THE COMPARATIVE ANALYSIS OF CHARACTERISTICS OF COMPENSATING CONVERTERS OF MICROMECHANICAL INERTIAL SENSORS

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I. INTRODUCTION

Microminiature electromechanical inertial sensors are created with electrostatic converters which possess high adaptability to manufacture. As a rule, created micromechanical sensors represent a multilayered design (glass, metal films and plates of monocrystal silicon).

II. PROBLEM AREA

The carried out researches have shown that electrostatic elements (position sensor and compensating converter) of micromechanical sensors possess a number of features which essentially influence upon the characteristics of devices: small value of reproduced force, nonlinear dependence between force and the impressed voltage, nonlinearity of conversion function depending on depth of modulation of a capacity backlash. Besides, use of such compensating converters makes stability of comparison voltage requirements and electronic part of sensors requirements. As if compensating converters have small sizes then their capacity is comparable to isolating capacity and capacity of conductors.

Noted circumstances make negative impact on characteristics of micromechanical inertial sensors and lead to search of new decisions within the limits of technologies of micromechanics. [1]

Electromagnetic converters of force on the basis of force of Ampere (Fig. 1) and with use of a ferromagnetic layer (a Fig. 2) are new alternative to classical electrostatic compensating converters (Fig. 3). These three schemes have been considered and their comparison is brought in this paper.

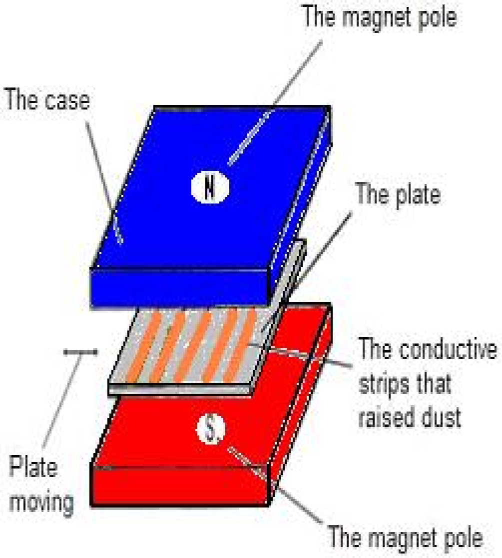

Fig. 1 Electromagnetic compensating converter on the basis of force of Ampere

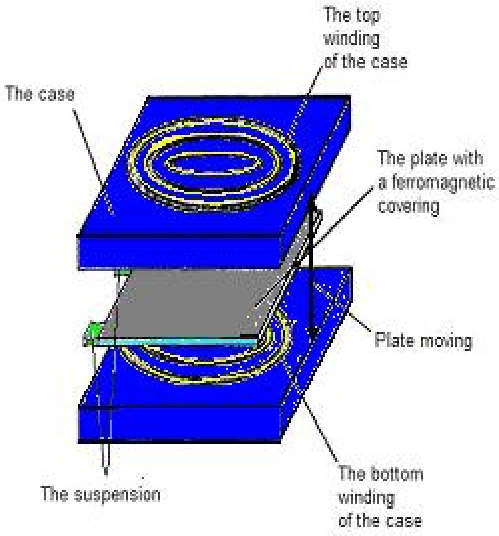

Fig. 2. Electromagnetic compensating converter of forces with use of a ferromagnetic layer

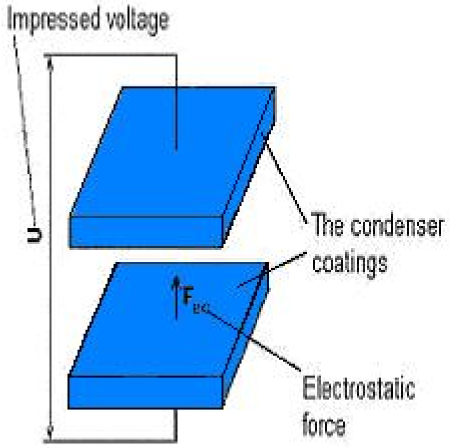

Fig. 3. Electrostatic compensating converter

III. ELECTROMAGNETIC COMPENSATING CONVERTER ON THE BASIS OF FORCE OF AMPERE

Let's consider in more details the scheme of electromagnetic compensating converter on the basis of force of the Ampere (Fig. 1). Let the size of a plate is 5mm×5mm (b_0 – width, l – length of a plate), a thickness of the raised dust layer of copper is 10 micron. Copper is raised dust by strips of some width b with backlashes between them Δ =10 microns (the size of a backlash is chosen from technological reasons). Depending on number of strips n their width is defined under the formula

$$b = \frac{b_0 - (n-1)\cdot\Delta}{n}.$$

Dependence of width of a strip on number of strips is presented in Fig. 4.

A melting current of a conductive strip equal [2]

$$I_m = \frac{\sqrt{\frac{4\cdot b\cdot\Delta}{\pi}}\cdot 10^3 - 0.005}{0.034}.$$

Dependence of melting current of a strip on number of strips is presented in a Fig. 5.

If a strips of a conductor layer are dusted both sides of a plate, then submitting on each strip a current making 75 % from a melting current, it is possible to reach values of force of Ampere equal

$$F = 0.75\cdot I_{пл}\cdot B\cdot 2\cdot n\cdot l\,,$$

B – the induction of a magnetic field created in a backlash (let B=0.1 T). Dependence of force of Ampere on number of strips is presented in a Fig.6.

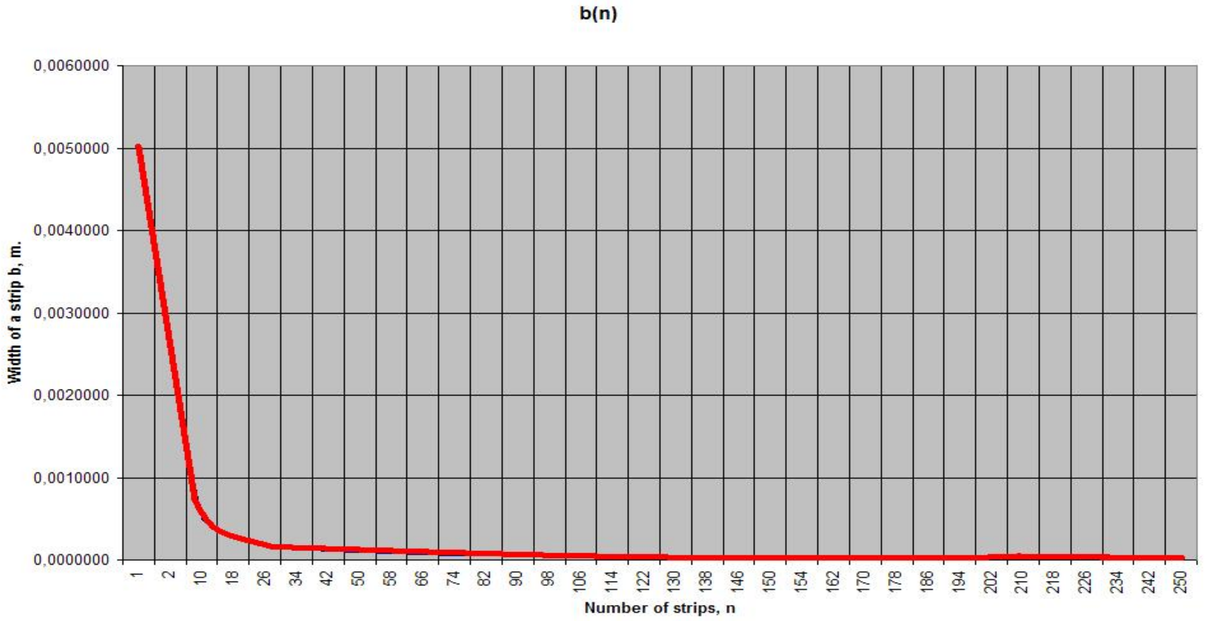

Fig. 4. Dependence of width of a strip on number of strips

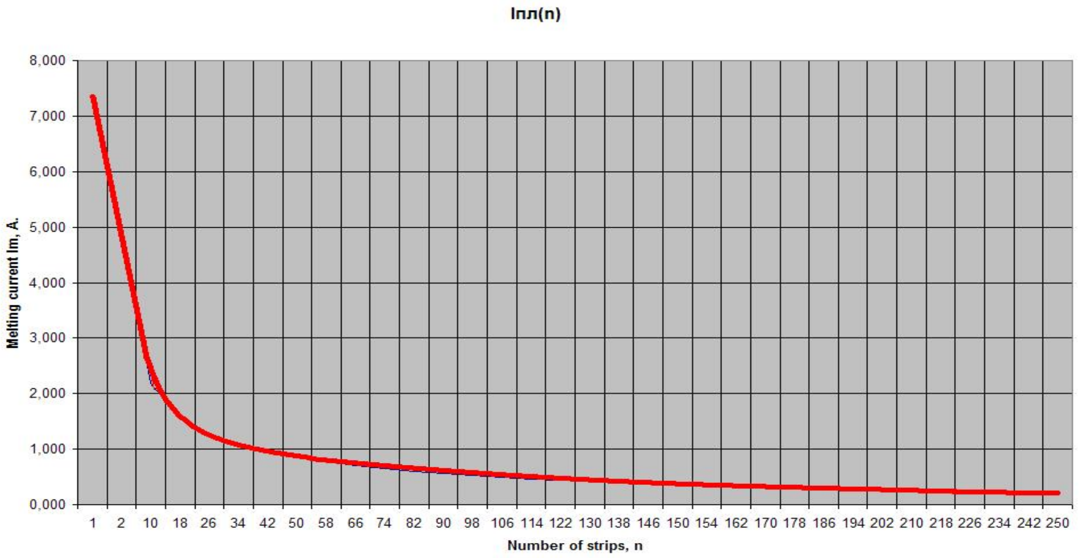

Fig. 5. Dependence of melting current of a strip on number of strips

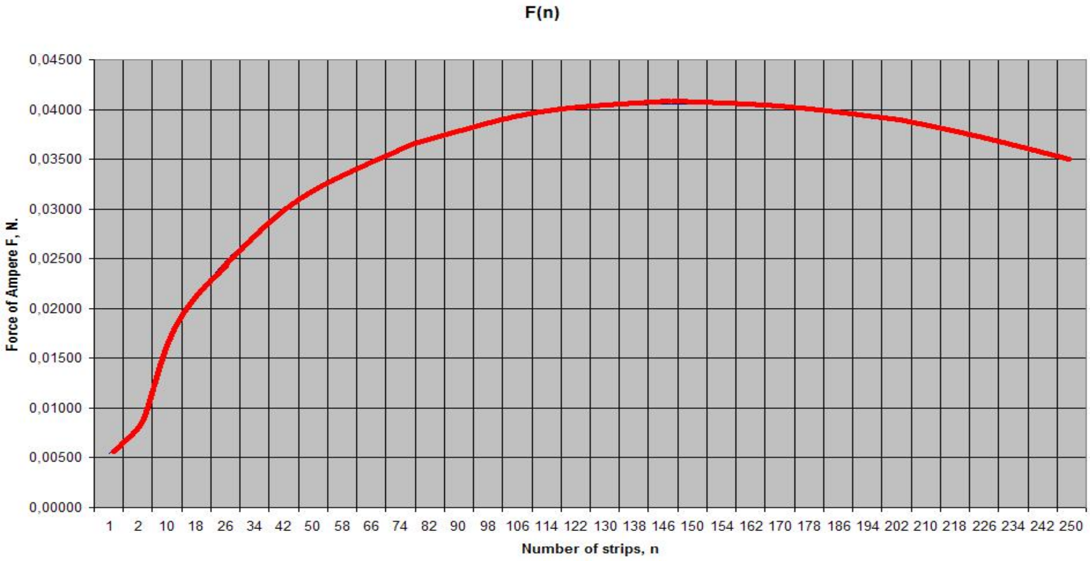

Fig. 6. Dependence of force of Ampere on number of strips

Table 1.

The calculations for electromagnetic compensating converter on the basis of force of Ampere

Number of strips, *n*	Width of a strip *b*, *m*	Melting current *Im, A*	Force of Ampere *F, N*
1	0.0050000	7.274	0.00546
26	0.0001827	1.271	0.02479
58	0.0000764	0.770	0.03350
74	0.0000577	0.650	0.03608
90	0.0000457	0.562	0.03795
122	0.0000311	0.438	0.04007
138	0.0000263	0.391	0.04049
150	0.0000234	0.361	0.04057
154	0.0000225	0.351	0.04055
178	0.0000181	0.300	0.04005
194	0.0000158	0.270	0.03935
210	0.0000139	0.244	0.03837
234	0.0000114	0.207	0.03641
250	0.0000100	0.185	0.03478

In case of a dusting of strips one side force will be equal

$$F = 0.75 \cdot I_{пл} \cdot B \cdot n \cdot l .$$

In Table 1 values b, I_m and F for various number of spending strips on a plate are presented.

Thus the dusting of 150 strips in width 23.4 microns on a plate is optimum. Total force of Ampere makes 0.0406 N.

IV. ELECTROMAGNETIC COMPENSATING CONVERTER FORCES WITH USE OF A FERROMAGNETIC LAYER

Let's consider the scheme presented in a Fig. 2. The magnetic field is created by the flat inductor with N coils in which the current I flows, and a backlash between them is Z. We consider the coil like set of N circular contours with a current in radiuses $n*z/2$, n – a contour serial number from the centre. We neglect thickness of a wire. Then the magnetic induction of all flat inductor in a point on an axis which is passing through the centre of a circle, on distance r from it is equal

$$B = \frac{\mu 0 \cdot z^2 \cdot I}{8} \cdot \sum_{n=1}^{N} \frac{n^2}{\left(\left(\frac{n \cdot z}{2} \right)^2 + r^2 \right)^{\frac{3}{2}}} ,$$

μ_0 – magnetic permeability of environment, I – current flowing in the coil.

Greatest possible current which the conductor layer will not begin melting decreases with increase in number of coils at a plate. Dependences of width of strips and a melting current on quantity of coils are similar specified in Fig. 4. and Fig. 5. The quantity of coils providing maximum induction B(T) of the created magnetic field in distance r from a plate along the normal to the surface line passing through the its middle, is defined taking into account melting current. Dependence of an induction on number of coils is specified in a Fig. 7.

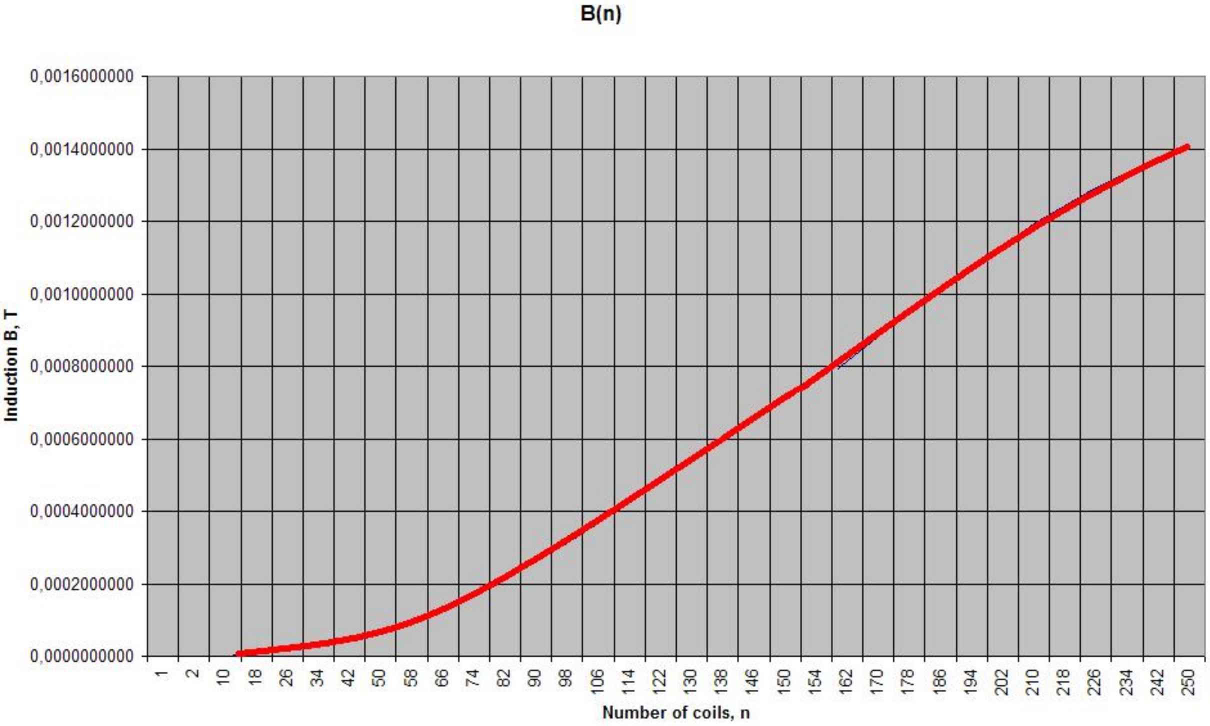

Fig. 7. Dependence of an induction on number of coils

Calculations of forces of electromagnetic compensating converter with use of a ferromagnetic layer are resulted in Tab. 2.

So, the maximum of induction is provided with the greatest possible number of coils (250).

Force F is defined as

$$F = \frac{\partial A}{\partial r} ,$$

A – work on plate moving on distance r.

$$A = p_m \cdot B ,$$

p_m – the magnetic moment created by a ferromagnetic layer, when it enter into an external magnetic field

$$p_m = J \cdot V ,$$

J – magnetisation of ferromagnetic layer, V – its volume.

$$J = \chi \cdot \mu_0 \cdot H \approx \mu \cdot B,$$

when $\mu \rhd\rhd 1$, $\chi = \mu - 1$ – magnetic susceptibility of ferromagnetic layer. [5]

Table 2.
Calculations for electromagnetic compensating converter forces with use of a ferromagnetic layer

Number of coils, *n*	Width of a layer, *b, m*	Melting current, *Im, A*	Induction *B, T*
1	0.0050000	7.274	0.0000000143
26	0.0001827	1.271	0,0000154200
58	0.0000764	0.770	0,0000990848
90	0.0000457	0.562	0,0002606607
122	0.0000311	0.438	0,0004858435
150	0.0000234	0.361	0,0007140991
178	0.0000181	0.300	0,0009467060
186	0.0000169	0.285	0,0010115706
194	0.0000158	0.270	0,0010718680
202	0.0000148	0.257	0,0011342636
210	0.0000139	0.244	0,0011914983
218	0.0000130	0.231	0,0012424856
226	0.0000122	0.219	0,0012915802
242	0.0000107	0.196	0,0013734059
250	0.0000100	0.185	0,0014088112

So

$$F = \frac{3 \cdot \mu \cdot \mu_0 \cdot B \cdot V \cdot z^2 \cdot I \cdot r}{8} \cdot \sum_{n=1}^{N} \frac{n^2}{\left(\frac{n \cdot z}{2} + r^2 \right)^{\frac{5}{2}}}$$

and taking into account initial data value of force makes

F=1.76*10^{-12} *N*.

V. ELECTROSTATIC COMPENSATING CONVERTER

Here you can see comparative calculation of the electrostatic converter which plates have the same sizes (5mm×5mm) and thickness is 200 microns, a backlash between plates δ =0.1 mm.

If voltage between plates of condenser is U=30 V (it is necessary to consider, that in case of the electromagnetic converter voltage will be much less) value of electrostatic force will reach

$$F = \frac{U^2 \cdot \xi \cdot S}{(2 \cdot \delta)^2} = 1.1 \cdot 10^{-5} H ,$$

ξ – dielectric permeability of environment, S – area of a plate.

The forces arising in electromagnetic compensating converter on the basis of force of Ampere thousand times more than electrostatic forces, and voltage much less.

VI. CONCLUSION

Thus, the comparative analysis shows that realisation in micromechanical compensating converters a magnetoelectric principles of transformation allows to create power characteristics approximately in 3690 times exceeding characteristics of electrostatic converters. Therefore creation such compensating converters gives possibility (taking into account some complication of the technology) expand essentially a range of measurements and minimise an error of sensors.

REFERENCES

[1] Tirtichny A.A. Modern sensors of control and navigation systems. Scientific session of SUAI. Part 1. 2007.

[2] Tempner I.Y., Osherov V.E The directory of the radio fan. Kiev.

[3] Vonsovskiy S.V., Shur Y.S. Ferromagnetism. Moscow., The state publishing house of the tehniko-theoretical literature.

[4] Levshina E.S., Novitsky P.V. Electric measurements of physical values. Leningrad, Energoatomizdat, 1983.

[5] Matveev A.N. Electricity and magnetism. Moscow, 1983