# POSSIBLE USE OF MECHANICAL-TO-ELECTRICAL TRANSDUCERS IN EXPERIMENTAL BIOLOGICAL RESEARCH

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Mechanical-to-electrical transducers (mechanotrons), used in engineering to measure displacement, forces, pressures, and other mechanical parameters, were tested as sensitive elements for recording contractile activity of isolated objects (the frog ventricle, a segment of rat ileum), and also the level of the arterial pressure in anesthetized animals. The results showed that mechanotrons are simple, convenient, and reliable instruments for such investigations.

KEY WORDS: mechanical-to-electrical transducers (mechanotrons); force detectors; pressure detectors.

Mechanical-to-electrical transducers, or mechanotrons, are used in engineering, including in medical instrument construction, as sensitive elements for measuring displacement, forces, pressures, accelerations, amplitudes of vibrations, and other mechanical parameters [1-5]. Mechanotrons compare favorably with other types of electromechanical transducers in their high sensitivity, simple design and circuitry, low supply voltages, high linearity of output characteristic curve of conversion over a wide range of measurements, and stability and reliability of readings.

Mechanotrons are electric vacuum instruments whose action is based on mechanical control of an electric current. A special feature of the mechanotron is that it has one or more movable electrodes, which move inside the evacuated container of the instrument in response to external mechanical action.

In a mechanotron transducer of displacement and force (Fig. 1a) the input mechanical signal (displacement $\alpha$ or force F) is applied to the outer end of the rod 1, folded to the membrane 2, which is part of the vacuum envelope 3. The moving electrode (the anode 4), secured to the inner end of the rod, moves relative to the stationary cathode 5, and this leads to a change in the anode current and the output signal fo the transducer.

In a mechanotron pressure transducer (manotron), the design of which is illustrated in Fig. 1b, under the influence of the pressure (p) to be measured the membrane 1 is bent, as a

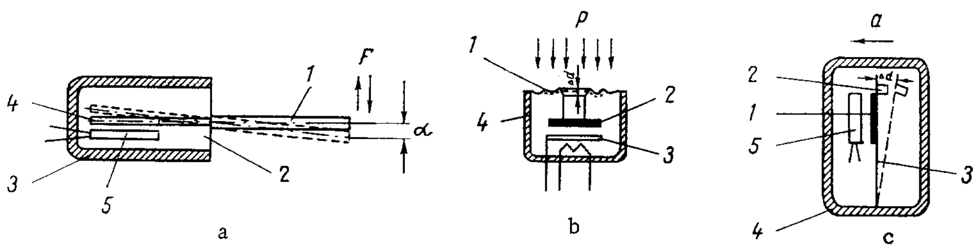


Fig. 1. Theoretical circuits of mechanotrons of different types: a) mechanotron transducer of displacement and force, b) pressure transducer; c) accelerometer. Remainder of explanation in text.

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TABLE 1. Principal Parameters of Diode Mechanotrons Recommended for Use in Biomedical Instruments

| Type of mechanotron | Parameter to be measured | Range of measurements | Sensitivity | Nonlinearity of output characteristic curve, % |
|---|---|---|---|---|
| 6MKh1S | Displacement and force | ±100 μ<br>±10 g·sec | >30 μA/μ<br>>200 μA/g·sec | <1 |
| 6MKh2B | The same | ±100 μ<br>2 g·sec | >40 μA/μ<br>>500 μA/g·sec | <4 |
| 6MKh5S | » » | ±1000 μ<br>±30 g·sec | >3 μA/μ<br>>40 μA/g·sec | <1 |
| 6MKh1B | » » | 0—140 μ<br>±0,5 g·sec | >20 μA/μ<br>>2000 μA/g·sec | <1 |
| 6MKh9B | » » | ±50 μ<br>±0,5 g·sec | >20 μA/μ<br>>3000 μA/g·sec | <1 |
| 6MDKh1B | Excess pressure | 760—1140 mm Hg<br>(0—0,5 kg·sec/cm²) | >500 μA/kg·sec/cm² | <2 |
| 6MDKh3B | » » | 760—7600 mm Hg<br>(0—10 kg·sec/cm²) | >100 μA/kg·sec/cm² | <2 |
| 6MDKh5S | Rarefaction (vacuum) | 0,1—100 mm Hg | >100 μA/mm Hg | <2 |

Note. For a detailed account of the design and electrical circuitry of the mechanotrons, see [1].

result of which the moving anode 2 is displaced relative to the cathode 3, firmly connected to the capsule 4 of the mechanotron.

Mechanotron acceleration transducers (accelerometers) are instruments of inertia type, in which relative displacement of the electrodes arises as a result of the action of forces of inertia. In the mechanotron accelerometer (Fig. 1c) the moving anode 1, together with the inertial mass 2 is fixed to one end of a flat spring 3. The second end of the spring is rigidly connected to the capsule 4 of the mechanotron. During an increase in the velocity of movement of the accelerometer (acceleration $a$), because of the action of forces of inertia on the mass 2 and the anode 1, the latter is moved relative to the cathode 5.

Soviet industry currently mass-produces 12 types of double-diode mechanotron transducers of displacement, force, and pressure [1, 2]. The principal parameters of some of the mechanotrons are given in Table 1.

Mass-produced mechanotron transducers are intended for measuring the specified mechanical parameters within the following ranges: displacements from 0.1 to 1000 μ, forces from 0.1 to 30 g · sec, excess pressures from 0 to 10 kg · sec/cm², and rarefaction (vacuum) from 0.01 to 100 mm Hg.

The relative error of mechanotron transducers lies between 1 and 5%.

During operation of a mechanotron as a rule it is connected to bridge measuring circuits (Figs. 2a and 3a); their output signal, moreover, is easily recorded by means of standard electronic automatic writers (for example, those of types KSP-4, N-327, ÉPP-09, N-338-2, etc.) or oscilloscopes. Power for the circuits is supplied by ordinary dry and storage batteries and other stabilized sources of power. In the near future it is also intended to mass-produce a small power unit (of the 506-E-262) type to measure the signals from diode mechanotrons.

The characteristics of the working ranges of the different types of mechanotron transducers given above are evidence that many of them can be used as sensitive elements for recording forces and pressures in biological investigations.

A preliminary assessment of the possibility of using mechanotrons for pharmacological investigations was undertaken in the Department of Pharmacology, I. M. Sechenov First Moscow Medical Institute. Mechanotron transducers were used to record the force of contraction of various isolated objects and also to measure the arterial pressure in acute experiments on animals.

The principle of the arrangements used to record isometric contractions (maximal displacement 100 μ) of isolated preparations is illustrated in Fig. 2a. The system consists of a mechanotron force transducer 1, the rod of which is connected through a flexible link 2 to the

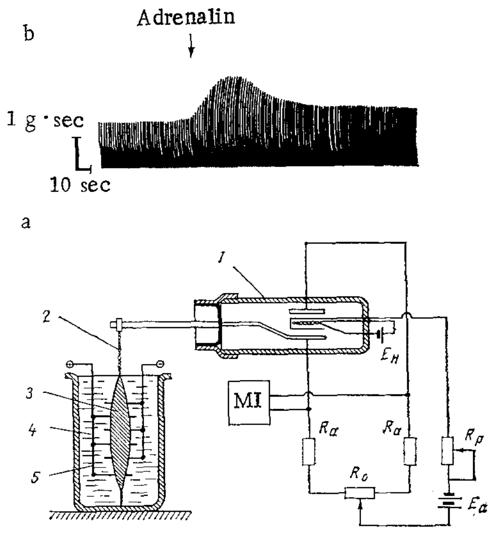


Fig. 2. Theoretical scheme of arrangements for recording contractile activity of isolated objects (a) and recording thus obtained reflecting effect of adrenalin ($1 \cdot 10^{-7}$ M) on source of contractions of isolated frog ventricle (b). Explanation in text.

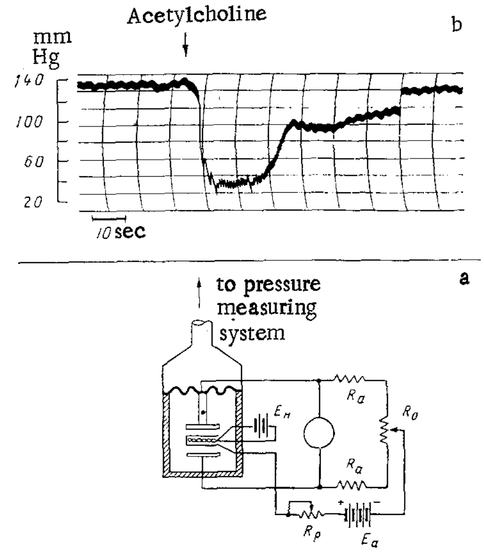


Fig. 3. Theoretical scheme of arrangement for recording arterial pressure (a) and recording thus obtained reflecting depressor action of acetylcholine (10 µg/kg, intravenously) on arterial pressure in an anesthetized cat (b). Explanation in text.

object 3, immersed in nutrient solution (in the vessel 4) and stimulated when necessary by an electric current from electrode 5. A type 6MKh1S mechanotron was used in the pilot scheme. To increase sensitivity of the mechanotron to the forces measured, its rod was lengthened by means of a special lever. The provision of a movable fixation point of the link from the object to be measured on the rod of the instrument enabled the sensitivity of the device to be altered over a wide range simply by moving it, so that forces of between 1-2 mg · sec and 30 g · sec could be measured.

The measuring circuit of the system contained sources of anode $E_a$ and heating $E_H$ voltages for the mechanotron, two fixed resistors $R_a$ (anode loads of the mechanotron), two control variable resistors $R_0$ and $R_p$, and the output measuring instrument MI (for example, a microammeter of the M265M type or automatic writer of N-338-2 type).

A recording of the positive inotropic action of adrenalin on the frog ventricle, contractions of which were evoked by single supramaximal stimuli applied at a frequency of 0.5 Hz, is illustrated in Fig. 2b.

Under analogous experimental conditions the mechanotron transducer also recorded clearly the negative inotropic effect of muscarinic (M) cholinomimetics on the myocardium and suppression of this effect by M-cholinolytics; the high linearity of the output signal of the transducer, moreover, ensured the simplicity and accuracy of quantitative evaluation of the action of agonists and antagonists on the basis of the recordings obtained.

It must be emphasized that, when working under isometric conditions, the myocardium of the isolated ventricle maintained a stable contractile response to electrical stimulation during 3-4 h of the experiment. Stable results also were obtained during repeated recording of the action of various pharmacological agents on the tone and contractile activity of an isolated segment of rat ileum by means of the mechanotron.

To measure the blood pressure in the femoral artery of anesthetized cats a device based on a pressure transducer (manotron) with transmission band of 50 Hz, the theoretical scheme of which is illustrated in Fig. 3a, was used. The electrical circuit is practically indistinguishable from that in Fig. 2a. Readings of the manotron were recorded on a type N-338-2 automatic water. The manotron was calibrated beforehand against a mercury manometer.

To illustrate the operation of the transducer, a recording of the depressor action of acetylcholine on the arterial pressure obtained by means of it is illustrated in Fig. 3b. As the calibration scale in Fig. 3 shows, the relationship between the readings of the transducer and the pressure measured by it is strictly linear.

The wide working range of the manotron used (from 0 to 300 mm Hg), the high linearity of the output characteristic curve, and the high level of the output signal enable the manotron to be used not only to measure arterial pressure, but also to record pressure in perfused vascular regions, the respiratory passages, the chambers of the heart, the lumen of hollow viscera, and so on.

It should also be noted that the manotron can measure negative pressures (rarefaction) to a magnitude of 100 mm Hg, i.e., that it can be used to study changes in pressure in the pleural cavity and the great veins.

On the basis of these trials the mechanotron transducers can accordingly be recommended as simple, convenient, and reliable sensitive elements for the study of biomechanical processes.

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