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# Force optimizations of a tubular linear reluctance actuator (TLRA) and tubular linear permanent magnet actuator with Halbach array (TLPM)

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**ABSTRACT** – This paper presents a characterizing study of two novel electromagnetic actuators i.e. Tubular Linear Reluctance Actuator (TLRA) and Tubular Linear Permanent Magnet Actuator with Halbach array (TLPM). The study concentrated on the varying parameter i.e. the number of winding turns and the air gaps. The simulation of 3D FEM analysis is used to show the differences between two designs in force and the effects of parameters variations.

## 1. INTRODUCTION

Electromagnetic actuators are used in a vast variety of applications that require high thrust, high accuracy and variant working ranges. The tubular type has rugged mechanical structure, almost same like a piston structure. The tubular type minimised the elimination of stray magnetic field. For the same sizes and weights, the force density delivered by tubular actuator is greater than planar actuator as previous study [1]. Electromagnetic linear actuator consists of two main components, which are the stator (stationary part) and the mover (moving part). TLRA structure consists of coil at stator and non-magnetic mover while TLPM consists of coil at stator and permanent magnet mover. TLPM provides the highest efficiency and trust force. This has led to the increment of the use of tubular permanent-magnet actuators in manufacturing, medical tools, transportation, advance electronic devices, and robotics as stated in previous study. TLRA has advantages in terms of very simple structure, ruggedness, and inexpensive [2-4].

## 2. METHODOLOGY

Two types of linear electromagnetic i.e. TLRA and TLPM are designed with same initial parameters. The varying parameter i.e. air gap (between stator winding coil and mover) and number of turns has been analyzed with same input current (0A to 20A with interval of 2A). The initial parameters of TLRA and TLPM are shown in Table 1 and Table 2.

Table 1 Initial parameter of TLRA.

| Parameter | Values | | |
|---|---|---|---|
| | **First Winding** | **Second Winding** | **Third Winding** |
| Number of turns | 17turns | 33turns | 66turns |
| Coil inner diameter | | 21mm | |
| Coil outer diameter | 25mm | 30mm | 40mm |
| Mover outer diameter | | 20mm | |
| Length of the mover | | 90mm | |
| Air gaps | | 0.5mm | |

Table 2 Initial parameter of TLPM.

| **Parameter** | **Values** |
|---|---|
| Number of turns | 66turns |
| Coil inner diameter | 21mm |
| Coil outer diameter | 40mm |
| Shaft outer diameter | 12mm |
| Magnets outer diameter | 20mm |
| Length of the mover | 90mm |
| Air gaps | 0.5mm |

The designs of TLRA and TLPM are shown in Figure 1 and Figure 2. The differences between the two structures in this study are; i.e. TLPM consists of permanent magnet on the mover shaft and TLRA consists of 3 steps of coil windings.

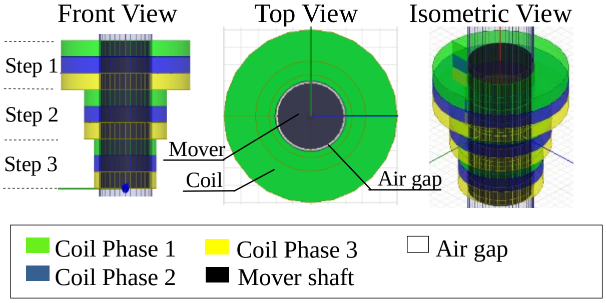


Figure 1 TLRA structure design.

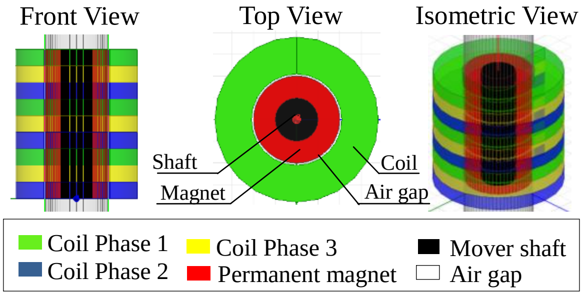


Figure 2 TLPM structure design.

## 3. RESULTS AND DISCUSSION

### *3.1 Varying winding turn*

As TLRA consists of set of step winding coils, the winding numbers of turn details for step 1 and step 2 are shown in Table 3. Winding turns for step 3 TLRA and winding set for TLPM are varied from 100 to 500 turns with the interval of 100 turns. The highest force generated by varying winding turn for TLRA is 760 N with 500 turns and for TLPM is 134N also with 500 turns as shown in Figure 3 and Figure 4.

Table 3 Sets of TLRA number of turns.

| **Steps** | **Number of turns** | | | | |
|---|---|---|---|---|---|
| | **Set 1** | **Set 2** | **Set 3** | **Set 4** | **Set 5** |
| Step 1 | 25 | 50 | 75 | 100 | 125 |
| Step 2 | 50 | 100 | 150 | 200 | 250 |
| Step 3 | 100 | 200 | 300 | 400 | 500 |

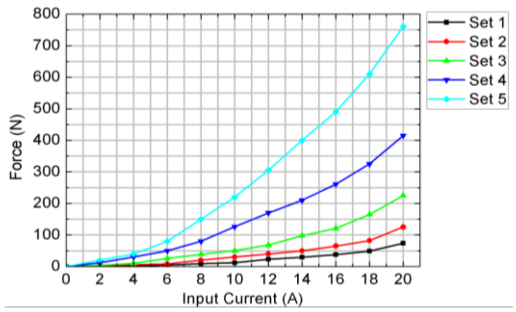


Figure 3 Forces vs number of turn variant for TLRA.

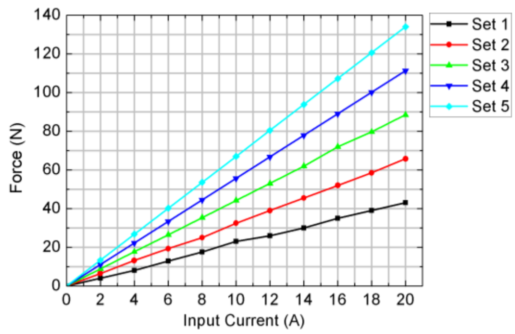


Figure 4 Forces vs number of turns variant for TLPM.

### *3.2 Varying air gap*

The air gap dimensions are varied from 0.5mm to 1.5mm with interval of 0.2mm. The highest force generated by varying number of turns of TLRA is 55N with 0.5mm air gap, while TLPM is 85N with 1.5mm air gap as shown in Figure 5 and Figure 6.

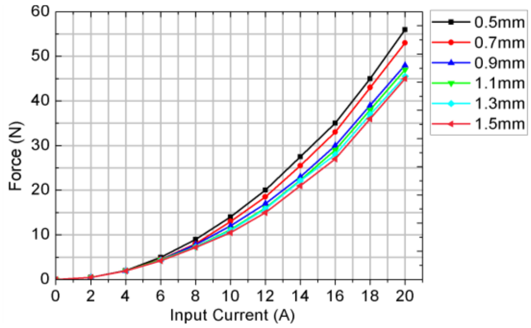


Figure 5 Forces vs air gap variant for TLRA.

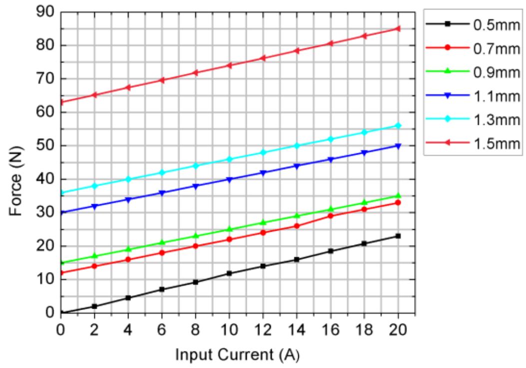


Figure 6 Forces vs air gaps variant for TLPM.

## 4. CONCLUSIONS

The FEM analysis proved that TLPM produced more force than TLRA due to the magnet and the Halbach array arrangement; however the cost of magnet is expensive. If larger number of step winding turns is used (500turns), TLRA can generate more forces (760N) compare to TLPM which is the optimum parameter for this study. The disadvantage of TLRA is high current consumption is required to generate high force.

## ACKNOWLEDGEMENT

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