INVESTIGATION OF HEMODYNAMICS BY A FLOW-PRESSURE TRANSDUCER

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The study of the cardiovascular system is usually linked with recording blood flow and arterial pressure and is most informative if these parameters are measured simultaneously.

Nowadays the volume velocity of the blood flow is measured by bandaged transducers of electromagnetic and ultrasonic instruments, and blood pressure is recorded through an intravascular catheter. Combining these recording systems into one design has many advantages but is bound up with the development of a transducer of volume velocity of blood flow for use with a catheter or the creation of a pressure transducer of bandaged type.

A study of the biomechanics of the blood vessel by recording its size and determining its intravascular pressure [9] demonstrated the high elasticity of the vessel wall, evidence that it can be used as intermediate membrane for a pressure transducer for measurement through the vessel wall. The writer has developed such a transducer and tested it in operation on the bench and in experiments on animals. The transducer consists of a construction of bandaged type 7 mm long, in the body of which is placed the sensitive pressure element. This sensitive element is a semiconductor strain gauge resistor bridge circuit of ChÉD-5-0.5 type, developed at the State Institute of the Rare Metals Industry.

Pressure elements, based on integral microcircuits, are 3 and 5 mm in diameter and have a sensitivity of 15-40 mV/100 mm Hg. The first prototype pressure transducers based on these sensitive elements were designed for intracavitary and intravascular investigations on animals.

Calibration of the transducers with the aid of a mercury manometer showed that their readings are linear over the range from 0 to 250 mm Hg. Temperature instability within the range 20-40°C differed depending both on the design of the transducer and the quality of the strain gauge circuit used, but it was usually 5% or less of the top value of the scale of measured pressure. Under real research conditions, at constant body temperature, this parameter was more stable. Electronic circuits of the instrument were produced in two versions: for alternating current using a carrier frequency and for direct current.

In the first version the instrument was based on a traditional circuit with 5 kHz generator and corresponding demodulator. The use of direct current was due to the need to eliminate induction of alternating current from the pressure transducer to sensitive elements of other measuring systems used in physiological research (for example, during recording of the neurogram) [6]. The use of direct current also proved to be convenient for the combined flow-pressure transducer, for it enabled the connecting leads of transducers of these two systems to be combined.

The electrical circuit of the dc instrument was based on a type K284UD1B operational amplifier (Fig. 1). The amplification factor of the circuit is determined by the ratio of the resistors R_6 and R_7, and it is usually about 100. Resistors R_1, R_5, and R_{10} constitute a voltage divider and serve to memorize the calibration signal of pressure transducers of different sensitivity. Resistors R_8 and R_9 are used to set the operational amplifier at zero: the drift of its zero line is negligible at under 50 μV/°C.

Operation of the bandaged pressure transducers was studied in experiments on animals in conjunction with the catheter system of the STETKhEM 23D transducer. The tests showed that

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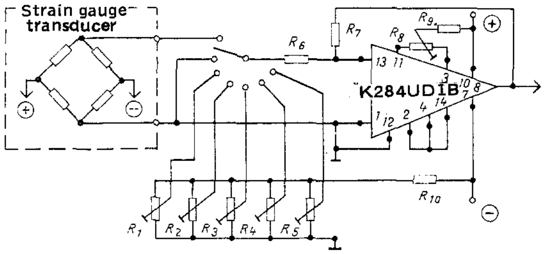

Fig. 1. Theoretical circuit of instrument for measuring pressure.

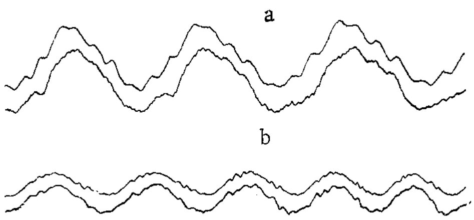

Fig. 2

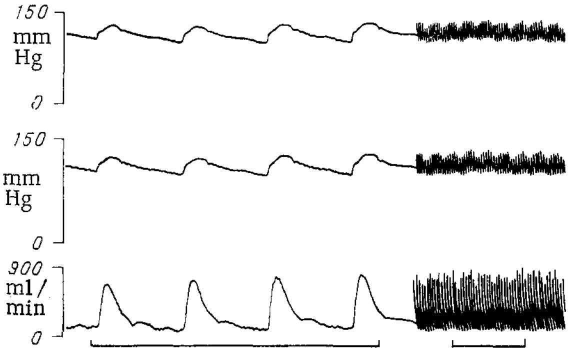

Fig. 3

Fig. 2. Testing flow–pressure transducer on a hydraulic bench in a Pitot tube. a) Simultaneous recording of flow measured by ultrasonic instrument (top curve) and differential manometer (bottom curve). Pulsation frequency 25 Hz; b) simultaneous recording of pressure curve by test transducer (top curve) and electromanometer of hydraulic bench (bottom curve). Pulsation frequency 50 Hz. Recording made on S8-2 storage oscillograph.

Fig. 3. Measurement of blood flow and pressure by a single transducer on cat thoracic aorta. Pressure curve recorded in the same place by the STÉTKhEM 23D transducer using a catheter illustrated above. Time marker 1 and 10 sec.

pressure recording is sufficiently accurate and that it can be combined with the blood flow transducer in the same construction.

The most suitable type of blood flow transducer was found to be the ultrasonic Doppler system which has been under development by the present writer for 15 years [1, 3, 5]. In the last few years the design of ultrasonic transducers has improved, their sensitivity has been increased, and the size of quartz crystal transducers has been greatly reduced, so that small transducers can now be produced for measuring blood flow in arteries and veins of rats in vessels 1 mm in diameter or less [2]. That is the reason why it was possible to combine sufficiently compact quartz crystal elements of the ultrasonic blood flow transducer with the pressure transducer in the same construction.

Combined flow – pressure transducers were tested in pulsating flows on the hydraulic bench used previously when studying ultrasonic pulsed transducers [4]. This bench was modernized to increase the frequency of pulsation of flow and pressure. To compare phases of pulsating flow and the flow transducer readings, a Pitot tube with type EM201 differential pressure transducer was used. The full pressure receiver of the Pitot tube was moveable, so that the flow profile of the liquid could be determined and its velocity measured by an ultrasonic instrument. Determination of this parameter is important when estimating accuracy of measurements of volume velocity of blood blood. For bandaged transducers, accuracy of measurement largely depends on accuracy of determination of the mean velocity of the flow profile. With a parabolic profile the vector of mean velocity in the section lies at a distance of $R/\sqrt{3}$ from the axis. The full pressure receiver was set to correspond to this point. Tests were carried out on a homogenized fluid with flow pulsation frequency up to 25 Hz (Fig. 2a). Velocity curves recorded by a differential manometer (bottom curve) and the ultrasonic instrument (top curve) coincided in both amplitude and phase.

To determine the frequency characteristic of pressure the frequency of the pulsating pressure of the hydraulic bench was adjusted to 50 Hz. Simultaneous recording of pressure created on the bench and that determined by the test transducer gave practically identical results over the whole range of pulsation of the hydraulic bench (Fig. 2b).

When the flow-pressure transducer was designed it was considered that application of the transducer band to the blood vessel would induce distortion because of the formation of reflected velocity and pressure waves during spread of the pulse wave. Analytical investigation showed that these distortions depended on the length of the band and diameter of the vessel [7, 8]. On the basis of suggested recommendations optimal dimensions of a transducer which would produce minimal distortions in the hemodynamics of the blood stream in use were chosen.

Operation of the transducers was studied in experiments on animals. Simultaneous measurement of pressure and blood flow by a single flow-pressure transducer, combined with recording pressure by the STÉTKhEM 23D catheter transducer is illustrated in Fig. 3.

Tests showed that simultaneous recording of pressure and blood flow velocity in virtually the same place can provide the fullest information about the hemodynamics of the vessel studied. The use of a bandaged flow-pressure transducer enables tests to be carried out on parts of the vascular system with difficult access for catheterization.

By the use of a combined flow-pressure transducer catheterization is not needed for pressure measurement and, in that way, the risk of thrombosis of catheter and blood vessel, which is always present under chronic experimental conditions, can be avoided.

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