LINEAR OSCILLATING GENERATOR

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1 INTRODUCTION

A broad variety of energy converters for primary energy (e.g. internal combustion machines) are using oscillating principles. In general, this oscillating motion is converted to a continuous rotary motion by means of drive rod and crank shaft. The further energy conversion into electrical energy is achieved by conventional rotating generator.

This crank gear reduces the efficiency by introducing additional friction, requires additional weight and volume and causes wear. By using an oscillating linear generator these disadvantages can be avoided and very efficient, nearly wear free, small sized and lightweight electrical gen sets can be constructed.

Therefore, this report deals with models of various Linear Oscillating Generators as below:

I. One-phase System with Ironless Translator in Cartesian Topology
II. One and Three-phase System of Translator with Back-iron in Cylindrical Type
III. Longitudinal Flux Generator in Cartesian Topology
IV. Halbach PM Machine in Tubular Topology
V. Reluctance Machine with Cylindrical Topology

The objective function of Linear Oscillating Generator is approximately 250 N force.

2 NUMERICAL CALCULATION OF PROPOSED MODEL

2.1 One-phase System in Cartesian Topology

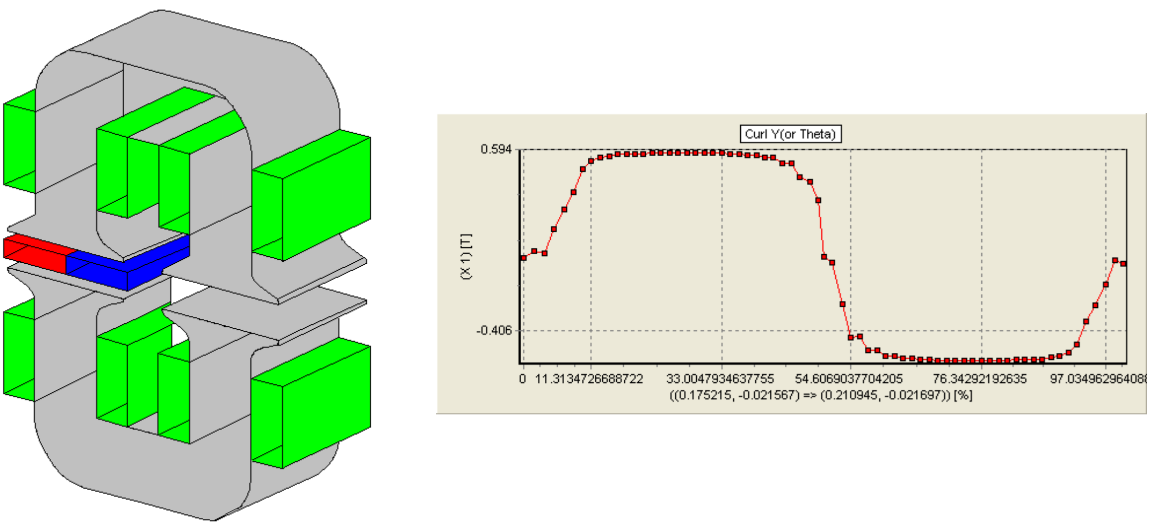

Figure 1: Configuration & Flux-density at No-load condition of One-phase System in Cartesian topology

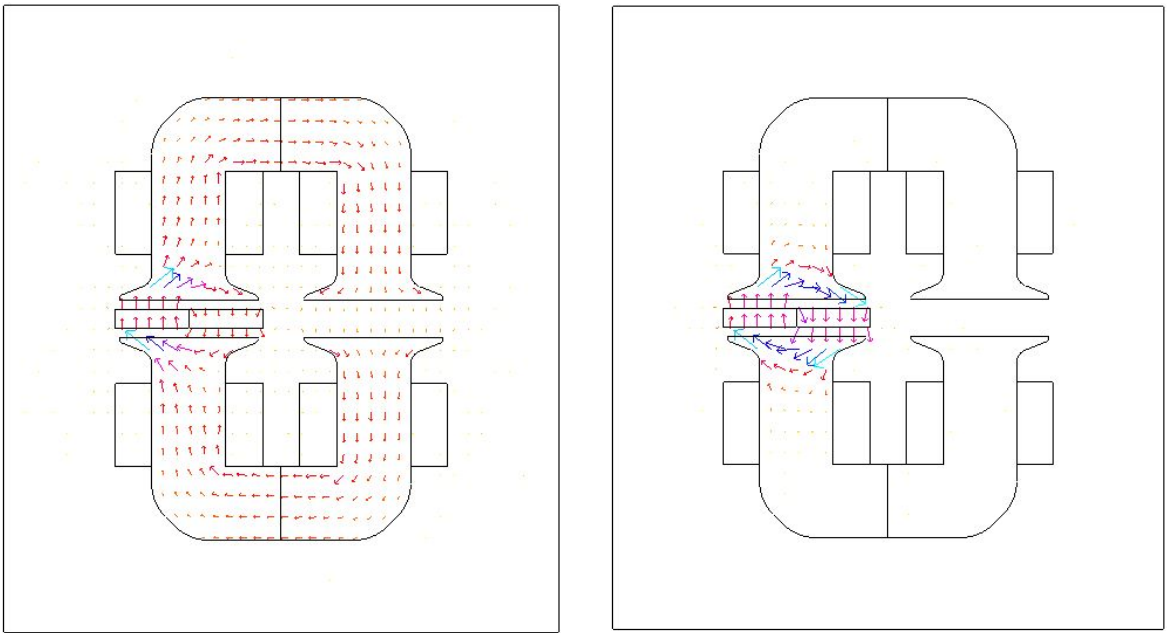

Figure 2: Flux-vector at Load & No-load condition resp.

The model is composed of one-phase concentrated winding with permanent magnet (PM) translator. The PM as translator is magnetized in vertical direction and its stroke is 40 mm in right and left direction. **Figure 1** shows configuration and flux-density in the air gap at no-load condition of one-phase system in Cartesian topology. Also **Figure 2** displays flux-vector at load and no-load condition respectively.

2.2 One-phase System in Cylindrical Type

Here the PM is in radial direction and has same N and S pole volume together (**Figure 3**). Therefore it is possible to expand capacity because there is no limit in size of PM. Due to 3-pole organization, the movement is smooth and natural in initialization. Likewise, it has stable structure because iron-core shields PM mover. The field plots for load and no-load conditions are shown in **Figure 4**.

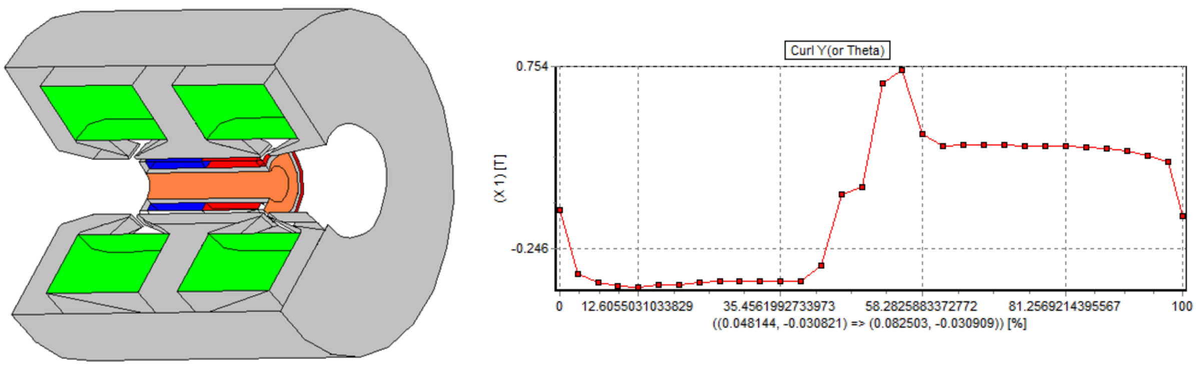

Figure 3: Configuration & Flux-density at No-load condition
of One-phase System in Cylindrical topology

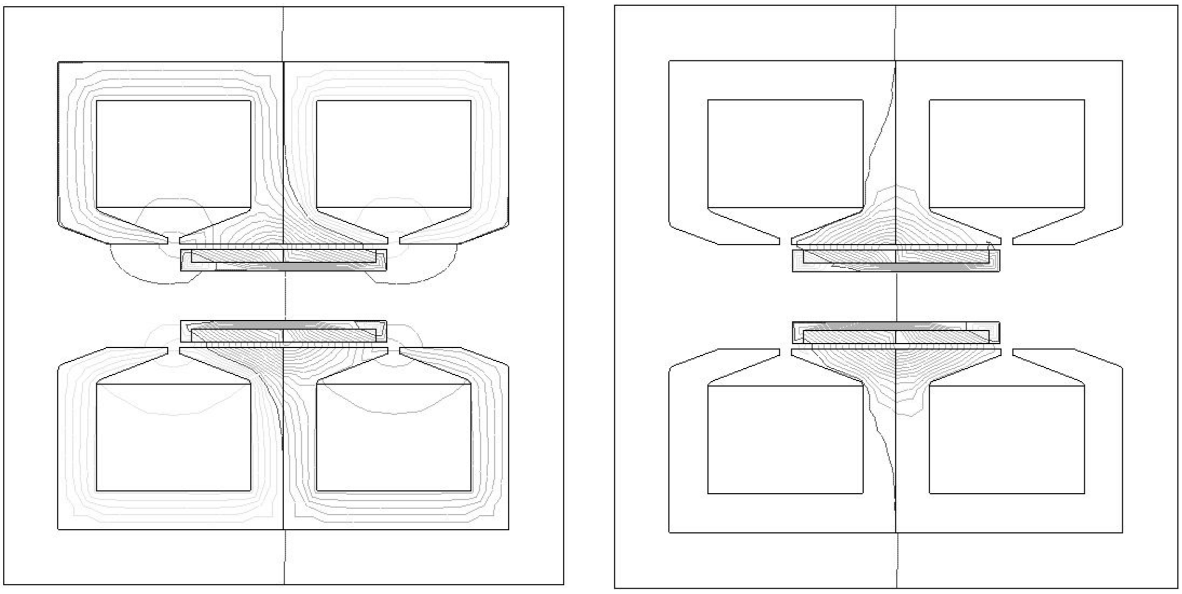

Figure 4: Flux-line & Flux-vector at Load and No-load condition resp.

2.3 Longitudinal Flux Machine

In general, Linear Oscillating Actuator (LOA) refers to a motor that performs a linear reciprocating motion with a certain stroke at a specific frequency and can be also used as a linear generator. The most suitable actuator is the moving PM type, which has the advantage of a high specific force. However, a conventional surface-mounted moving PM LOA has some weak point in production. The novel flux concentration-type LOA has an embedded PM configuration that has been proposed (**Figure 5**). Besides, the research about skewing of the PM is accomplished to reduce torque ripple [1].

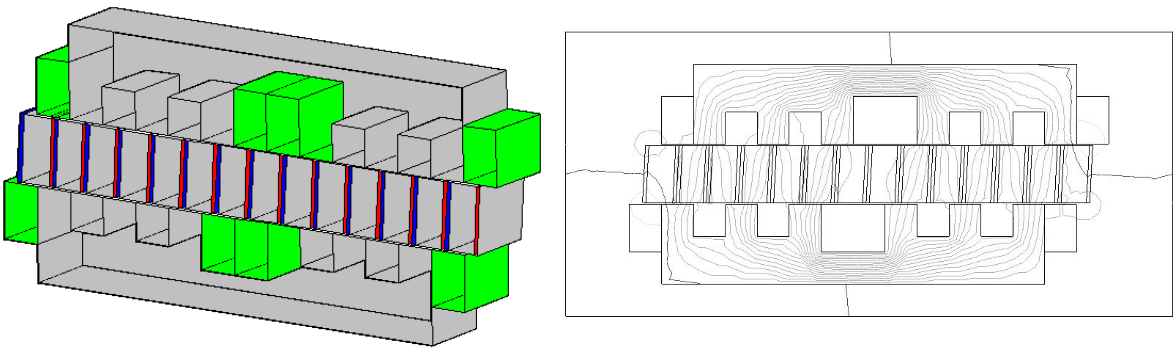

Figure 5: Configuration & Flux-line of One-phase Linear Oscillating Generator with skewed magnets

2.4 Halbach PM Type

Tubular topology of the various linear machines is most compatible system because they have zero net radial force between the armature and stator, no end winding and are volumetrically efficient. Furthermore this has a high efficiency and force density. A Halbach PM Type machine has two coils per pole-pair per phase, displaced by electrical 120 degrees. This machine topology has unique features in terms of high power density, high efficiency and low moving mass, which are essential for achieving a high power output and dynamics [2].

Figure 6 shows configuration and winding scheme in three-phase Halbach PM Machine. There is flux-vector in air gap of radial PM and x-axis direction at load condition, flux-density in air gap at no-load in that respectively in **Figure 7**.

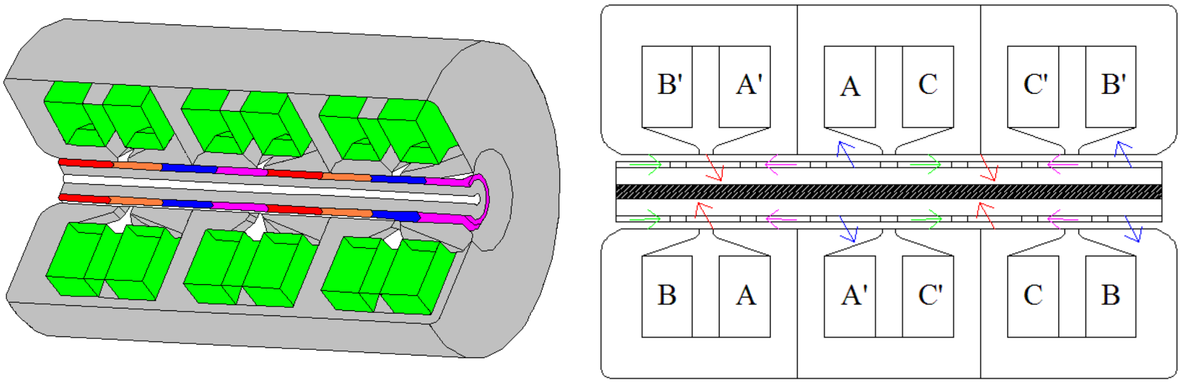

Figure 6: Configuration & Winding-type of Three-phase Halbach PM Machine

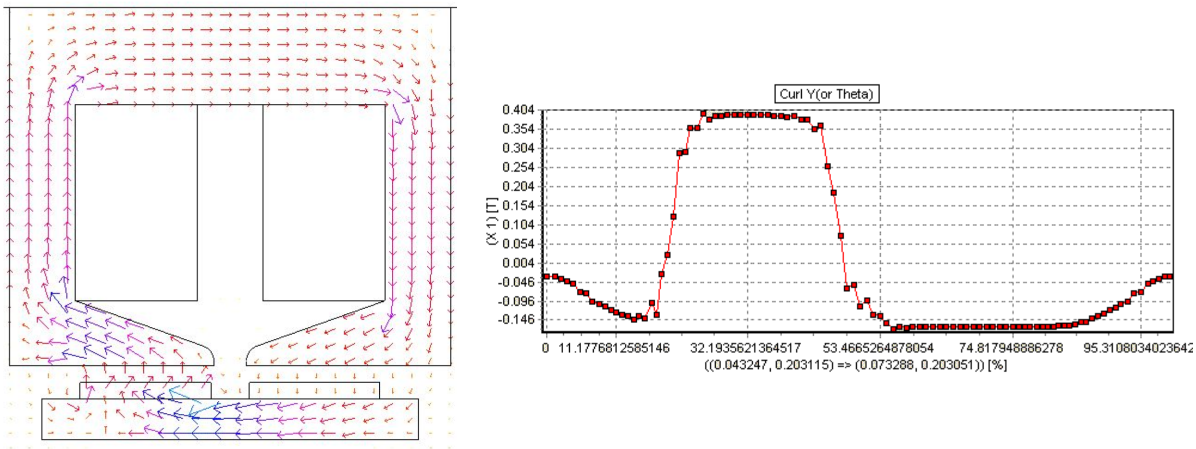

Figure 7: Configuration & Flux-line in air gap at No-load of Three-phase Halbach PM Machine

2.5 Reluctance Machine in Tubular Topology

As below **Figure 8**, the inner part (the mover) is a shaft made of ferromagnetic material with transverse slots. The outer part (the stator) consists of identical phase sets. Each set is magnetically self-contained and consists of magnetic core, which is formed of two discs and one ring, and of a spool-type coil. The discs might be implemented using Soft Magnetic Composite (SMC) materials [3]. In four-phase system, each phase is separated by means of non-magnetic spacer for the length which is electromagnetically equivalent to one quarter of a cycle of the phase inductance variation [4].

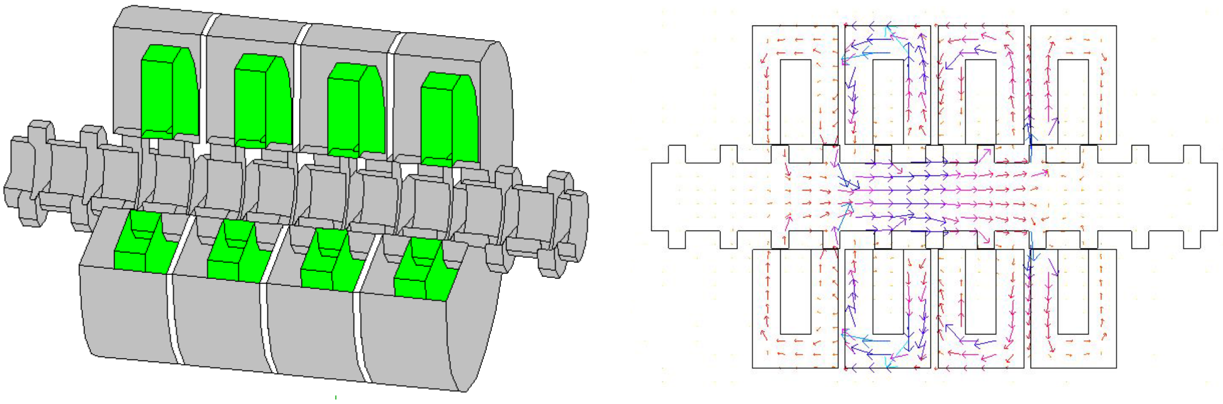

Figure 8: Configuration & Flux-line of Tubular Reluctance Machine

3 CHARACTERISTIC ANALYSIS METHOD

If the magnetic vector potential and current density has only a z-axis component, the governing equation for 2-dimensional analysis of Linear Oscillating Generator can be expressed in a magnetic vector potential *A* as follows:

$$\frac{1}{\mu}[\frac{\partial}{\partial x}(\frac{\partial A}{\partial x}) + \frac{\partial}{\partial y}(\frac{\partial A}{\partial y})] - J_o - J_m = 0$$

Where μ is the inverse of permeability, *A* is the magnetic vector potential, and J_o, J_m is the input current density and PM respectively. However, there is only a J_o term in the reluctance machine because this has not PM [5].

4 RESULT AND DISCUSSION

The investigated structures are compared in **Table 1**.

Table 1: Comparison of Result

Type	Unit	I	II	III	IV	V
Force	[N]	248,9	250,6	247,2	277,2	242,8
Stator Voltage	[V]	127,7	177,7	738,4	205,3	98,8
Current Density	[A/mm^2]	13,75	2,95	3	3	4,83
Resistance	[Ω]	2,61	1,24	2,25	1,12	0,96
Reactance (f = 167 Hz)	[Ω]	4,63	20,03	14,34	8,51	57,4
Force Density	[N/mm^2]	0,037	0,01	0,03	0,03	0,0077
Mass	[kg]	1,0032	2,089	0,814	0,755	4,976
Coil Loss	[W]	409,1	420	64,1	173,8	371,3
Power Factor	-	0,84	0,45	0,99	0,97	0,22
Efficiency η	[%]	85,8	85,7	97,5	93,7	84,7

The numerical calculation is performed by Finite Element Method. As task for this report has planned the investigation in terms of

- power to weight and volume ratio,
- efficiency and
- reactive power consumption.

The above **Table 1** indicates that the one-phase system in Cartesian topology has the best power density. But its efficiency is not relatively higher than other models. On the contrary, Halbach PM Machine is better than one-phase system in Cartesian topology in efficiency aspect, although power density is low a little. As a result, longitudinal flux machine produces good outcome in total machine type.

5 CONCLUSION

This report was performed by analytical calculation and simulation by FEM. These represent characteristics in one-phase system in Cartesian and cylindrical topology separately, longitudinal flux machine in Cartesian topology, Halbach PM Type and reluctance machine in cylindrical topology respectively.

This will give elaborate information about the design and the performance data of linear oscillating gen sets and in parallel tools for calculation, simulation and the design of linear oscillating machines will be available.

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