Comparative Study on Different Variable Reluctance Linear Machine Structures (With/Without Permanent Magnets)

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1. Introduction

The field of linear electrical machines is widely expanding. Numerous practical applications in diverse areas having dynamic markets are already taken in study. This tendency is expected to continuously increase in the coming years [1]. Therefore any new results in this field could be of real interest for the specialists round the world.

Linear variable reluctance machines are attractive for industrial applications due to lack of windings on either the stator or translator structure. Further, their windings are concentrated rather than distributed, making them ideal for low-cost manufacturing and maintenance [2]. Concentrated windings also enable a naturally fail-safe system that can operate even with a phase shorted or open [3].

In the paper four construction variants of the variable reluctance linear machines will be studied by means of high precision numeric field computations.

The force development capability and the force/mass (volume) ratio of the linear machine variants taken into study will be analyzed in order to find out the best construction variant.

2. The Linear Machines Taken into Study

The starting point of the study was the three-phased modular double salient permanent magnet variable reluctance linear machine exhaustively studied formerly by the members of our research team, both in its linear and surface variants [4, 5].

A picture of a three-phased linear variant of this motor is given in Fig. 1.

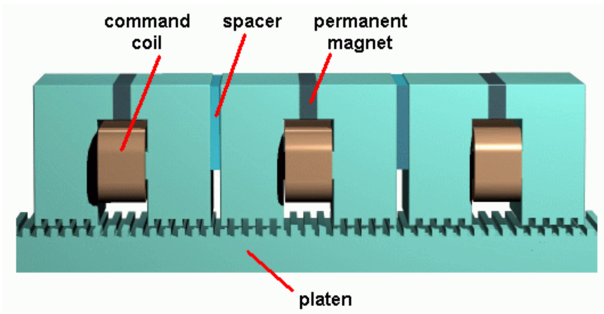


Figure 1. The modular double salient permanent magnet linear motor.

A view of its mover module is shown in Fig. 2.

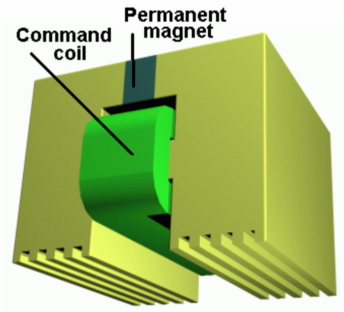
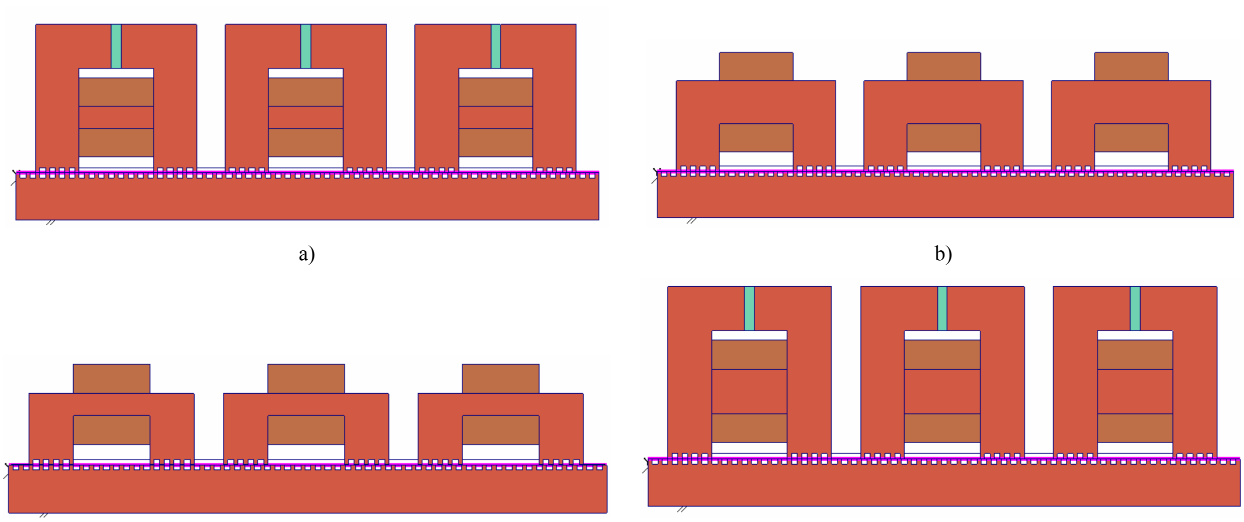


Figure 2. One module.

The main goal of the study is to find out the effectiveness of the permanent magnet from the linear motor's structure. The compared motor structures were selected as to be as close as possible of the linear motor considered as starting point.



a) b) c) d)

Figure 3. The variable reluctance linear motor structures to be compared

Hence the following linear motors were studied:

i.) The modular double salient permanent magnet linear motor (see Fig. 3a) – *a* variant

ii.) The switched reluctance linear motor (without permanent magnets and having the same cross section of the mover's iron core as that of the poles of the initial machine, Fig. 3b) – *b* variant

iii.) A motor structure similar to the initial one, having the permanent magnet and the iron core above the coils taken out (Fig. 3c) – *c* variant

iv.) A permanent magnet motor variant in which the core branch parallel to the permanent magnet has the same cross section as that of the module's poles (Fig. 3d) – *d* variant.

The air-gap, the teeth structure on both armatures and the platen of the motors was considered identical in all the four cases.

3. Results of the Field Computations

The comparative study was performed via high precision two-dimensional (2D) finite elements method (FEM) based numerical field computations. The MagNet package was selected to build up the models and to run the simulations.

The models were set up by imposing the same conditions in all the cases: the same materials for the iron cores and for the permanent magnets, the identical dimension constrains for the triangular elements in each part of the linear motors in study, the same edge subdivisions of the construction slice surfaces in the air-gap, the same settings of the solver, etc.

The generated mesh round the air-gap of the linear machines in study is given in Fig. 4.

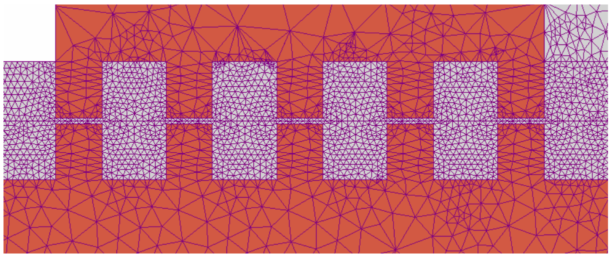


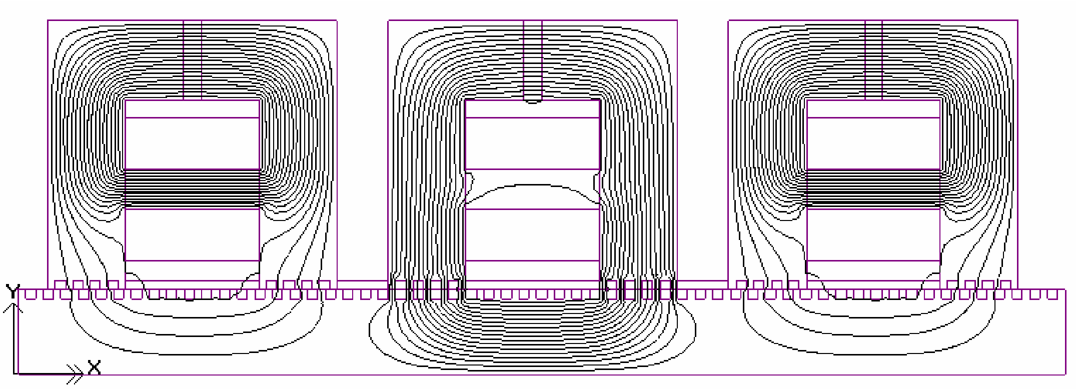
Figure 4. The mesh round the air-gap.

In order to set up the static characteristics of the four linear motors in study the transient analysis was performed in all the four cases, imposing the positions of the mover in which the field computations should be performed.

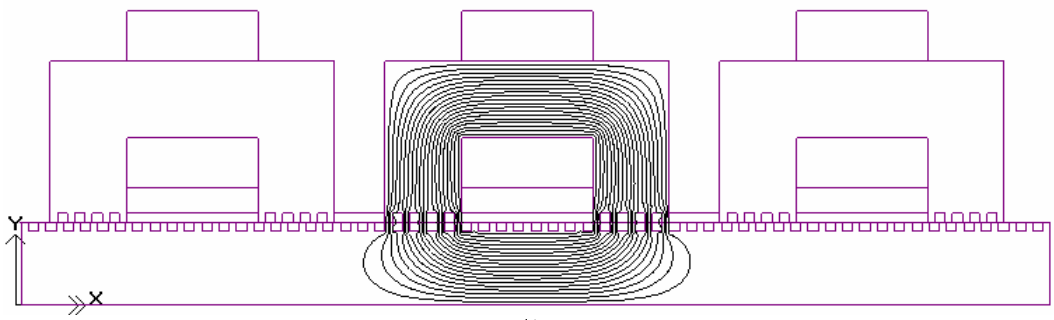
In each case 21 positions (at a distance of 0.05 mm) were considered between the aligned and un-aligned position of the two armature's teeth.

Next a part of the obtained results are given. The flux lines shown in Fig. 5 were plotted for the case when only the central module has its coils energized, and the teeth of this module are aligned with the teeth of the platen. In the case of the two variants having permanent magnets in their structure (variants *a* and *d*) in the two passive modules only a few flux lines are crossing the air-gap. The main flux is flowing through the core branch connecting the two poles and placed under the permanent magnet.

In all the four cases when the module is active almost the entire magnetic flux generated by the permanent magnet and/or by the command coil is forced through the air-gap. Hence at each time only a single module of the machine is developing significant forces. Applying the current pulses through the coils in accordance of the mover's position continuous linear movement can be achieved.

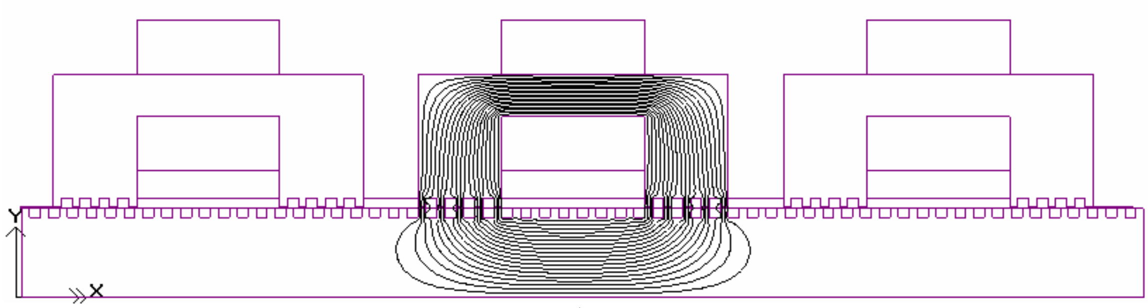


a)

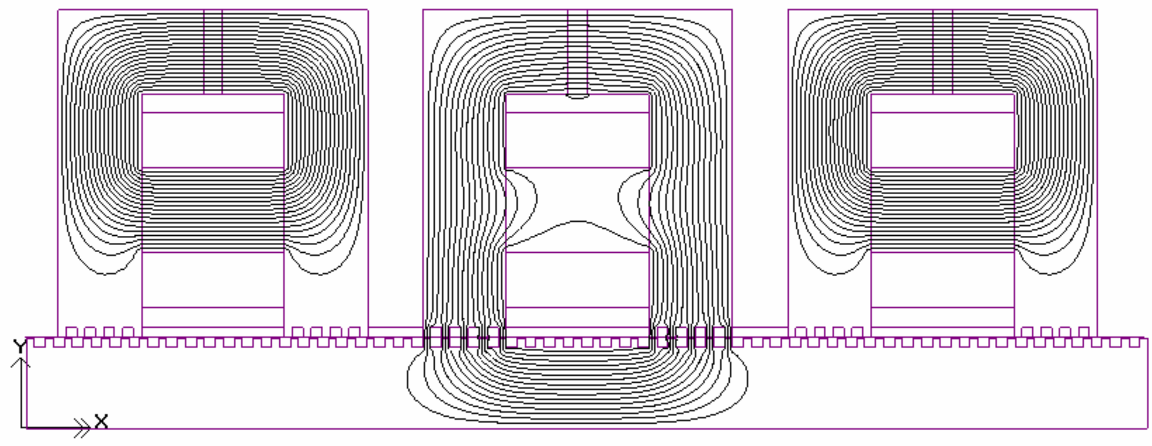


b)

Figure 5. The field lines obtained via FEM based computations for the four linear motor structures



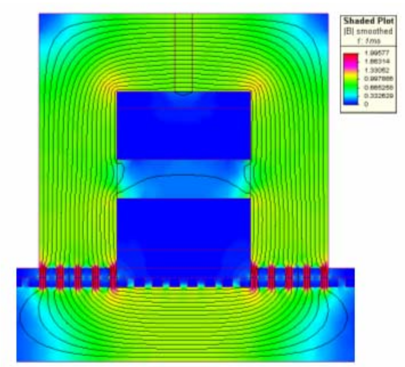
c)



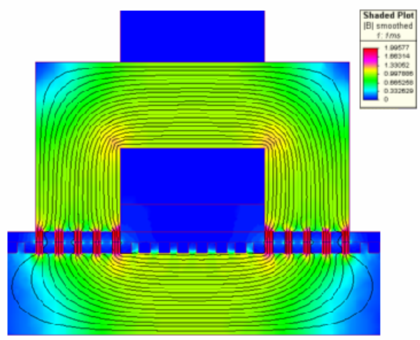
d)

Figure 5. The field lines obtained via FEM based computations for the four linear motor structures

In order to highlight the magnetic flux concentration through different parts of the analyzed linear machines next the color maps of the magnetic flux densities are given (in Fig. 6) for the middle, the active module of the linear machine.



a)



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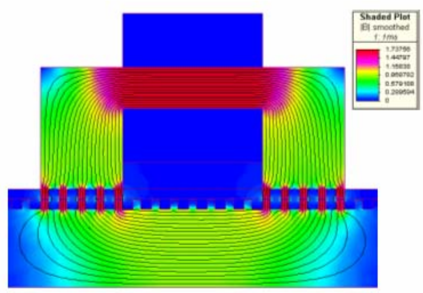

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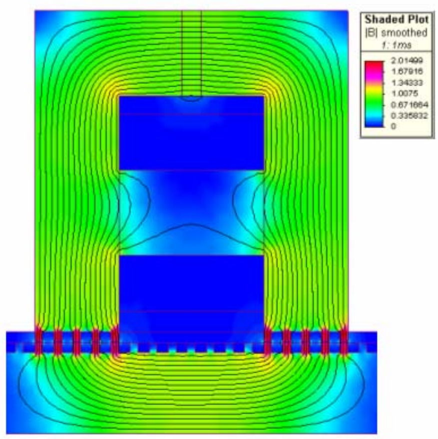
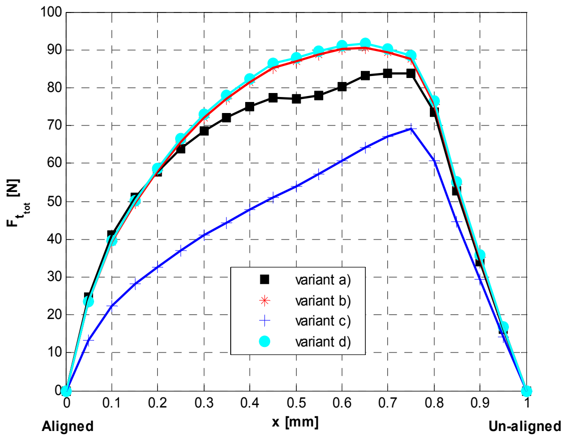


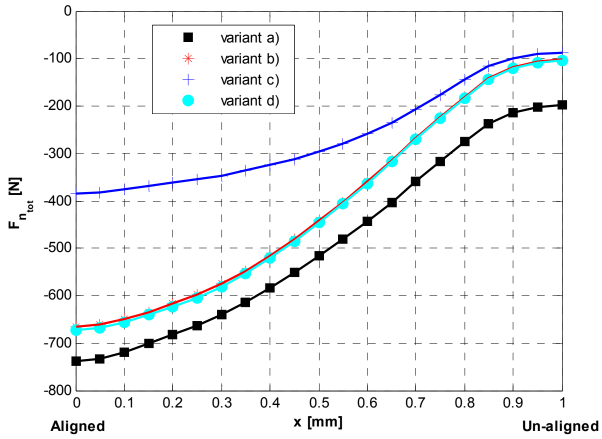
d)

Figure 6. The color map of the magnetic flux density obtained via field computations for the four linear motor structures

To more emphasize the differences between the four linear machine structures in study the static characteristics were plotted upon the results of the field computations. The tangential force (thrust) vs. displacement and the normal force (the attractive force between the two armatures) vs. displacement are given in Fig. 7.



a) tangential force (thrust) vs. displacement



b) normal (attractive) force vs. displacement

Figure 7. The static characteristics

As it can be seen the initial variant (named *a*) can be improved as its developed force is concerned. Both the *b* and *d* variants have higher thrust and less normal force. Variant *c*, although it has the smallest normal force, is out of the competition.

4. Conclusions

The force development capability and the force/mass (volume) ratio were selected to be the main figures in our comparison.

In order to highlight the differences between the linear machine variants in study the following table was filled out, which contains the mass of the mover, the maximum, respectively the medium tangential force generated by the motor and the medium tangential force over mass ratio.

Table 1: Main characteristics of the four linear machines in study

Item	Variant a)	Variant b)	Variant c)	Variant d)
Mass, m, [kg]	1.95	1.19	0.85	2.12
Maximum tangential force, $F_{t_{\max}}$, [N]	83.91	90.63	82.78	69.06
Mean tangential force $F_{t_{mean}}$, [N]	56.86	60.31	51.22	39.93
$F_{t_{mean}}/m$, [N/kg]	29.16	50.68	60.25	18.83

Variants *a* and *b* have both the maximum and the mean tangential force, and their normal force is near the smallest from the four linear machines in study. But these two variants, having similar static characteristics, have a very important difference: variant *b* do not have permanent magnets. Its mover is relatively light; hence it has far the greatest $F_{t_{mean}}/m$ ratio from the three variants having good force development capabilities.

Therefore finally it can be concluded that the best linear machine structure of this category is clearly the linear switched reluctance machine (variant *b* in our study). It is cheap due to lack of permanent magnet, but it has the same force development capability as its permanent magnet counterpart.

References

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