Design of a Stepper Transducer with Ferroliquid

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Abstract **This paper presents a new conceptual project of a transducer using a magnetic fluid and thereby achieves a relatively high performance. Due to magnetic properties of used liquids, resulting forces increase several times.**

Keywords **Actuators, Transducers, Ferroliquids**

I. INTRODUCTION

Modern electrical and mechanical engineering industry often uses an electromechanical converter in their products, these converters are often called as transducers, or actuators. Designers have a wide range of transducers at their disposal nowadays, with various static and dynamic properties based on different physical principles (see eg. [1], [2], [3], [4]). Common requirements imposed on all transducers are, among other things, a low weight, small dimensions and a high performance. A new type of a magnetic fluids using transducer possess all these properties. This work is devoted to this type of transducer.

II. PRINCIPLES OF A STEPPER TRANSDUCER WITH FERROLIQUID

The mechanical force of a transducer is usually caused by direct or alternating magnetic field acting on the moving part. This part consists of an iron armature, or coil powered by the electric current. The armature, resp. the coil is a part of the magnetic circuit that can perform motion - linear or rotary. This represents a mechanical output of a transducer. The magnitude of this force depends on the magnetic induction ; it obviously increases with the decrease of the reluctance of the passing magnetic flux. The main idea of the new transducer lies in the fact that the air gap needed in the magnetic circuit is replaced with the magnetic fluid.

III. STEPPER TRANSDUCER WITH FERROLIQUID AND ITS MATHEMATICAL MODEL

Both movable and fixed parts of the transducer are provided with slots. If the magnetic field $\boldsymbol{B_1}$ acts on those parts, a force $\boldsymbol{F}$ will operate between the two parts. This force has a tangentional component F_1 and a normal component F_2, as can be seen on Fig. 1. The movable part will move, but only to the "tooth-to-tooth" position. In this position, the force F_1 disappears, while the force F_2 reaches its maximum, Fig. 1b. Next slide step is achieved by canceling the magnetic field $\boldsymbol{B_1}$ and starting a magnetic induction $\boldsymbol{B_2}$ in other parts of the identical transducer, which is associated with the previous parts, but shifted by half the tooth pitch, Fig. 1c. The whole process is repeated.

Other way to achieve the stepper movement of the transducer movable part in one direction is the use of a mechanical part, i.e. spring with ratchet or bolt.

The force F_2 has no effect on the output force of the transducer but can be unsettling. In order to remove this force F_2, a pair of described systems is symmetrically connected.

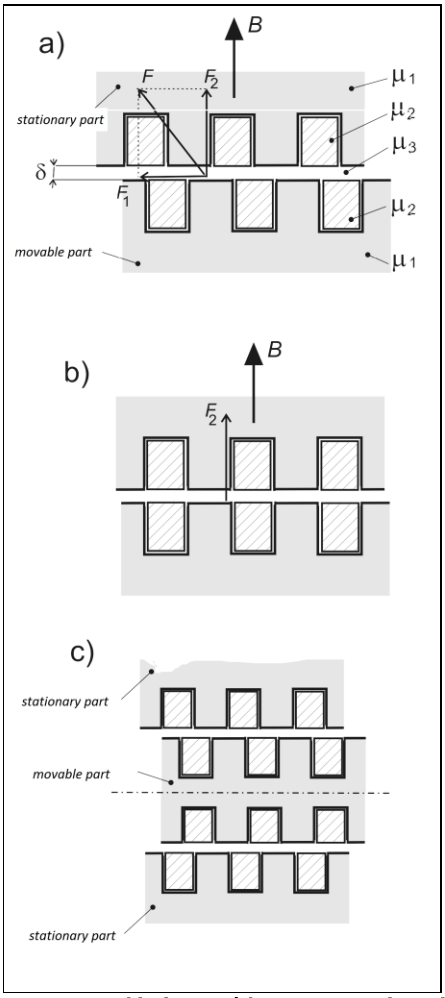

Fig. 1. Possible design of the stepper transducer driver

The mathematical model of this transducer will be discussed only briefly due to the limited scope of this article. We use axial coordinates (x, y), then specify the definition area, then introduce the boundary conditions and solve the equation for $\boldsymbol{A}$:

$$\mathrm{rot}\,\frac{1}{\mu}\,\mathrm{rot}\,\boldsymbol{A} = \boldsymbol{J} \tag{1}$$

The magnetic induction is then determined from the relationship $\boldsymbol{B}$ = rot $\boldsymbol{A}$. The force is counted from the relationship (from the well-known Maxwell stress tensor):

$$F_m = \frac{1}{2} \oint_S [H(nB) + B(nH) - n(HB)] dS \quad (2)$$

Alternatively, the strength of F_2 can be determined with the help of energy of the magnetic field, or using formulas of Lorenz-Korteweg-Helmholtz.

IV. Study of Forces in the Stepper Transducer

Static characteristics of the proposed stepper actuator is the dependence $F_1 = F_1(x)$. It features following parameters:

- Geometrical dimensions of teeth and the air gap, incl. shape of teeth.
- Permeability: $\mu_{r1} \rightarrow \infty$, μ_{r2} (for example $\mu_{r2} = 1$) and μ_{r3} (magnetic fluid, for example $\mu_{r3} = 2$ to 10).
- Magnetic induction $\boldsymbol{B}$.

A number of numerically simulated experiments were calculated, using mathematical model of a transducer mentioned on Fig. 1a and 1b. On the next figure, resulting static characteristics obtained by the numerical simulation of the stepper transducer can be seen. A ferrofluid with relative permeability of μ_r=4 was used to fill its gasp. Another simulation was made using an air gasp and results were compared.

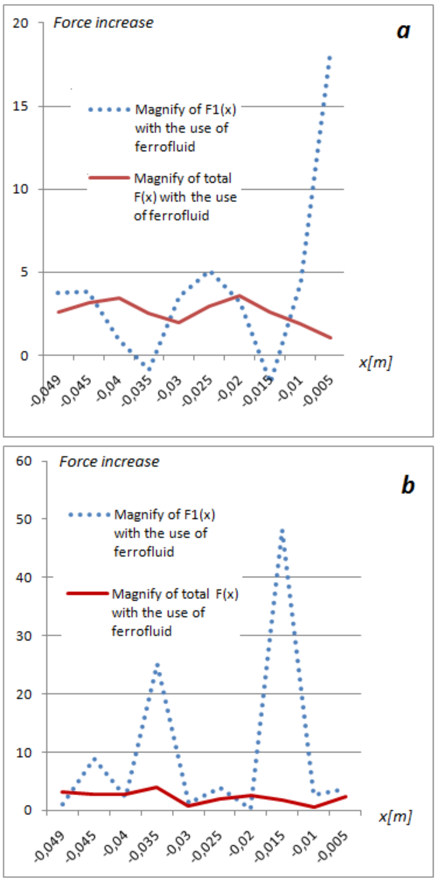

Fig. 2. Static characteristics of forces generated by 3-teeth stepper transducer in different positioning, resulting forces are in ratio to the forces generated by the same transducer without the use of ferrofluid in its gasp. Thickness of the gasp is a) 2mm; b) 0.2mm.

As we can see on Fig. 2. , total generated force increases due to the improvement of the magnetic circuit and is comparable to the increase of the used material permeability as was expected. Another important and very interesting information is the increase of the force in the direction of the movement. While using a magnetic liquid, we obtain different permeability in different parts of the transducer. The direction of resulting forces changes with these permeabilities, this can be deduced from (2) or from other mentioned ways of determining electromagnetic forces. The best way to notify this is perhaps from Lorentz-Korteweg-Helmholtz formula [5,6]:

$$f_m = J \times B - \frac{1}{2} H^2 \operatorname{grad} \mu \quad (3)$$

According to this theory, the volume density of force depends among other things on the change of the material properties. This theory clearly explains the changes in the forces direction while using different materials in the driver gap.

V. Conclusion, Other Development Works

We have shown that filling the air gap with a magnetic fluid greatly increases the performance of a transducer. This confirms the correctness of our project. In the next stage of our development there are several needs:

- Optimization of the transducer design with the aid of the numerical optimization methods; the criteria function is F_1.
- Transducer design, including sealing air gap filled with the magnetic fluid.
- Transducer dynamical analysis, with respect to the flow of the magnetic fluid.

Resulting total force increases several times due to the improvement of the magnetic circuit, this number is comparable to the relative permeability of the used fluid. Forces in the direction of the movement can be increased even more with a proper arrangement of the device and magnetic properties of its parts.

VI. Acknowledgements

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VII. References

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