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METHOD OF MEASURING PRESSURES UP TO 1 GPA ON A PULSED GAS-DYNAMIC DEVICE

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The design of a manganin gauge for pressure measurement up to 1 GPa *is described. This gauge, intended for operation in the most intense sites of a pulsed source of the working gas in a gas-dynamic device, is described. The electrical circuit for measurement and recording of the pressure is given. The oscillogram of one of the experiments demonstrates the operation of the gauge on an* A-1 *adiabatic device in the conditions of a real cycle of preparation and removal of the working gas.*

In the gas-dynamic experiment on pulsed aerodynamic devices, there is almost always a need to measure the pressure in a pressure chamber, because this allows one to independently monitor and estimate the flow parameters in the working section. It is also necessary because it is not always possible to introduce pressure gauges directly in a flow without perturbing markedly the working medium.

In the process of performance of pulsed aerodynamic devices of the Hotshot or Longshot type, shock wind tunnels [1], and adiabatic gas-compression devices with a heavy piston [2], particular difficulties arise in measuring the pressure P_0 in the pressure chamber. The gauge is affected by the rapidly varying high-intensity pressure (up to 200 MPa) and by temperatures of up to 2000–4000 K. On superhigh-pressure devices [3], these difficulties even aggravate since the working pressure in the pressure chamber reaches 1–1.5 GPa, which is 5–10 times higher than the working pressures on the conventional pulsed aerodynamic devices.

The time of the operating mode t_e on pulsed aerodynamic devices is in the interval from 0.01 to 0.3 sec or greater. During this period, the gauge is exposed to a chemically aggressive gas of high temperature and density. The dimensions of the working space accessible for location of a pressure gauge in the pressure chamber is often very small (less than 0.06 cm^3) [3, 4].

The measurements are complicated at a pressure greater than 500 MPa, because, in practice, it is impossible to supply the working gas from the pressure chamber to the gauge even through a capillary channel, as is done, for example, on Hotshot-type pulsed devices [1]. The presence of such a channel also leads to a noticeable deterioration of the dynamic characteristics of the measuring tract of the system. One can solve this problem by means of special compact electrical wires 6 (Fig. 1), which allow the operation at high pressures. Such electrical wires are made with the use of explosion compression of a body 5. The method was described in [5]. As the insulator, a porcelain thermocouple straw 3 is used. Multiple use of the nozzle plug with these electrical wires and with pressure and temperature gauges in a dynamic regime at pressures of up to 1 GPa and temperatures of up to 1700 K has shown high reliability of this device. Figure 1 also shows the positions of other elements of the nozzle plug: a nozzle insert 4, a pressure gauge 1, and a wire temperature meter 2.

A method that is based on the resistance variation of a manganin wire during its volumetric compression was used for pressure measurement [6]. The gauge made from this wire has a series of attractive qualities:

1. The resistance variation is linear in the pressure range from 0 to 3 GPa [7] (the nonlinearity is less than 1%).

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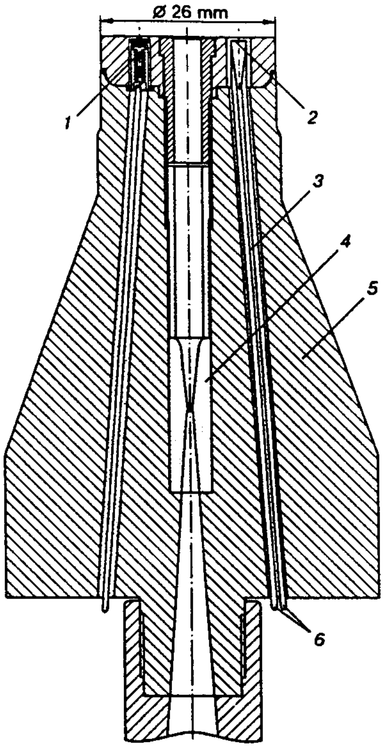

Fig. 1

2. A rather low temperature coefficient of resistance ($\alpha_T < 10^{-7}$–10^{-8} K $^{-1}$ at room temperature) [8] upon heating the wire increases markedly and becomes two orders of magnitude greater at $T = 100°$C.

3. The manganin wire is widely applied in industry and has stable characteristics and a sufficiently high specific resistance. For example, the linear resistance of a wire of diameter 0.05 mm is 2.63 Ω/cm, which allows one to fabricate small-sized gauges with rather high resistance.

4. Manganin has a sufficiently high coefficient of piesosensitivity ($\alpha_p = 2.5 \cdot 10^{-5}$ MPa $^{-1}$), which allows one to reliably employ it at $P_0 \geqslant 100$ MPa. With the use of a bridge circuit of switching having a single active gauge, the magnitude of the useful signal, recorded from the bridge, is $U_{\text{out}} = (\Delta R/R_0)U_0/4 = (\alpha_p P_0 R_0/R_0)U_0/4 = (\alpha_p P_0)U_0/4$. For example, if $U_0 = 20$ V is used for supply of the bridge, we obtain $U_{\text{out}} = 0.122$ V for the working pressure $P_0 = 1$ GPa. Modern measuring systems record the signal of this level to within high accuracy.

5. In contrast to piezogauges, manganin gauges allow the static calibration of the measuring system.

The scheme of a miniature gauge intended for operation in the conditions of a small-sized pressure chamber of an aerodynamic device is shown in Fig. 2. The isolated wire 5 of diameter 0.05 mm (the resistance of up to 500 Ω) is double-wound on a glass textolite frame 6. The gauge is attached to a plug 7 between the electrical leading-in wires 8, and the leading-out wires 9 are soldered to them. A protective cap 4, which is filled with oil 3, is put on the gauge and pressed against the plug by a tie 2. In a drainage cavity, there are several layers (3 or 4) of a copper net 1, which, as experiments showed, ensures cooling of the gas acting on the gauge even for a measurement time longer than 0.7 sec.

This design reliably protects the gauge against the action of a high-temperature gas during the trial (whose duration is of the order 0.5 sec or greater) and ensures the pressure measurement in a pressure chamber with good response and accuracy. The absence of noticeable heating of the gauge is demonstrated by the oscillogram of the working cycle in Fig. 3, where the displacement of the zero line is almost not observed after the process ends.

The presence of the cap, having a definite rigidity, leads to the fact that the pressure $P_{0(\text{m})}$ to be

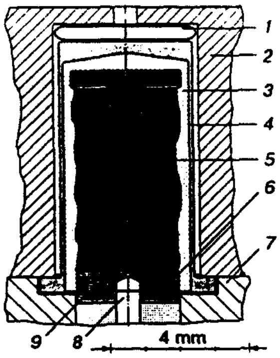

Fig. 2

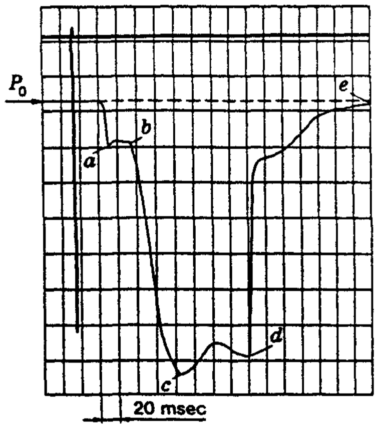

Fig. 3

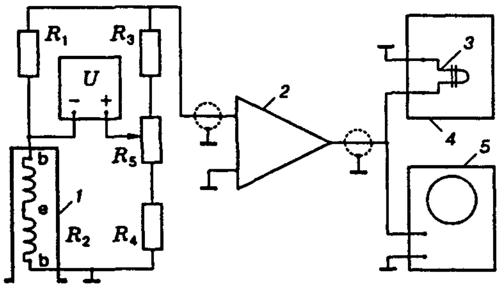

Fig. 4

measured differs from P_0 by the quantity ΔP_0 [$P_{0(m)} = P_0 - \Delta P_0$]. The quantity ΔP_0 is determined by elastoplastic deformation of the cap and depends on its design and material. To decrease this additional error of P_0 measurement to a level of $\Delta P_0/P_0 \leqslant 1\%$, soft brass or steel caps (elliptic cylinders) with a wall thickness less than 0.1 mm are used.

Under the action of pressure P_0, the decrease in the oil volume equals

$$\Delta V_{\text{oil}} = V_{\text{oil}} \chi_{\text{oil}} P_0,$$

where χ_{oil} is the coefficient of oil compressibility. It is equal to 0.7–0.4 GPa^{-1} at room temperature and decreases with pressure.

The coefficient of decrease in the volume of the elliptic cap (see [9]) is of the value

$$\chi_{\text{cap}} = 0.157[12(1-\mu^2)(1-b^2/a^2)/\pi E](a/h)^3(a/b),$$

where E is Young's modulus, μ is the Poisson ratio, a and b are the principal and minor semi-axes of the ellipse, and h is the wall thickness ($h \ll a$). If, for example, $a = 4$ mm, $b = 3$ mm, and $h = 0.1$ mm, for steel we have $\chi_{\text{cap}} \approx 10.2\ \text{GPa}^{-1}$. As a result, we have $\chi_{\text{oil}}/\chi_{\text{cap}} \approx 0.07$–$0.04$. Therefore, the elasticity of the cap has no effect on the indications of the gauge.

For short-term modes ($t_e < 0.2$ sec), a fluoroplastic cap can be used. Young's modulus of this cap is much less than for brass, and therefore the effect becomes negligible. For such a cap shaped even like the standard cylinder with a wall thickness of approximately 0.2 mm $\chi_{\text{cap}} \geqslant 30\ \text{GPa}^{-1}$, we have $\chi_{\text{oil}}/\chi_{\text{cap}} \leqslant 0.01$.

Figure 3 shows the oscillogram that demonstrates the operation of the gauge in the conditions of an actual cycle of preparation and removal of the working gas on an A-1 adiabatic device [3]. The jump a is the pressure rise (up to ≈140 MPa) in the first stage of operation. The section a–b is the time of launch of the second stage, the section b–c is the secondary compression up to 885 MPa, and the section c–d is the working cycle of a quasi-steady state outflow. The gauge fixes pressure oscillations arising from resonance phenomena in the energy supply system. The point d shows the moment of stoppage of the displacing piston. After the pressure drop (behind the point e), the nonshifted zero line is fixed.

A variant of the block diagram for measurement and recording of the pressure P_0 is given in Fig. 4. A gauge 1 is included in one of the bridge's arms (b and e are the beginning and end of the double-wound coil of the pressure gauge, respectively). An amplifier 2 serves for matching the output resistance of the bridge and a load resistance 3. As the recording unit 4, one can use an N-115 or N-117 circuit oscillograph (the circuit resistance is approximately 20 Ω) or an C8-17 or C 9-16 electronic oscillograph with a memory unit 5.

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