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To the calculation of the equation of measurements of a MEMS vacuum transducer

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Abstract. The article is devoted to the numerical method of calculating the vacuum transducer, created by MEMS technology and designed to measure the absolute pressure in a wide range from 10 to 10,000 Pa**.**

Measurements of low absolute pressures are the most important measurements in vacuum technology. In this regard, it is important to develop low absolute pressure measuring instruments on new principles. At VNIIM n. a. D. I. Mendeleev we works on improvement of the vacuum gauge of resonance type, created since 2015 by MEMS technology [1]. Refinement of the theoretical model using modern numerical computer technology is an significant task.

Below is a calculation of the conversion factor of MEMS vacuum gauge with a given geometric dimensions. Metrologically significant dimensions are shown in figure 1.

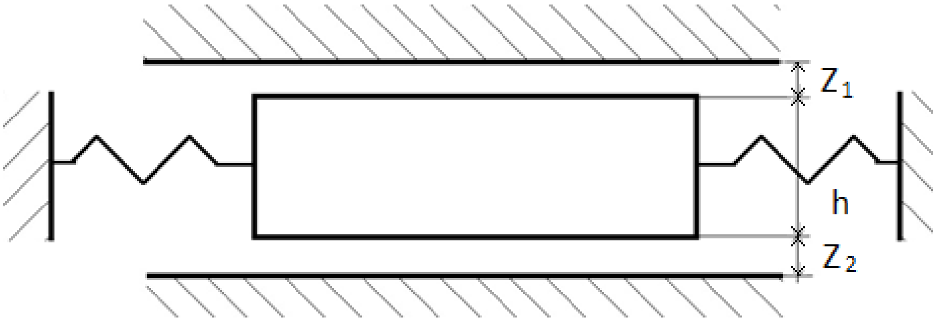

Figure 1. Metrologically significant dimensions: h – the thickness of the movable plate; Z_1 - the thickness of the gap №1; Z_2 - the thickness of the gap №2.

The following is a summary table of the numerical values of the parameters.

Table 1. Metrologically significant dimensions.

Mark	Parameter	Value
h	Plate thickness	100 μm
Z_1	Gap thickness	3 μm
Z_2	Gap thickness	3 μm
L_1	Plate length	3 mm
L_2	Plate width	3 mm

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We perform a preliminary calculation of gas leaks through the edges of air gaps at the time of changing the position of the plate during vibrations.

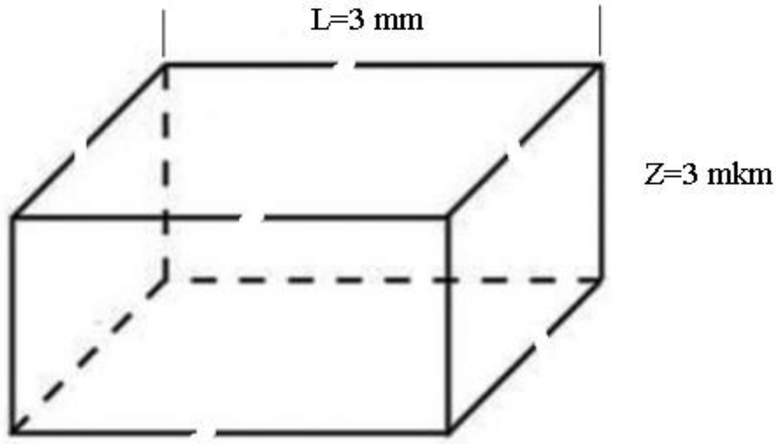

Figure 2. Air gap Z_1.

The total surface area of the parallelepiped describing the air gap:

$$St = 4 * L_1 * h + 2 * L_1 * L_2 = 4 * (3 * 10^{-3} * 3 * 10^{-6}) + 2 * (3 * 10^{-3} * 3 * 10^{-3}) = 1{,}9 * 10^{-5}\ m^2$$

Total area of the side faces of the air gap:

$$Ss = 4 * L_1 * h = 4 * (3 * 10^{-3} * 3 * 10^{-6}) = 36 * 10^{-9}\ m^2$$

The ratio of the area of the side faces to the total area is total 0,2 %.

When moving the moving plate at a relative small cross-section of air gaps (0,2 %), small amplitudes of motion and frequency of 100 Hz or more, the expiration of the gas from or flowing into the gaps Z_1 and Z_2can be neglected. Thus, the number of gas molecules in the gap during the time equal to the period of oscillation can be considered constant.

According to the Boyle-Mariotte law for the case of isothermal process, the dependence of the pressure in the gaps on the movement of the plate is expressed by the formula:

$$\mathrm{P} * \mathrm{V} = \mathrm{const}$$

$$\mathrm{P}_1(dZ) = \mathrm{P} * \frac{\mathrm{Z}_1}{\mathrm{Z}_1 + \mathrm{dZ}}$$

$$\mathrm{P}_2(\mathrm{dZ}) = \mathrm{P} * \frac{\mathrm{Z}_2}{\mathrm{Z}_2 - \mathrm{dZ}}$$

where $\mathrm{P}_1(dZ)$ и $\mathrm{P}_2(dZ)$ - the current gas pressure in the gaps in depending on the displacement of the movable plate, P - measured gas pressure.

Thus, the differential pressure and pneumatic force acts on the plate from the two gaps:

$$F_p(\mathrm{dZ}) = \left(\mathrm{P}_1(\mathrm{dZ}) - \mathrm{P}_2(dZ)\right) * \mathrm{S},$$

where S = $\mathrm{L}_1 * \mathrm{L}_2$ – area of the movable plate from the air gap.

Pneumatic stiffness of the gas spring $\mathrm{G_p}$ we find from the ratio pneumatic power $\mathrm{F_p}$ of movement dZ:

$$\mathrm{G_p} = \frac{\mathrm{F_p}}{\mathrm{dZ}}$$

From the formula of oscillations we find the cyclic frequency

$$\omega = \sqrt{\frac{G_m + G_p}{\mathrm{m}}},$$

where G_m- the mechanical stiffness of the suspension, m – the mass of the movable plate (m= $\mathrm{L}_1 * \mathrm{L}_2 * h * \rho$, the density of silicon $\rho = 2200$ kg/m^3).

The square of the resonant frequency of oscillation

$$f_p{}^2 = \frac{G_m + G_p}{4 * \pi^2 * m}$$

The results of numerical calculations for the pressure range are presented in figures 3 (dependence of the frequency of oscillations on pressure) and 4 (dependence of the square of the frequency of oscillations on pressure).

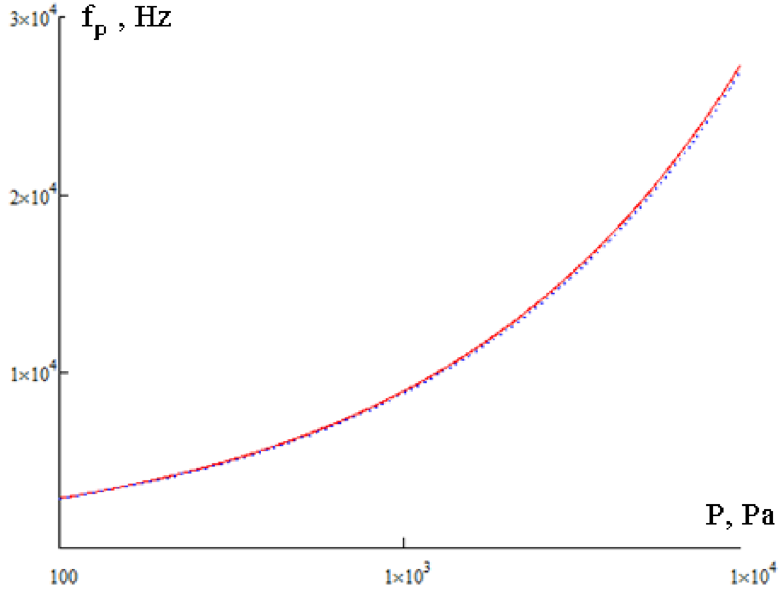

Figure 3. Frequency dependency on pressure.

In figure 3, we can see the coincidence of the results of the numerical calculation of the dependence and the calculation of the analytical formula derived in [1]:

$$P=K *(f_p{}^2 - f_{p.m.}{}^2),$$

where $f_{p.m.}$- value of resonance frequency at zero pressure. The discrepancy is about 1 %.

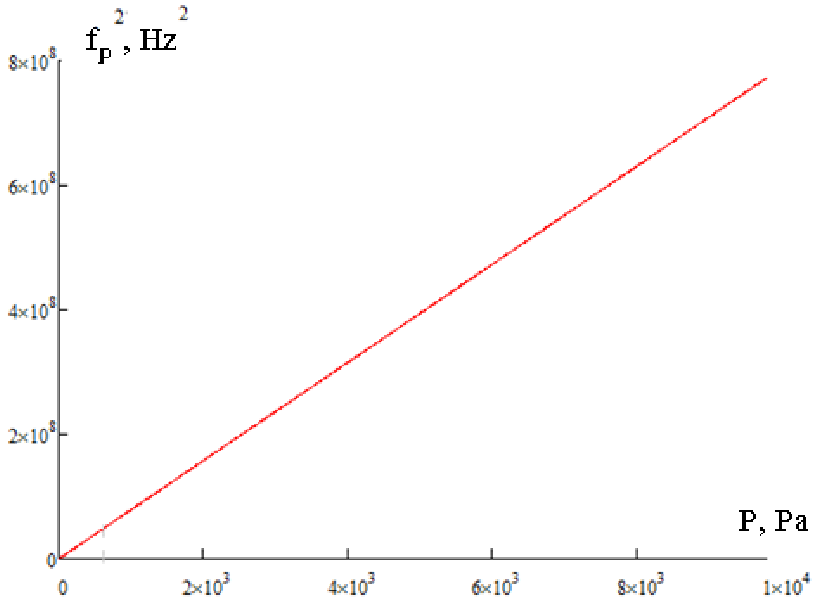

Figure 4. Frequency square dependency on pressure.

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The obtained results confirm the thesis about the high degree of linearity of the dependence of the square of the frequency on the measured pressure (figure 4).

References

[1] Gorobey V, Garshin A and Kuvandykov R 2017 *Vacuum equipment and technology - 2017. Proceedings of the 24th all-Russian scientific and technical conference with international participation*