machine force (in per unit). Sample of the results is shown in figure (4), where the effect of PM height (4 – a) and its width (4 – b) on the force are clearly depicted.

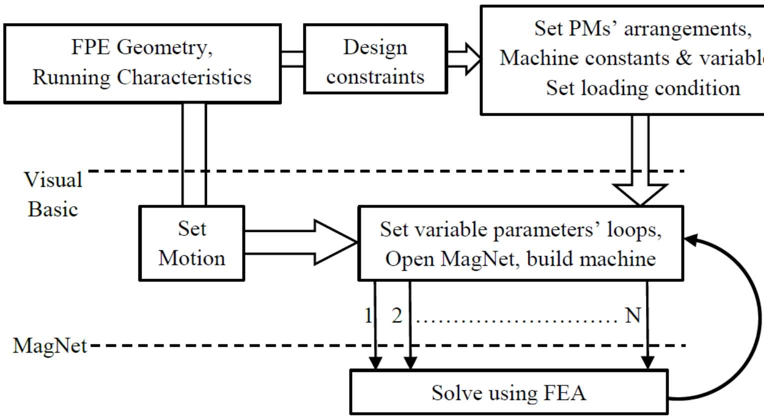
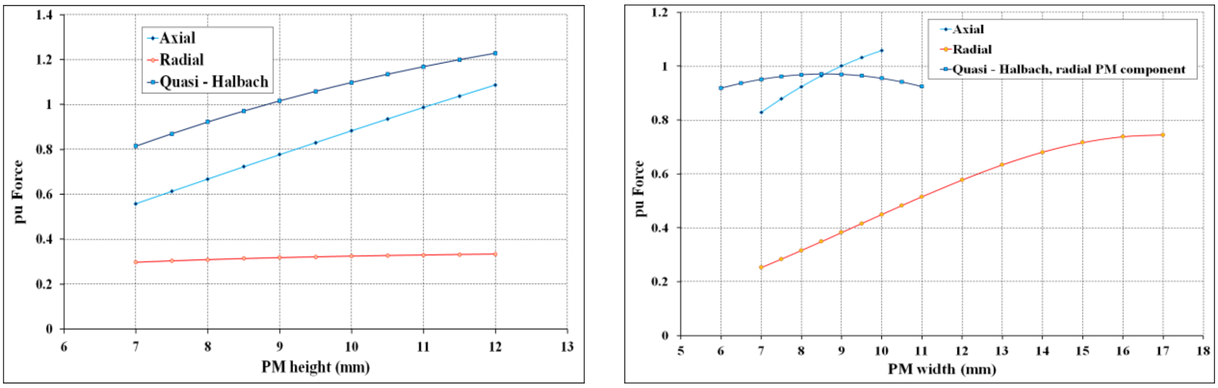


Figure (3): Manual optimisation procedure based EC-FPE constraints



(a) (b)

Figure (4): PM dimensions effect on force capability (a) PM height; (b) PM width

Results of optimising the Radially magnetised machine shows that even with magnets spanning the full pole pitch, the target force cannot be achieved and so it is not compliant with the specification. The performance of the remaining two machines is shown in Table I.

Table I: Weighting criteria

Criterion	Weighting (percentage)	Axial machine		Quasi – Halbach machine	
		Value	Weighted Score	Value	Weighted Score
% Efficiency	20	96.5	19.3	98.9	19.78
Translator mass (kg)	30	4.211	17.89	3.711	22.89
Magnet mass (kg)	50	1.77	50	2.98	34.2
Total	100	---	87.19	---	76.87

In the comparison table, the Quasi-Halbach magnetised machine shows higher efficiency, yet the Axially magnetised machine has a lighter moving (PM) mass. A weighted scoring system is used to select the most appropriate design. Thus, the Axially magnetised machine is adopted for the application with the EC-FPE. Furthermore, it is anticipated that the use of only one magnetisation type of PMs saves money during manufacturing. In the main paper, the predicted performance of the final design when subjected to the predicted EC-FPE profile is presented and discussed. Full parameters of a prototype machine will also be given

[1] J. Wang, M. West, D. Howe, H. Zelaya-De La Parra and W. M. Arshad, "Design and Experimental Verification of a Linear Permanent Magnet Generator for a Free Piston Energy Converter," IEEE Trans. EC, Vol. 22, No.2, pp. 299-306, 2007.
[2] P. Zheng, C. Tong, G. Chen, R. Liu, Y. Sui, W. Shi, and S. Cheng, "Research on the Magnetic Characteristic of a Novel Transverse-Flux PM Linear Machine Used for Free-Piston Energy Converter," IEEE Trans. Mag., Vol. 47, No. 5, pp. 1082-85, MAY 2011.
[3] I. Boldea, "Variable Speed Generators," CRC, ISBN/ASIN: 0849357152, 2006.