Design of a Linear Transverse Flux Actuator for Fast Positioning

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***Abstract* — Transverse flux motors feature high force densities and hence compact designs. Unfortunately, their complex three-dimensional geometries hamper industrial series production. This is especially true when the machine's dimensions are very small. The numerical computation of a linear transverse flux actuator, which is simultaneously compact and manufacturable, is presented here. The use of powdered soft magnetic composites is appropriate for this application. The finite element method is used to calculate the forces, the inductance and the back-emf. The actuator is designed for high dynamic and accurate positioning.**

Linear Transverse Flux Actuator

When compared to other machine types, transverse flux machines feature high achievable force densities up to 4 N/cm^2 and even more, because the coil flux is linked to all the mover poles [1]. Figure 1 shows a linear transverse flux actuator. The mover comprises three high energy NdFeB-magnets magnetised in the direction of motion and two ferromagnetic connections representing the mover poles (Fig. 2).

Powdered soft magnetic composites are particularly appropriate for this application, because the use of permanent magnets enlarges the airgap magnetically and hence reduces the relative importance of the material's permeability [2]. Furthermore, the stator comprises two components of the same geometry, which are easily formed in a die followed by a sintering process. This permits industrial series production, even when the dimensions are very small.

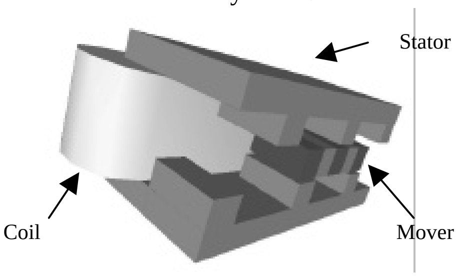


Fig. 1: Linear transverse flux actuator.

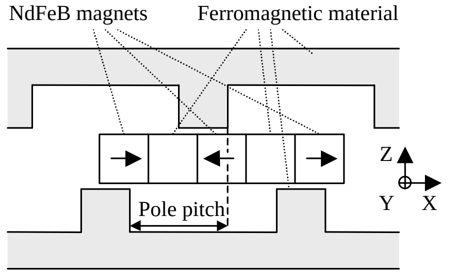


Fig. 2: Basic geometry of the transverse flux actuator.

Fundamental Behaviour

The analysis of this actuator requires a 3D-approach, due to the complexity of the flux patterns. The total force F_{tot} is the sum of a reluctance force F_{rel} and a force originating from the current in the coil, called the net force F_{net}. The y-component of the force is not considered here, as it remains small relative to the others. The fundamental behaviour of this device is studied by the finite element method. The 3D mesh, obtained by applying solid modelling, is strongly refined close to the teeth and the mover in order to obtain an accurate field solution around the mover. The forces are determined from this solution by further improving the accuracy of the local field solution around the mover, using a local analytical approximation of the Laplace equation [3]. The position-dependency of the surface force density components, for a constant current in the coil, is plotted in Fig. 3. The position is expressed in terms of the number of pole pitches (Fig. 2).

Double Motor Requirement

It is impossible to generate a constant driving force in the direction of motion because zero-force positions appear along the trajectory. Moreover, holding the mover in a fixed position requires a constant current in the coil to compensate for the reluctance force. This yields very low efficiencies. These problems are solved by joining a second, identical actuator to the construction to form a double arrangement. Both movers are connected by a non-ferromagnetic material. The second actuator is shifted relatively to the first motor over a distance of half a pole pitch, in order to obtain an approximately constant resulting net force in the direction of motion when both coils are driven by the same current.

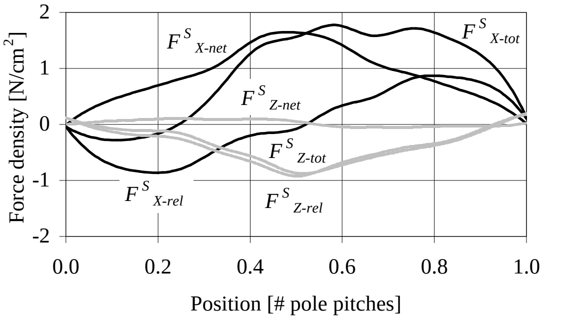
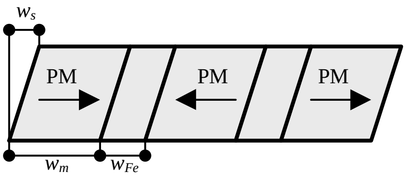


Fig. 3: Position dependency of the x and z-component of the surface force density, for the geometry of figure 2.



$$f_S = \frac{w_S}{w_m} \qquad f_{Fe} = \frac{w_{Fe}}{w_m}$$

Fig. 4: Physical meaning of the skewing ratio f_S and the iron-magnet ratio f_{Fe}.

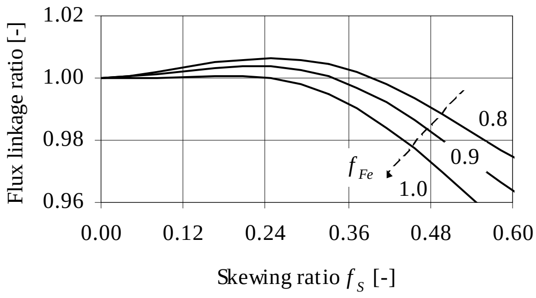


Fig. 5: Flux linkage dependency on the skewing ratio f_S and the iron-magnet ratio f_{Fe}..

OPTIMISATION OF THE FORCE CHARACTERISTICS

For optimising the shape of the force characteristics The skewing ratio f_S and the iron-magnet ratio f_{Fe} are introduced (Fig. 4). The effect of both parameters is expressed in terms of the flux linkage ratio ξ

$$\xi(f_S, f_{Fe}) = \frac{\left. \int_0^\tau F_{X-net}\, dx \right|_{f_S\,;\,f_{Fe}}}{\left. \int_0^\tau F_{X-net}\, dx \right|_{f_S=0\,;\,f_{Fe}}} \quad , \tag{1}$$

and is plotted in Fig. 5. Values for ξ larger than unity are possible because the dimensions of the stator poles are not altered when the iron-magnet ratio f_{Fe} is decreased. It is possible to obtain still higher flux linkages. To avoid a drop of the flux linkage if higher currents have to be applied, some margin is retained and both parameters are derived from the present optimum in Fig. 9: $f_S = 0.3$ and $f_{Fe} = 0.8$. The optimised characteristics are compared with the previous characteristics in Fig. 10.

DYNAMIC SIMULATION

Besides the optimisation of the force characteristics, the 3D finite element calculations are also used to determine the inductance and the back-emf. The position dependency of the inductance is very small, due to the use of permanent magnets, having a permeability of approximately unity. It is shown that the back-emf is computed numerically as follows:

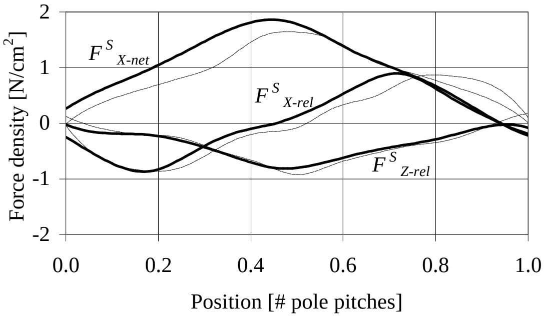


Fig. 6: Position dependency of the x-components of the surface force density, for the optimised geometry (bold line) and for the geometry of figure 2.

$$e_{bemf} = 2\frac{F_{net}\, v}{i} \tag{2}$$

in which v is the speed of the mover and i the current in the coil. The speed is obtained by solving the mechanic equation of motion with F_{net} as input. As a result, all required parameters are known to allow for a dynamic simulation of the behaviour including the PWM-control scheme.

CONCLUSIONS

The numerical analysis of a linear transverse flux actuator is presented. Powdered soft magnetic composite materials are particularly interesting for this type of application. The forces, the inductance and the back-emf are calculated by the finite element method, using a 3D mesh constructed with solid modelling techniques. To avoid zero-force positions, a second actuator is joined and shifted relatively to the first one. It is shown that the obtainable net force can be increased by combining the effect of skewing and iron width adaptation. The dynamical behaviour of the actuator is simulated by coupling the electromagnetic system to the mechanical equation of motion, by applying the back-emf formula.

ACKNOWLEDGEMENT

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