MECHANICAL MEASUREMENTS

INERTIAL-PLASMA INSTRUMENTS WITH INPLATRONS FOR MEASURING MOVEMENT PARAMETERS

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INPLATRONS

1. We are witnessing a pronounced penetration of electronics into all the technical spheres. Completely new types of equipment, such as electronic, ionic, and photonic devices, are being developed for similar purposes parallel to the existing well-designed and widely-used mechanical, opticomechanical, and electromechanical devices, and in many instances gradually replacing the latter (at the same time competing among themselves).

These systems are perfected and adopted with great difficulties, but having attained a working condition they are always advantageous with respect to precision, sensitivity, universality of application, reliability, durability, etc. In addition to these technical advantages, an important part is played by general tendencies for a preferred development of new technical equipment and the extension of its application in view of a certain technical obsolescence of installations not yet provided with this new equipment.

The above fully applies to measurement techniques and instrument making. In particular such conditions are beginning to arise in movement parameters' measuring equipment which already incorporates atomic-nuclear and laser gyroscopes, electronic accelerometers, etc.

The accelerometers, gravity meters, tachometers, gyroscopes, and other instruments described below and based on the inertial-plasma effect belong to the same category of measuring equipment. They completely lack relatively moving and elastic mechanical components of the type of rotors, seismic masses, springs, and dampers. These instruments function on the electron-ionic level, thus providing a very high sensitivity and a possibility of setting and regulating parameters by purely electrical means. The mass and overall size of their sensing elements are very small and their basic circuit design is very simple, thus facilitating their mass production by means of the usual electronic and vacuum production methods. This equipment's electrical circuits are on the whole simple in regard to economic supplies. In many instances no amplifiers are required. It is possible to miniaturize both separate elements and instruments as a whole.

In the early designs of the author and his collaborators the gas-discharge tube which contains the sensing element and the device as a whole were called inplat (inertial-plasma transducer of accelerations) [1] and gyroplin (gyroscope based on a plasmo-inertial device) [2]. However, since it is possible in both cases to use the same tube connected to different circuits, it was found advisable to provide all the gas-discharge tubes developed for the study or practical application of the inertial-plasma effect with the name of inplatron.

Inertial-plasma Effect and the Possibility of Its Utilization for Developing Measuring Instruments. 2. The inertial-plasma effect consists of the aggregate of the subsequently-mentioned oscillatory phenomena in low-temperature plasma glow-discharges in inert gases, their mixtures, other gases, and in particular air at pressures of 10^{-2}-10^{-1} MPa and discharge currents of $i_c = 10^{-4}$-10^{-3} A. A more or less contracted gas-discharge column is then formed. The discharge gap is $L \approx 10$ mm. The tubes with a cold or heated cathode are connected to the schematic shown in Figs. 1a and b. A part of the provided experimental data was obtained with buffer voltages $U_{b1} = U_{b2} = U_b$, with each of their respective negative sides connected to one of the x-transverse electrodes and their positive sides to the circuit point A.

The experimental graphs shown below were obtained with the tubes filled with a mixture of 90% neon and 10% xenon at 67 MPa. Their typical volt-ampere characteristic is shown in Fig. 2. Tests were made mainly on the sections AB and BC [3-5].

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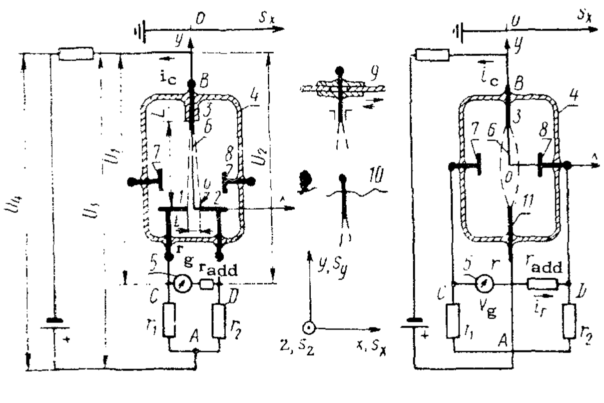


Fig. 1

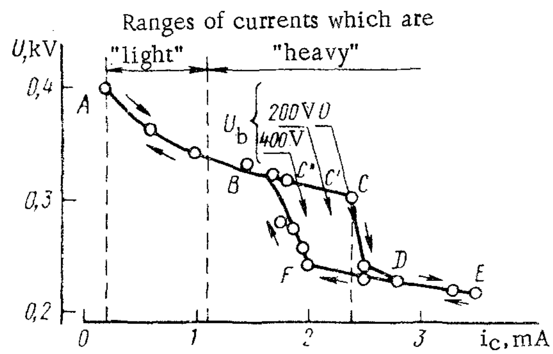


Fig. 2

Fig. 1. Schematic of the equipment: a) with the differential anodes 1 and 2; b) with the rod anode 11; 3) cathode (glazed in some of tubes); 4) bulb; 5) measuring instrument; 6) contracted discharge; 7, 8) x-transverse electrodes (in some of the tubes); cathode versions; 9) on a ground-glass seal; 10) on a membrane.

Fig. 2. Typical volt-ampere characteristic. The discharge is shown in sections: AB) diffused and contracted in the form of a wide column; BC) diffused and contracted with a filament appearing on the cathode side; DE) thin filamentary; DF) filamentary with a diffused edge. When the buffer voltages U_b (see Fig. 4) are connected to the x-transverse electrodes, the hysteresis area contracts and the point C approaches B. $U = U_1 \approx U_2$ (see Fig. 1).

In order to bring the circuit into an operating condition it is balanced up to $i_g = 0$ or $V_g = 0$ by adjusting the resistors r_1 and r_2. Rough adjustment is possible by means of a small displacement of the electrodes, if they are fixed on elastic membranes, ground-glass seals, or movable axes with an external magnetic drive. All the effects of natural electric, magnetic, and acoustical fields as well as external airflows become unnoticeably weak when the tubes are mounted in protective iron screens with a wall thickness of about 0.5 mm. In order to eliminate mechanical resonances, the internal mounting of the tubes and their fixing must be simple and stiff.

3. When the gas-discharge column of the equipment shown in Figs. 1a is affected in the x-axis direction by alternating inertial forces (for example, when the tube is placed on a vibration rack which produces an acceleration $\ddot{s}_x = w$) or by alternating electric or magnetic fields which vary according to the harmonic law, the column is provided with transverse forced oscillations with respect to the differential anodes at frequency ν of the external effect. Phase shift δ arises in the stable-state condition between the external effect and current i_g at the output of the initially balanced bridge circuit. For example, in the case of inertial excitation, a frequency rise from tenths of a hertz increases the phase shift from 0 to π passing through $\pi/2$ for a frequency $\nu = \nu_1$ of the order of units of hertz (Fig. 3). With a further rise in frequency, yet another transition of the phase shift through $3\pi/2$ can be observed, and this occurs at a frequency ν_2 which is in the range of hundreds of hertz. In the case of electrically or magnetically excited forced oscillations it is also possible to obtain phase shifts of $\pi/2$ and $3\pi/2$ in the same frequency ranges.

On the whole the above system is in an overdamped condition and its amplitude-frequency characteristics have no resonance peaks. However, resonance peaks are obtained, if the system is provided with a feedback proportional to the speed of the column's relative oscillations and are obtained, for example, by means of an electric field produced between the auxiliary x-transverse electrodes (see Figs. 1a and 4). A positive feedback then produced a peak near ν_1 (Fig. 5a) and a negative feedback near ν_2 (Fig. 5b).

The displacement of the column is also observed under the effect of constant inertial, electric, or magnetic fields. The inertial field is, naturally, equal to a gravitational one, thus making it possible to obtain static characteristics (Fig. 6a) by dipping the equipment in the plane xy to and angle α (see Fig. 4). The column, which has a higher mean temperature than the ambient medium in the bulb behaves as a body with a smaller density than the medium and floats towards the higher anode. When the tube is rotated about its axis parallel to y, the resulting centrifugal forces displace the column towards this axis owing to the above difference in densities. If the x axis is then directed along a radius, a current will flow through the bridge.

A rising discharge current produced a longitudinal splitting of the discharge into a more contracted bright "core" in the form of an emerging filament and a diffused "envelope" (see Fig. 2).

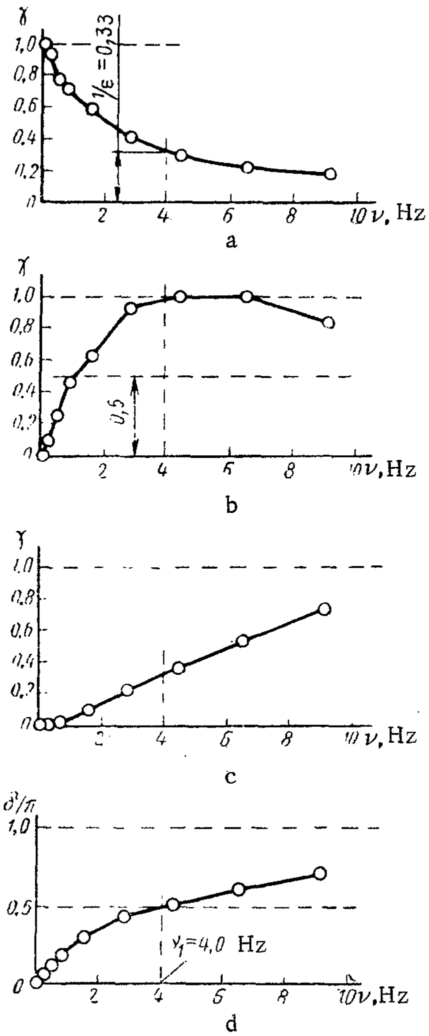


Fig. 3

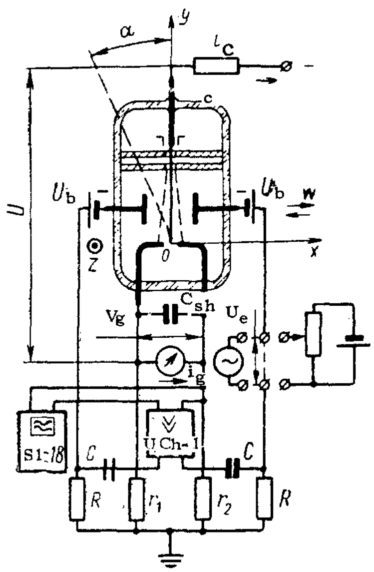


Fig. 4

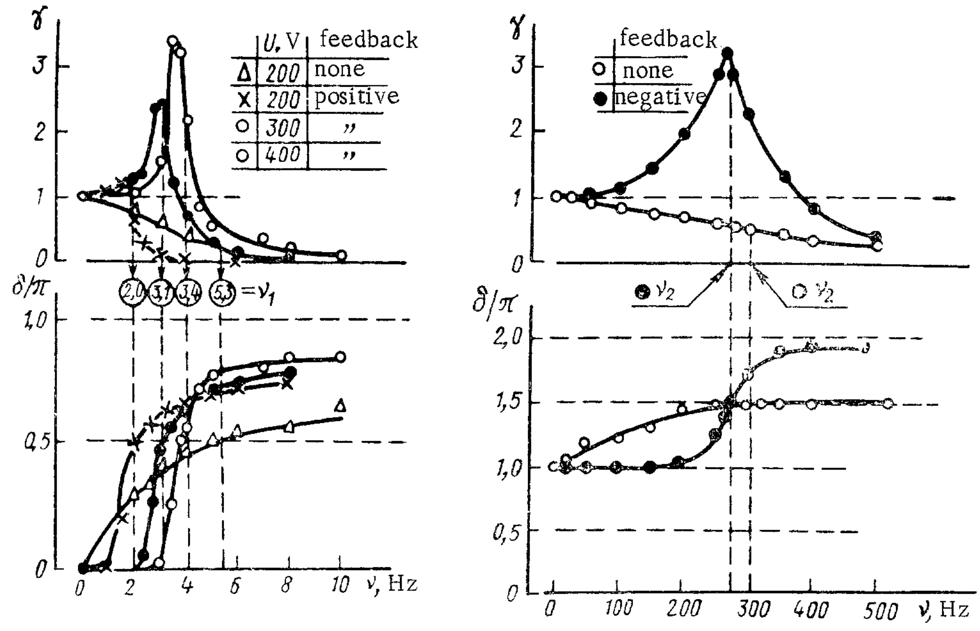
Fig. 3. Typical frequency characteristics in the low-frequency range ($i_c = 3.1$ mA): a, b, and c) amplitude-frequency characteristics for acceleration, velocity, and displacement respectively; γ) magnification factor; ε) effective damping; d) phase-frequency characteristic; δ) phase shift.

Fig. 4. Circuit incorporating feedback with differentiating RC networks. Electrical excitation is provided by connecting a dc or ac voltage U_e to the x-transverse electrodes, and magnetic excitation by a field with an induction of the order of 10^{-2} T directed along the z axis and formed by additional coils with the current I_m (not shown on the drawing).

In a dc electric field produced between the x-transverse electrodes the core and envelope are displaced in opposite directions, as if they carried respectively a positive and negative space charges. At the same time the transition from a "light" to a "heavy" discharge current changes the sign of the output current i_g, which passes through zero for a certain mean value of the discharge current ($i_c = 1.1$ mA in Fig. 6b). Thus, the core and envelope, which are displaced in the transverse electric field in opposite directions, produce in the current i_g independent armlets of opposite signs, which can compensate each other.

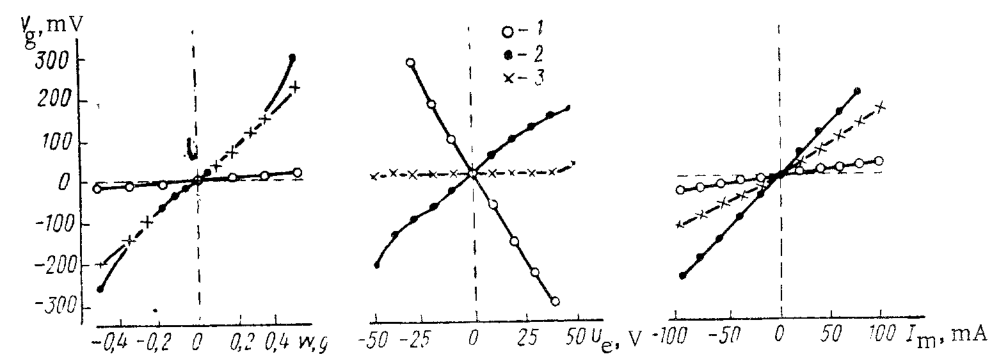
Figure 6b shows the static characteristic of the tube under the effect of a constant magnetic field produced by external coils with the current I_m.

If the electric field between the x-transverse electrode is alternating, the core and the envelope oscillate, and are displaced at low frequencies in opposite directions to each other. For "light" currents the phase shift of i_g is then π, and for "heavy" currents it is zero.



a b

Fig. 5. Amplitude-frequency and phase-frequency characteristics: a) positive velocity feedback and inertial excitation; $i_c = 1.6$ mA; amplification factor of 10^3; $C_{sh} = C = 0.1$ μF; R = 100 kΩ; b) negative velocity feedback and electrical excitation; $i_c = 0.3$ mA; amplification factor of 10^3; $C_{sh} = 0$; C = 0.1 μF; R = 13.8 kΩ; $U_b = 200$ V.



a b c

Fig. 6. Static displacement characteristics of the charge in the following fields: a) gravitational; b) electric; c) magnetic. Discharge current i_c denoted as 1 = 0.3, as 2 = 1.7, and 3 = 1.1 mA.

By comparing the type of contraction with the frequency characteristics obtained for "heavy" and "light" currents it is possible to show that ν_1 is probably related to the oscillations of the core, and ν_2 to those of the envelope.

It is important to note that the resonance rise in the column oscillations at the frequency ν_1 and the simultaneous independent oscillations of the core and envelope are observable visually even with a naked eye.

Phenomena similar to the above are observable also when the tube is fed with a 50 Hz voltage.

4. By providing nonzero initial conditions in the form of mechanical, electric, or magnetic pulses, the particles forming the gas-discharge column can oscillate collectively across the longitudinal axis of the column, which then begins to vibrate between the anodes as a single body. For low pressures of the medium the column returns to the balanced position aperiodically. However, with a rising pressure the attenuation is reduced and the movement of the column becomes oscillatory with a frequency of $\nu_{at.1} \approx \nu_1$.

With a positive velocity feedback the aperiodic movement becomes oscillatory with an attenuation depending on the feedback factor. If it is sufficiently large, there appear virtually harmonic self-oscillations at a frequency of

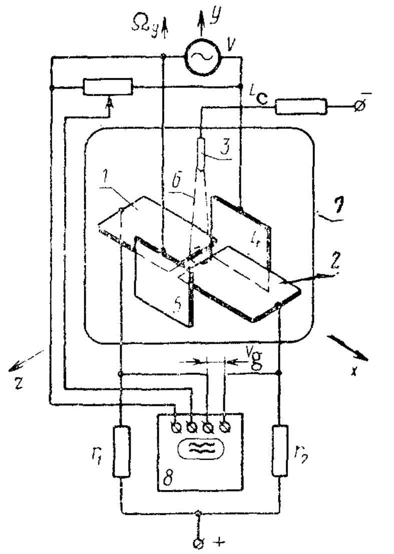


Fig. 7. Schematic of the equipment for observing the gyroscopic effect: 1, 2) differential anodes; 3) cathodes; 4, 5) z-transverse electrodes; 6) gas-discharge column; 7) bulb; 8) double-beam electronic oscillograph.

$\nu_{so.1} \leq \nu_{at.1}$ in the range of units of hertz. A negative feedback produces free oscillations at the frequency $\nu_{at.2}$ or self-oscillations at the frequency $\nu_{so.2}$. Moreover, $\nu_{so.2} \approx \nu_{at.2} \approx \nu_2$, i.e., they lie in the range of hundreds of hertz. With a rise in pressure of the medium the position of the column between the electrodes becomes unstable, and its transverse oscillations at the frequency $\nu_{so.1}$ may arise spontaneously or be produced by an external shock, even without a feedback.

With a further rise in pressure, the position of the column between the electrodes becomes even more unstable – the slightest shock or asymmetry displaces it to the side of one or the other anode.

5. For a uniform rotation of the tube about the z axis (see Fig. 1a) with an angular velocity of Ω_z, the particles which move between the electrodes along the y axis respond to the Coriolis acceleration along the x axis, and the bridge is provided with current i_g, which is proportional to and has the same sign as Ω_z over a wide range [6]. Owing to the edge distortions of the discharge shape, the particles comprising the gas-discharge column can also be provided with a constant transverse velocity, for instance, along the z axis. In this case the column is displaced along the x axis when the tube is rotated about the y axis [7, 8]. The displacement along x can be alternating [9], if the column is driven along z by means of alternating fields (Fig. 7). In this case the amplitude of i_g is proportional to Ω_y, and the phase with respect to the reference voltage is reversed with a changed direction of rotation.

It is obvious that the installations assembled according to Figs. 1 and 4 and used for scientific research are at the same time ready-made accelerometers suitable for measuring acceleration $\ddot{s}_x$ and provided with sensing elements in the form of their gas-discharge tubes, namely inplatrons.

In the same manner the equipment shown in Fig. 7 is a high-speed gyroscope whose inplatron serves as an element sensitive to the angular velocity Ω_y.

Electromechanical Models for Designing Instrument Schematics. 6. The designing of schematics for instruments based on the inertial-plasma effect must, obviously, be made on the basis of its general theory. Unfortunately, there arise important difficulties. As a matter of fact, for a mathematical representation of the observed phenomena on the level of microscopic quantities it is necessary to solve simultaneously many equations. In a general case such a system comprises Maxwell, hydrodynamic, thermal-conduction, and dynamic equations with all types of effective mechanical, magnetic, and electric forces taken into consideration. If it is born in mind that the equations have to be repeated for positive, negative, and neutral particles, with each one being repeated for three degrees of freedom, it becomes clear that the total number of equations, despite certain simplifications, amounts to several dozen. Moreover, boundary conditions and external system equations have to be taken into consideration.

Further simplification and idealization are obviously possible, but nevertheless the problem remains complicated. Let us note that the very physical nature of the discharge contraction, which is basic for all the phenomena under consideration, has not been as yet sufficiently clarified and it has been studied only in particular cases at the level of nonrigid idealizations.

Below we point out another method for developing the theory and designing of schematics.

The experimental investigations carried out by us provide the possibility of compiling phenomenological macroscopic equations on the basis of the general theory of transducers the physical essence of whose factors is not related to microscopic quantities, or is related to them partially. This approach is fully justifiable for establishing the mutual relationships and purposefulness of experimental investigations and can be used for computing schematics of practical designs. Thus, on the basis of the above experimental investigations it is possible to assert that the "discharges–electrodes –external circuit" form a single oscillatory system which has at least two natural frequencies related to the partial systems of the core and the envelope.

Figure 8 shows as an example mechanical models which represent the oscillatory systems under consideration and have frequency characteristics similar to the experimental ones. Different idealization levels adopted in developing the theory of the inertial-plasma effect must lead to such models.

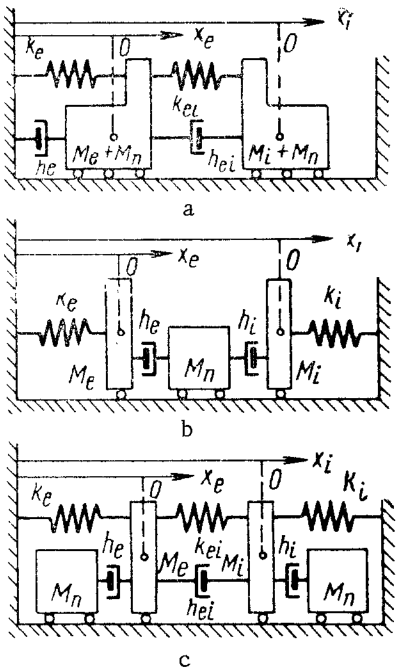


Fig. 8. Mechanical models of the "discharge – electrode – external circuit" oscillatory system: x_e and x_i are coordinates; k_e, k_i, and k_{ei} are quasielasticity factors; h_e, h_i, and h_{ei} are resistance factors; M_e, M_i, and M_n are the effective masses related to the partial systems of the envelope e, the core i, and the medium n.

If it is taken into consideration that the natural frequencies are wide apart (at four to six octaves), it becomes possible in solving many problems, especially for technical applications in the range of the order of 0-10^2 Hz, to remain content with the system's approximation entailing a single oscillatory degree of freedom. Then, within the tube operating range which provides system linearity, the movement equation of the column's positive end can be written in the form

$$\ddot{x} + 2\,\theta\dot{x} + \omega_{01}^2\,x = (\eta - 1)\,\ddot{s}_x, \tag{1}$$

where $\ddot{s}_x$ is the tube's acceleration of following in the direction of the x relative coordinate which is rigidly referred to the bulb, ϑ is the attenuation constant,

$$\eta = \frac{\Delta_{md}}{\Delta_{cm}} > 1 \tag{2}$$

is the ratio of the mean densities of the medium Δ_{md} and the column Δ_{cm},

$$\omega_{01} = \sqrt{\frac{K}{M}} \simeq 2\,\pi\nu_1 \tag{3}$$

is the natural frequency with K and M being the effective factors of quasielasticity and the mass referred to the active segment of the column's positive end.

7. The system's quasielastic forces are of a thermal origin and are related to the formation of a stable column, but they also clearly depend on the electric fields between the anodes and, it would appear, that they arise to a substantial separation of charges, with the positive ones being predominant in the core and the negative in the envelope. Moreover, in the electromechanical model it is not essential to distinguish whether the charges are actually separated or produce that effect.

An example of effective separation consists of the operating condition with ambipolar diffusion of positive and negative particles which move from the column's axis, where they are in excess, to the bulb walls. Since the mobility b_- of electrons considerably exceeds the mobility b_+ of ions, there arises in a stable-state condition the field strength

$$E_1 = \frac{1}{n}\,\frac{D_+ - D_-}{b_+ + b_-}\,\mathrm{grad}\,n, \tag{4}$$

which retards electrons and accelerates ions. In the latter expression D_+ and D_- are the diffusion factors of positive and negative carriers and n is the concentration which, according to the condition of quasineutrality, is the same for particles of either sign [10, Vol. 1, § 60].

It now becomes possible in principle to find from the Poisson equation

$$\mathrm{div}\,E_1 = 4\pi\rho, \tag{5}$$

the corresponding distribution of charges $\rho(x, y, z)$ which produces the field E_1.

It is possible that there also exist in the inplatron other charge-dividing physical mechanisms due to the weak ionization of the gas which is at a relatively high pressure (~ 10^{-1} MPa) and to the specific boundary conditions of the closely located electrodes.

In particular, at the rate that the discharge current drops and the pressure rises, the ambipolar diffusion condition in the core is transferred to the envelope as a free diffusion of electrons to the periphery, thus infringing the quasineutral condition of the plasma [11, Ch. VI, § 35, paragraph 11].

The displacement of the column end with respect to the anodes (see Fig. 1a) unbalances the bridge and, therefore, there appears a potential difference between the anodes and the resulting additional field E_2 with the voltage

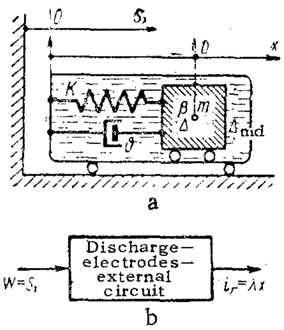


Fig. 9. Electromechanical analog: a) oscillatory system; b) system as a whole considered as a transducer.

component E_{2x} in the direction of the x axis. On the other hand, owing to the nonuniform charges structure along the cross section of the column, the charged particles of its certain active area V at the positive end are beginning to be affected by the force

$$F(x) = \int_V E_{2x} \rho \, dV \approx -kx, \tag{6}$$

where k is the quasielasticity factor which forms part of the factor K in Eq. (3). If this force remains negative with a rise in x it tends to restore the displaced column. Then, within the limits of the accepted approximation, $K > 0$ and the above linear equation will also hold. However, if F(x) becomes positive with a rise in x, it can lead to a loss of stability and the appearance of self-oscillations or thrusting of the column to a new stable position of equilibrium. It is obvious that in these cases linear approximations can be used only for establishing the boundaries of the instability area. For the conditions under consideration of relatively weak currents, high pressure, and new neutral particles' concentration of the order of 10^{19} cm^{-3}, there occurs an intensive exchange of momenta owing to the collision between the neutral and charged particles which are controlled by the electric fields. Therefore, the column behaves as a single body consisting of an aggregate of heavy particles in its active area V with a total mass of

$$M = \beta m, \tag{7}$$

where m is the mass of a single particle and β is the entrainment factor.

The term $\eta \dot{s}_x$ in (1) represents the quasiarchimedean force acting on a unit mass. Its appearance is due to convection fluxes arising in the inertial field (equal to the gravitational field) which, however, by themselves, divorced from other processes occurring in the system, could not explain the appearance of the observed effects.

Equation (1) represents the mechanical oscillatory system shown in Fig. 9a. This system can have at low frequencies the same frequency characteristics as an actual system (see Figs. 3 and 5a). Since the displacement x of the column's positive end is proportional to the bridge output current i_g (or the voltage V_g) we find [3] that

$$i_g = \lambda x, \tag{8}$$

and the solution of (1) with respect to x can be regarded as the response of the transducer to an external signal, such as the acceleration w(t) imparted to the inplatron's casing (Fig. 9b).

Ultimately we reduced the representation of the actual system to an electromechanical model, an analog characterized by the parameters ω_{01}, ϑ, η, and λ. These parameters can be determined empirically for a finite number of standard equations and used in computing the instruments' designs.

When gyroscopic effects are used (section 5), the right-hand side of (1) must be replaced by terms proportional to the Coriolis inertia force components applied to various particles in the direction of the x axis. This problem can be solved in different ways depending on the design of the tube and the utilized velocity components of the particles.

Of course, theory on the level of macroquantities, from which (1) is deduced cannot replace general physical investigations. It has already been pointed out that this is a very complicated problem. Nevertheless, in this connection important results have recently been obtained and will be published.

Inertial-plasma Instruments. 8. The first installations of the type of Fig. 1 were developed by the author in 1953-54. The idea on which their functioning was based consisted of the following. Let the charged particles of the same sign fill the space between the plane electrodes 7 and 8 (see Fig. 1b) located at a distance d between them. If the tube receives an acceleration $\ddot{s}_x$, these electrodes will move with respect to the charged particles and will be electrified to a potential difference of

$$V_g = \frac{md}{q} \ddot{s}_x, \tag{9}$$

where m and q are the mass and charge of a single particle.

However, it can be easily calculated that, even if ions of the heaviest elements are used, the sensitivity of the device will not exceed 10^{-9} V/g [12]. An experimental checking in deliberately unfavorable conditions of a diffused-discharge quasineutral plasma has confirmed the very low sensitivity which, however, was several orders higher than the calculated one, and this seemed to be incomprehensible.

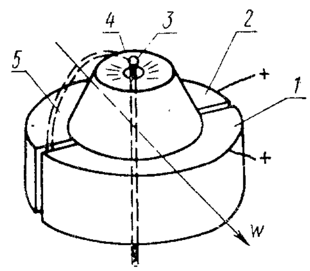


Fig. 10. Hughes' accelerometer: 1, 2) anodes; 3) cathode imbedded in the insulator; 4, 5) gas-discharge column.

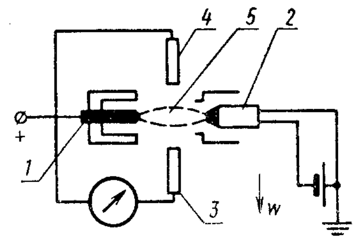


Fig. 11. Stocker and Weston accelerometer: 1) anode; 2) cathode; 3, 4) probe electrodes; 5) gas-discharge column.

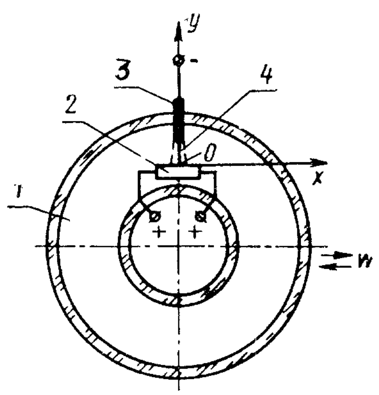


Fig. 12. Inplatron with the toridal bulb 1 and the film resistance 2 which forms the anode; 3) cathode and 4) gas-discharge column.

The author of this article together with V. Ya. Dotsenko [1], S. Hughes in the USA [13] and B. Stocker and G. Weston in Britain [14] used in the sixties independently of each other a contracted discharge formed at higher pressures of the medium in the bulb. This raised sharply the sensitivity of accelerometers.

It should be noted that the resonance properties of the system "discharge – electrodes – external circuit" and the effective separation of charges was noted only in our work. On the one hand it led to the discovery of the aggregate of the above-mentioned mutually-related phenomena which constitute the inertial-plasma effect, and on the other hand to a meaningful utilization in actual instruments of the electrically produced quasielastic force, the feedback for correcting the characteristics and stabilizing the equipment by means of external magnetic and electric fields, and the Coriolis inertial force which arises in rotating the tube. The greater sensitivity of instruments as compared with the calculated one also obtained a natural explanation. According to (7) and (9) instead of m it is necessary to consider the mass of all the neutral particles drawn in by a single charged particle into a collective movement.

9. Hughes' patents [13] describe an accelerometer in wich, mainly under the effect of convection fluxes, the gas-discharge column is displaced between semicircular differential anodes (Fig. 10) connected to the circuit in a manner similar to the one shown in Fig. 1a. The bulb was filled with a mixture of 95% argon and 5% nitrogen at 100-250 mm Hg. The instrument had a supply voltage of 1,000 V, a discharge current of 2 mA, a sensitivity of 20 V/g, a sensitivity threshold of the order of 10^{-6} g, and an upper measurement limit of about 0.1 g. It is noted, without specific data, that the bulb can be filled with a liquid and the system can be fed with alternating current. No frequency characteristics are provided. It would appear, that, owing to large damping and a negligible restoring force, the system was greatly overdamped.

Figure 11 shows the schematic of the Stocker and Weston accelerometer [14] filled with a mixture of neon and xenon in different proportions and at different pressures. Its heated-cathode discharge current of 50 mA formed the higher so-called "filament" contraction (see Fig. 2). The column's displacement with respect to the probe electrodes, which correspond to the electrodes 7 and 8 of Fig. 1b, produces their electrification. Tests were made only with a constant acceleration up to 50 g. Frequency characteristics were not provided.

The author and V. Ya. Dotsenko [1, 3] mainly used the circuit of Fig. 1a, and in the initial stages that of Fig. 12 with its film resistance 2, which forms, when the column is displaced, two unequal resistance arms of the measuring instrument's bridge circuit. Instruments made to this circuit have an extended linear range, but they are a little less sensitive, since in order to prevent the film resistance from burning out the discharge current must be reduced. The toroidal shape of the bulb, on the contrary, tends to raise sensitivity, owing to stronger convection fluxes, but it leads to a considerable rise in the time constant.

In order to eliminate stray sensitivity to angular acceleration components, it is advisable to use accelerometers with cylindrical anodes and several cathodes (Fig. 13).

It is also possible to use shunted ring electrodes (Fig. 14) which rotate in an external constant or alternating magnetic field with the induction **B**. These arrangements provide a particularly large number of possible utilizations of inplatrons in general control circuits with analog, frequency, or pulse-frequency outputs [15].

The sensitivity threshold of the tested accelerometers lies according to [13] below 10^{-6} g (probably considerably lower), but different types of interference can have a large effect on the precision of measurements. Even in-

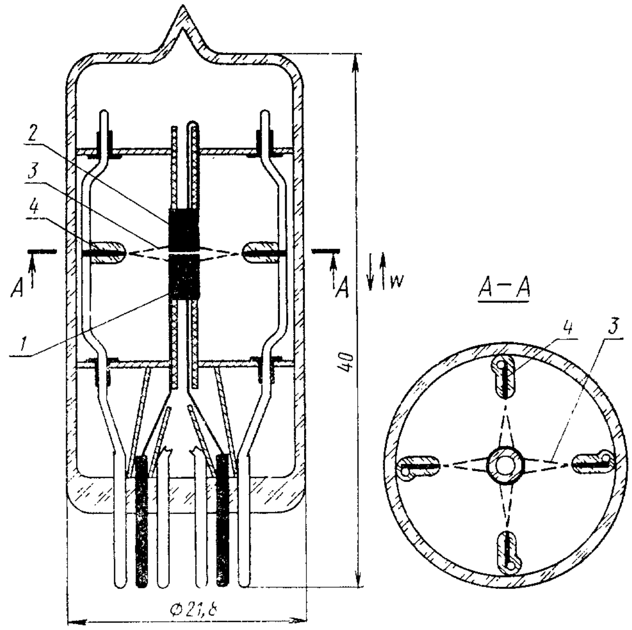


Fig. 13. Inplatron with the cylindrical anodes 2 and 1, four gas-discharge columns 3, and the cathodes 4.

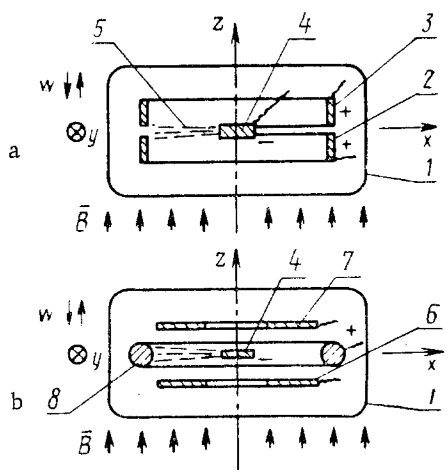


Fig. 14

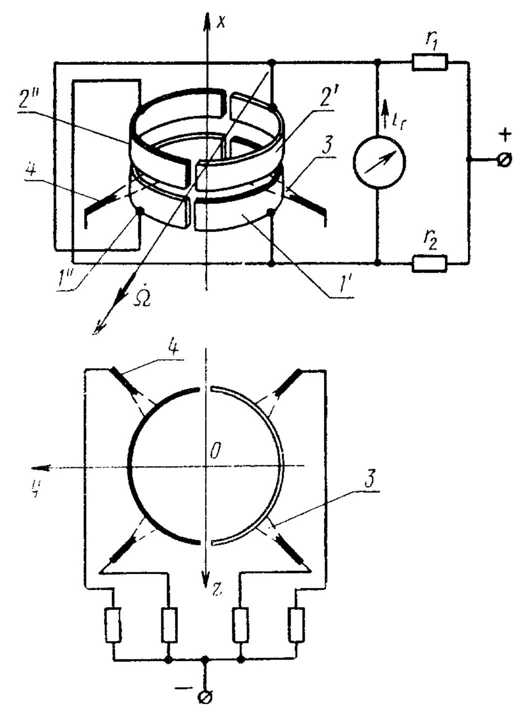


Fig. 15

Fig. 14. Inplatrons with annular electrodes in bulb 1 and column 5, which rotates in the external magnetic field **B**: a) with the differential cylindrical anodes 2 and 3 connected to the cathode 4 as shown in Fig. 1a; b) with the ring anode 8, the cathode 4, and the transverse electrodes 6 and 7 connected as shown in Fig. 1b.

Fig. 15. Inplatron with the semiannular anodes 1', 1'', 2', and 2''. The four gas-discharge columns 3 are formed by means of the cathodes 4 connected in parallel to a common circuit.

significantly small admixtures of stronger atoms change the nature and stability of the discharge contraction. Therefore, the cleaning of gases and electrodes, and the filling and ageing of tubes must be provided for with stringent requirements, similar to those specified for semiconductors. The electrodes should be carefully machined. Sections with irregularities, chips, and burrs produce deformations in the shape of the discharge, displace it from the tube axis, and make the gas-discharge column "stick" persistently to these sections, thus leading to the burning of electrodes. Moreover, for a general stabilization of measurements, especially with respect to drifting, an important part is played by the stability of the external circuit elements and the reliability of contacts. The life of tubes and their reliability with time are sharply reduced with a rising discharge current and the resulting pulverization of electrodes and metalization of components inside the bulb. If the current is below 1 mA, the life is virtually unlimited, however, the system's sensitivity

$$\gamma = \frac{\Delta i_g}{\Delta w} \tag{10}$$

then decreases, although it still remains sufficiently high to be able to measure in many instances without amplifiers.

10. The above accelerometers have a zero frequency characteristic, i.e., they can also measure constant acceleration. Therefore, they can be used as gravimeters, inclinometers, and tachometers.

If the cylindrical anodes of the Fig. 13 inplatron are cut along their generating line and the resulting parts connected crosswise as shown in Fig. 15, an accelerometer is produced which is sensitive to angular acceleration about the z axis. The coupling of adjacent half rings produces an accelerometer sensitive to linear acceleration along the x axis in a manner similar to the one shown in Fig. 13.

The provision of feedback (see Fig. 4) with differentiating and integrating elements serves to change considerably the instrument's frequency characteristics, its natural frequencies, and its effective damping (see Fig. 5). Therefore, the instrument can be provided with the operating conditions not only of an accelerometer, but also of a vibrometer and a velocity meter.

On the basis of the gyroscopic phenomena described in section 5, it is possible to develop instruments for measuring angular velocities. For instance, the equipment shown in Fig. 7 is a kind of vibration gyroscope sensitive to angular velocities about the y axis. It is possible to use the gyroscopic effect present in the systems shown in Fig. 14, whose columns rotate in an electric or magnetic field [2].

Operating conditions leading to the appearance of self-oscillations serve to use the above equipment as low-frequency generators of harmonic oscillations.

Even more unstable operating conditions leading to the throwing over of the column to one or the other of the anodes (section 4) serve to use the inplatrons as high-speed triggers operated by inertial, electric, or magnetic forces.

CONCLUSIONS

The above-mentioned considerations are of a preliminary nature. The application of inertial-plasma instruments is extremely varied, with the same tube, an inplatron, being used, depending on its circuit and the method of setting, as a linear or angular accelerometer, gravimeter, inclinometer, tachometer, vibrometer, velocity meter, high-speed gyroscope, vibrations' generator, trigger, etc.

The basic advantages of instruments which use inplatrons have already been indicated. They consist of the absence of relatively moving or deforming components, the possibility of setting and regulating parameters electrically, miniature size, simple design and connecting circuits, economic supplies, and high stability.

Their frequency ranges have not yet been investigated. The few instruments which have been so far developed are in the low-frequency range from 0 to 1-12 Hz, but there was no conscious selectivity in this problem. At the same time it should be noted that by varying supply conditions and the external-circuit elements' parameters it is possible to change the equipment's natural frequencies by a factor of two to three and the effective damping within any limits.

The sensitivity threshold of these instruments is very low. For instance, for accelerometers and gravimeters it would appear to be considerably lower than 10^{-6} g. However, drift in the reading device and the stability of the equipment as a whole, including the dispersion of parameters in externally similar tubes, as well as changes with time have reduced the measurement precision in the developed devices to the order of 10^{-4}-10^{-2} g. It can be assumed that all these indexes referring to a small number of experimental models can be substantially changed and improved. The results so far obtained and the tendencies which will now be developed will determine the possible fields of the inertial-plasma instruments' application. They may consist of the following:

precision high-sensitivity systems;

particularly robust systems for measuring large accelerations or high rotating speeds, as well as instruments with an unlimited life;

simple, miniature, inexpensive systems with medium or low precision, including those with trigger action;

instruments with a wide range of measured values, including systems whose parameters can be changed purposefully over wide ranges.

Computations related with the designing of these instruments require a further development of the inertial-plasma effect theory. The macroscopic equation (1) with its empirical coefficients and the electromechanical model of Fig. 9 reflect to a certain extent the physical substance of this effect and can serve initially as a basis for computing design schematics.

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