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DYNAMIC SIMULATION OF A TRANSVERSAL FLUX OSCILLATING MOTOR

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Abstract - The paper proposes a new type of transversal flux motor – transversal flux oscillating motor. The dynamic simulation of a prototype of this kind of motor is presented in order to demonstrate that the transversal flux linear motor is able to operate like an oscillating motor. This simulation allows to draw a lot of conclusions that are very useful for the command system of this motor. Experimental tests have been made, which validate the correctness of the dynamic simulation. The results of the paper show very clear the possibility of using of Transversal Flux Linear Oscillating Motor in a lot of industrial applications as: vibration testing, and vibration processing.

Index terms: transversal flux electrical machines, simulink dynamic simulation, linear oscillating motors, controlled vibrations.

1. INTRODUCTION

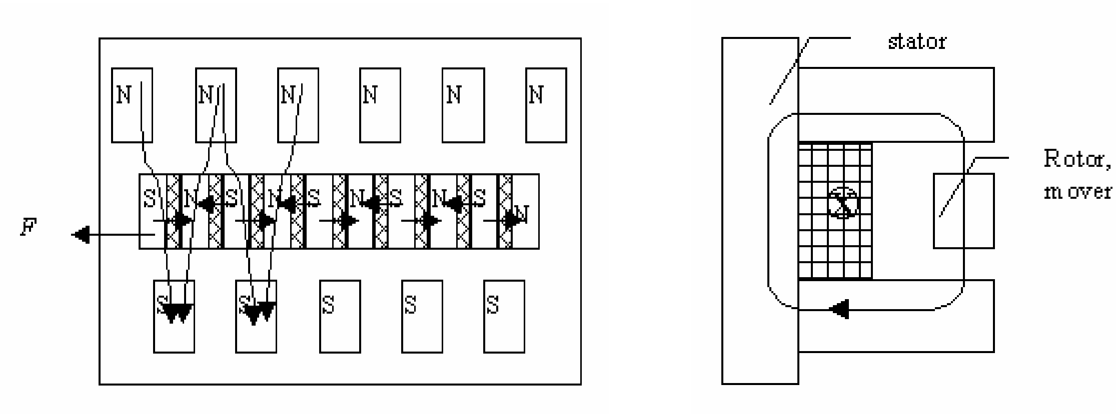
This transversal flux oscillating motor (**TFOM**) is based on the linear transverse flux (**TF**) motor. The main feature of transverse flux machine (motor or generator) is the fact that the magnetic flux in U – shape cores is perpendicular to the stator conductors and direction of motion. There are [1 – 3] two types of TF machines:

- TFE machine, with an excitation winding in stator and passive rotor, like in case of reluctance synchronous machine);
- TFM machine (Fig. 1), with a stator excitation winding and permanent magnets in rotor (active rotor), they have higher parameters than TFE motor.

In order to simulate the dynamical behavior of TFOM must be known the real position dependencies of magnetic flux and the developed force of the motor for a pole pitch (not the ideal dependencies). These dependencies have been obtained as a result of a Magnetic Field Finite Element Simulation of an existing prototype. In Fig. 1 is depicted the simplest mechanical structure of a TFM motor. It is presented only one-phase synchronous motor. For starting, usually will be used a two-phase motor.

2. TFOM DATA

Based on the FEM simulation of TFOM, force and flux dependencies have been calculated only by a pole pitch length (τ), and from these data it have been constructed the dependencies for a pair of poles (2τ length) and for negative excitation currents due to the symmetry properties. It was used the following symmetry relations:



a) *b)*

Fig. 1 Mechanical structure of a TFOM:
a) plane vue, *b)* cross-section

- $F'(I,x)=F(I,x)$ for $0<=x<=\tau$ and $I>0$;
- $F'(I,x)=-F(I,2\tau-x)$ for $x>=\tau$ and all I;
- $F'(I,x)=-F(-I, \tau-x)$ for $0<=x<\tau$ and $I<0$.

In an analog way, for fluxes we can use the relations:

- $\Phi'(I,x)= \Phi(I,x)$ for $0<=x<=\tau$ and $I>0$;
- $\Phi'(I,x)= \Phi(I,2\tau-x)$ for $x>=\tau$ and all I;
- $\Phi'(I,x)=- \Phi(-I, \tau-x)$ for $0<=x<\tau$ and $I<0$.

These dependencies are presented in Figs. 2 and 3.

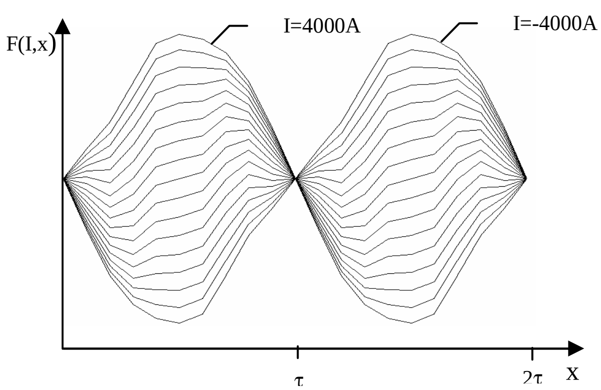


Fig. 2 The overall developed force of a TFM (reluctance and Lorentz force)

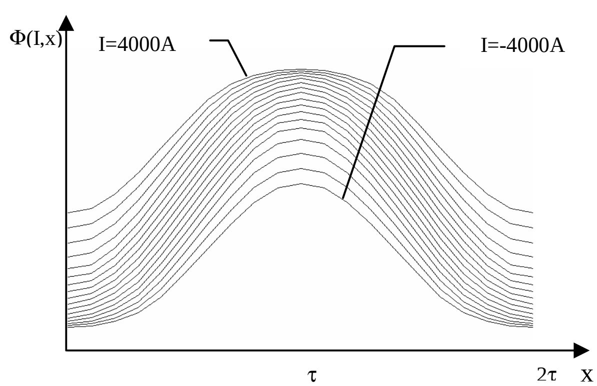


Fig. 3 Magnetic Flux dependence on moving armature position and excitation current

The force developed by TFM (Lorentz force) is sensitive to the sign of the current (unlike at TFE). The abatement from the sinus shape is due to the presence of reluctance (or cogging) force.

Another available motor data are:

- Coil resistance: 1.6 (ohms/phase);
- Mover weight: 6.66 Kg;
- Turns number: 76.

3. SIMULINK MODEL OF TFOM

The dynamic behavior of TFOM is described by two kinds of equations: mechanical and electrical equations. The electric circuit is described by voltage equation:

$$u = Ri + \frac{\partial \Psi}{\partial t} = Ri + N\frac{\partial \Phi}{\partial t}. \qquad (1)$$

The mechanical behavior is described by the moving equation:

$$f = m \cdot \ddot{x} + c\dot{x} + kx. \qquad (2)$$

It is supposed that the TFOM is supplied from a current source with square wave.
Taken in consideration the dependence:

$$\Phi(Ni, x)\ and \quad f(Ni, x), \qquad (3)$$

presented before, it was elaborated the following simulating model for TFOM. It has been used SIMULINK 4.0 from MATHWORKS Inc [9].

According with the first equations it is made a model for one phase motor, presented in Fig. 4.

In Fig. 5 is presented a second phase of TFOM which is shifted with τ/2 relative to phase 1. The current for second phase will be also shifted with T/4, but outside in the command block presented in Fig. 7.

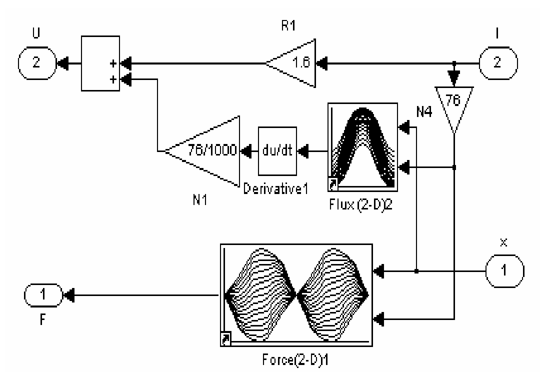


Fig. 4 The model of phase 1 of TFOM

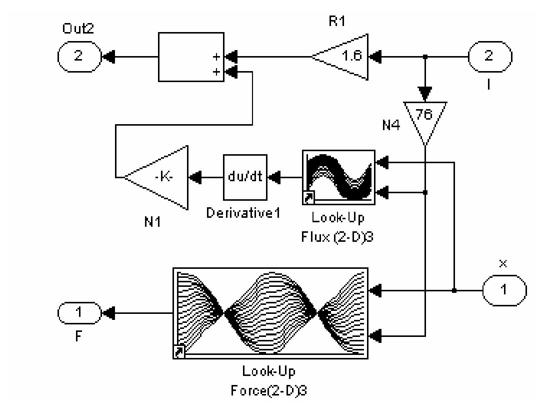


Fig. 5 The second phase model of TFOM

In Fig. 6 is presented the command model of TFOM where are synthesized the command signals as current and measured x (displacement) dependence. For the second phase, the x reference is added with x_0=10mm=τ/2, in order to delay the electric signal (I).

All these blocks are integrated in a general model, presented in figure 7, which includes measuring points and a feeding which allows us to prescribe the shape and amplitude of displacement and to reproduce it. By changing the displacement reference we can test the operation of TFOM in a lot of different conditions. Some simulation results are presented in the next chapter.

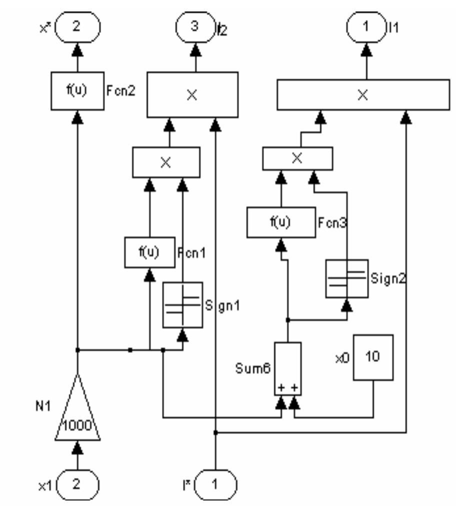


Fig. 6 The command model of TFOM

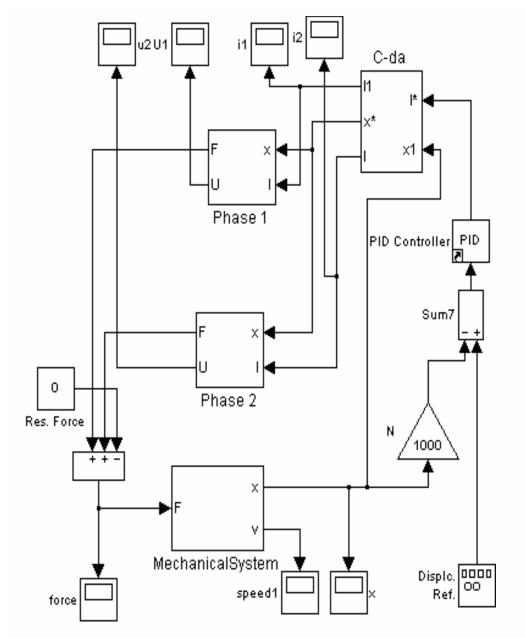


Fig. 7 Simulink model of TFOM

4. SIMULATION RESULTS

We have prescribed a vibration of 4 Hz frequency and 120mm amplitude and we have considered that *k=c=0*. In figure 8 can be seen the prescribed signal (dot-line) and the measured signal (full-line). The identity of prescribed and real displacement of sinus shape with 120mm amplitude and 4 Hz frequency obtained in the case of no springs is almost perfectly.

In Fig.9 is presented the developed force of TFOM. It can be seen the ripples caused by the currents in the two TFO stators. But these ripples don't appear in the displacement, because the moving mass acts as an mechanical filter.

In figure 10 is presented the current shape of a TFOM phase. It can be seen the lack of commutation when the displacement has a maximum value.

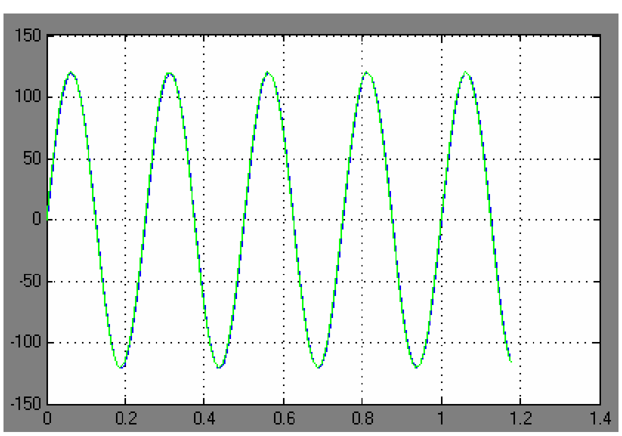


Fig. 8 The displacement (measured-full line and prescribed dot-line)

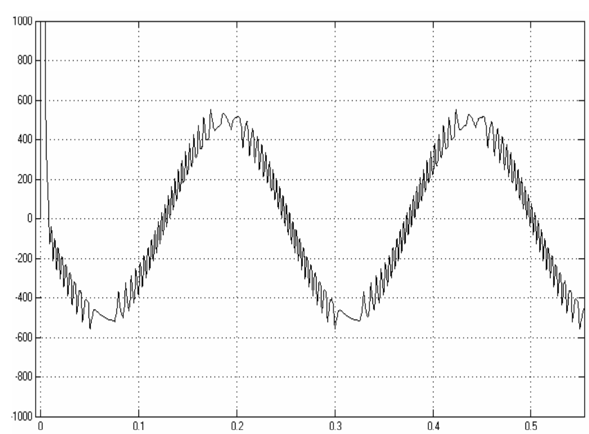


Fig. 9 The developed force of TFOM

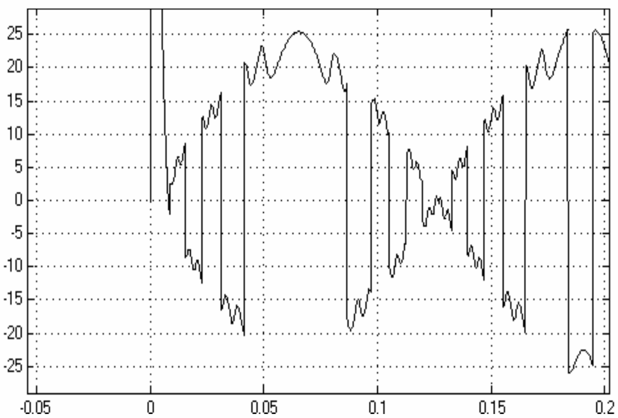


Fig. 10 The current shape of a phase of TFOM

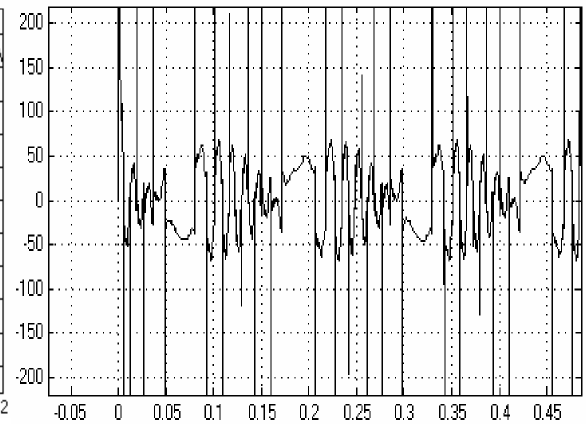


Fig. 11 The voltage shape of a TFOM phase

In Fig. 11 can be seen the shape of voltage of one phase of TFOM and in Fig. 12 is presented the shape of a force developed by a single phase of a TFOM with sinusoidal reference. Because the current is imposed, the phase voltage will have a lot of harmonics. These voltage peaks can become dangerous for the supplying converter, but this is provided with snubbing circuit (protective). This type of supplying, with current imposed, implies the presence of a close loop after current, and is very often used in practice.

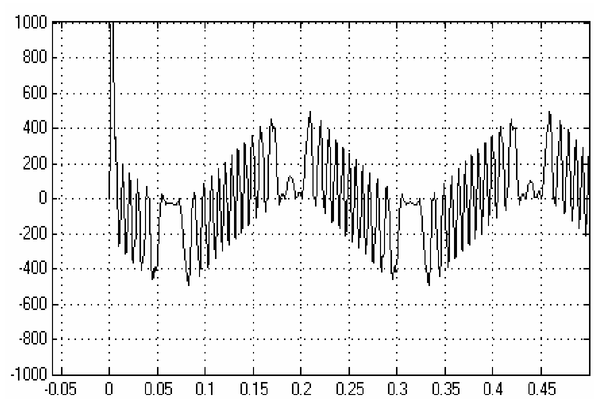


Fig. 12 The developed force by a single phase of TFOM

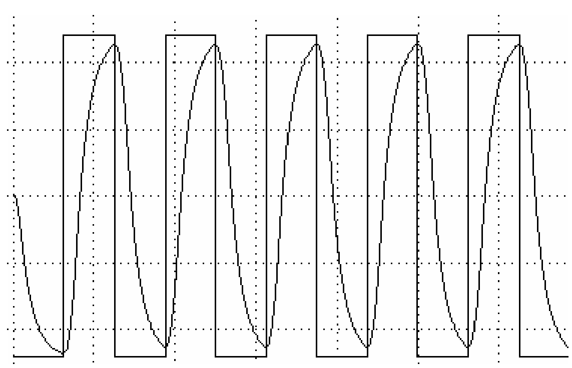


Fig. 13 The displacement in the case of square shape prescription

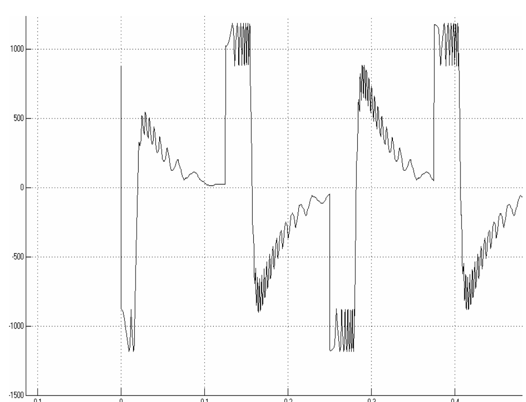


Fig. 14 The overall developed force in the case of square reference

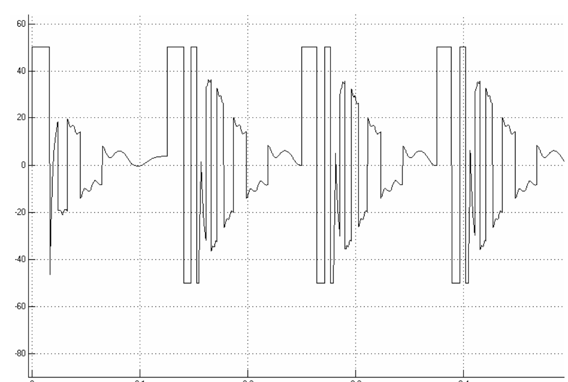


Fig. 15 The current shape in the case of square reference

Now we will study what it happens when the shape of reference displacement is changed. For the beginning let's try the square shape (Fig. 13), and the same parameters (120mm, 4 Hz). The developed force in this case is shown as in Fig. 14 and the current shape in figure 15.

It is interesting to see the response in the case of saw-tooth shape of reference (Fig. 16). It can be seen that the TFOM cannot follow the reference with high slope, like in the case of square shape reference. Because of this fact, the vibrations are unsymmetrical.

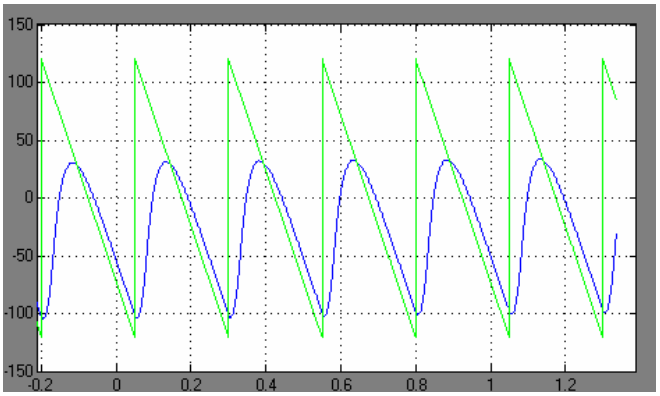


Fig. 16 Saw-tooth shape of reference (displacement)

5. CONCLUSIONS

The simulation results obtained in different situations allows drawing a lot of useful conclusions.

This Transverse Flux Oscillating Motor (**TFOM**) can operate very well without springs, but only in the presence of a close-loop (feeding) after vibration displacement. All the tentative to put TFOM in vibrating operation as an open system without springs fell down. This fact can be explained because the feeding loop works as a spring: $f - Kx = ma$, where K is the regulator proportional constant (feeding loop gain).

This model has real parameters, so the electronic engineers can use it for dimensioning of its command circuit. The model has also a didactical importance, allowing the understanding the operation principle of this kind of oscillating motor. But this model demonstrate the possibility of industrial using of this kind of linear motor as an oscillating motor (TFOM) and hence results a lot of industrial application.

The model is realized in SIMULINK 4.0 (from MATLAB 6.0) and can be developed further to have other facilities.

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