METHOD OF ADEQUATE CONTROLLED STIMULATION OF MECHANORECEPTORS

O. B. Il'inskii and V. P. Kudrin

UDC 612.815.1.014.424-08

This article describes instruments used for several years in the authors' laboratory for the experimental study of single mechanoreceptors.

Solenoids, piezocrystals, and electrodynamic systems are most commonly used in physiological experiments to stimulate mechanoreceptors [1, 3-6, 8, 13]. Experience has shown that of these the most suitable for this purpose are electromechanical stimulators (EMS). The principle of their operation is the same as that of dynamic loudspeakers.

The construction of one such converter is shown diagrammatically in Fig. 1 I. In the field of a powerful ring magnet (2) is placed a coil (17) fixed to an elastic membrane (4). When an electric pulse is applied to the winding of the coil, the coil moves in the constant magnetic field. Its movements are transmitted to the test object by means of a thin-walled glass tube (10). To prevent lateral displacement of the rod a second, very soft, membrane (11) is used. Oscillations of the system are easily prevented by oil damping. In some cases to increase the damping effect a light disc (14), moving in the chamber (12) containing oil (13), is fitted over the rod. To increase the amplitude of the oscillations, the magnetic gap of the system (between the elements of the magnetic circuit—the core of the magnet (1) and the iron closing ring (3) into which the coil is placed) must be made as small as possible (1.0-0.8 mm). The approximate number of turns in the coil must be 700-1200 (PEL wire 0.07-0.04 mm in diameter is usually used).

To obtain mechanical stimuli with a sufficiently steep leading edge, the weight of all moving elements of the system must be as small as possible. The body of the coil (6) and the membrane (4) have therefore been made in some cases from pressed foam plastic or from paper soaked with glue. To improve reproduction of high frequencies an EMS with more rigid membranes may also be made. Metal membranes may be used, for instance, if thin enough. However, such EMS usually generated strongly oscillating stimuli, very difficult to damp down. The end piece of the glass rod may be made detachable. In this way the same EMS can be used to stimulate different parts of the surface of the test object. In some cases the diameter of the tip of the glass rod in the experiments was a few microns, while in other experiments it was 1.5-2 mm.

During the experiment the EMS was fixed to a micromanipulator (MM-1) by means of a stout metal rod (16) and was brought near to the test object under control of a long-focus binocular loupe (MBS-2). To avoid accidental movements of the EMS in a vertical direction, the concavo-convex sliding disks of the micromanipulator were replaced by parallel flat disks.

By means of the EMS mechanical impulses of both small and of very considerable amplitude (from 0 to several millimeters) can easily be obtained. High frequencies are reproduced by such converters less well than by piezocrystals. For practical purposes, however, it is not essential to use rhythmic stimulation in the experiments.

The EMS reproduces frequencies of 1-2 kc perfectly satisfactorily. The amplitude of the mechanical impulses generated by such stimulators bears a linear relationship with the magnitude of the electrical pulses applied over a sufficiently wide range of displacements.

When working with mechanoreceptors it is extremely important to record the amplitude, duration, and shape of the mechanical stimulus in the course of the actual experiment. However, because of technical difficulties, most investigators have, until recently, recorded the mechanical impulse outside the

---

Laboratory of General Physiology of Reception, I. P. Pavlov Institute of Physiology, Academy of Sciences of the USSR, Leningrad. Presented by Academician V. N. Chernigovskii. Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 64, No. 10, pp. 100-103, October, 1967. Original article submitted December 31, 1965.

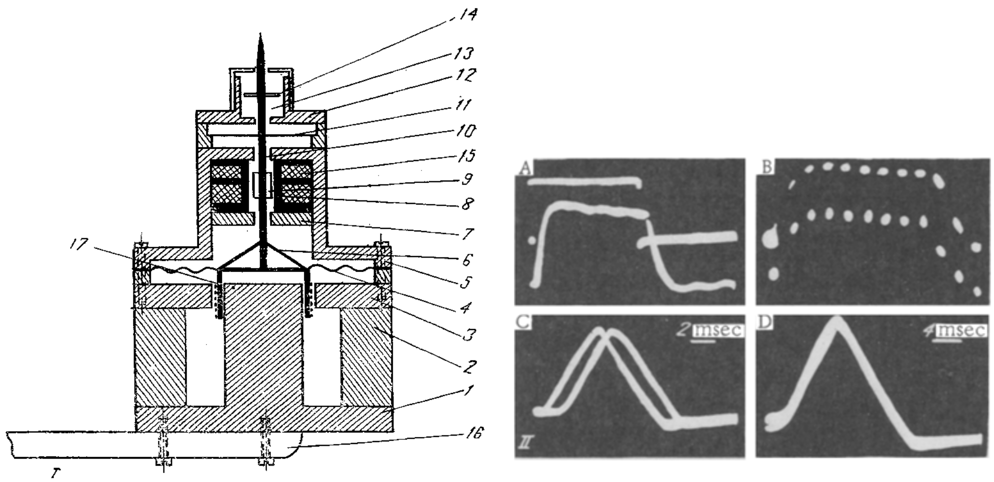

Fig. 1. Diagram of construction of electrodynamic system (I) and specimens of mechanical impulses generated by the electrodynamic system (II). A) Top beam—shape of electrical pulse, bottom beam—shape of mechanical impulse described by means of an inductive pick-up; B) left tracing—shape of electrical pulse, right tracing—mechanical impulse of electrodynamic system corresponding to this pulse; C and D) top beam—tracing of shape of mechanical stimulus by means of a photoelectric pick-up, bottom beam—tracing of shape of this same stimulus by means of an inductive pick-up. Sweeping speed the same in A and B. Time markers in C,0.2 msec. Remainder of explanation in text.

experiment, in specially selected conditions [3, 8, 11]. On the other hand, in cases when the mechanical stimulus could be recorded during the actual experiment, as a rule a photoelectrode method was used [2, 4, 9, 10, 12], and although accurate, this is not convenient enough in use. A capacitance method [7] or a mechanotron [6, 14] has been used much less frequently.

In recent years, besides a photoelectric method the authors have used an inductive method of recording the mechanical stimulus. This method has proved accurate and convenient enough in work, and it can be recommended for use in experiments with various mechanoreceptors.

The construction of the inductive pick-up is shown diagrammatically in Fig. 1I. An outline coil (8), made in two sections with thin (0.12-0.15 mm) wire (15), is housed inside the screening case of the EMS (5 and 7), and a small piece of soft iron (9), the core of the coil, is fixed to the glass rod. Displacement of the core disturbs the contour of the master oscillator, and this can be recorded by means of the special instrument illustrated in Fig. 2I. The master oscillator in the recording instrument (generating oscillations with a frequency of the order of 1.5-2 Mc) is assembled on one half of a 6N3P tube. High-frequency loading of the cascade is by means of a choke-coil. The cascade of a high-frequency amplifier, working in class C conditions, is assembled on the other half of the tube. An RC filter is used for high-frequency filtration. The low-frequency amplifier is constructed on a 6Zh5P tube. The contour of the master oscillator is tuned to resonance by means of the capacitor C_1. Work with the system is carried out in the linear segment of its characteristic curve.

Specimen tracings obtained by means of the method described are given in Fig. 1II. Electrical stimuli fed into the input of the EMS (A and B) are given for comparison, and in addition the shape of the mechanical impulse recorded by inductive and photoelectric methods is compared (C, D). It can be seen that the shape of the mechanical stimulus recorded by the two different methods is practically identical.

When analyzing the properties of mechanoreceptors, it is very important to be able to stimulate them with mechanical impulses of different duration and shape (rectangular, sinusoidal, saw-tooth, etc.). In addition it must be possible to apply single and double impulses, and also to stimulate the receptors rhythmically. Such a wide variety of electrical pulses, to be fed into the input of the EMS, can be generated by means of the NGPK-3M* generators of Soviet manufacture, and also by devices constructed by the authors

*The NGPK-3M is an ultra-low frequency generator. However, its circuit can easily be modified to widen its range of oscillations toward the higher frequencies.

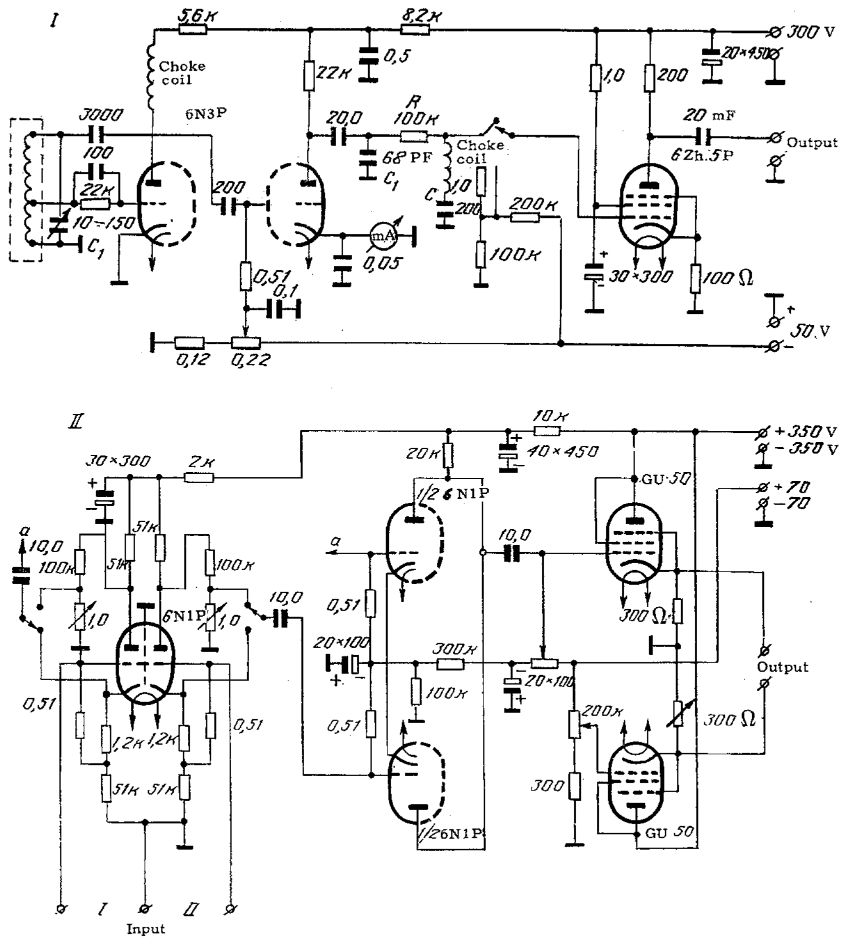

Fig. 2. Circuits of the inductive pick-up I, mixer, and matching device II. Explanation in text.

themselves enabling pulses from different generators to be mixed and separated, and also enabling the output of the generators to be matched with pick-ups, whose internal resistance is small (100-1500 Ω). The circuit of the matching and mixing device is shown in Fig. 2II. To obtain a low output resistance the output is constructed on the circuit of a cathode follower. For mixing two impulses of different polarity, two-phase-inversion cascades with separate loading are provided at the input of the circuit. The second 6N1P tube acts as mixer with a common anode loading. To ratard the pulse from the second generator relative to the first stimulus, a retarded pulse generator is used. So that the NGPK-3M apparatus may work in periodic triggering conditions, it is connected to the master oscillator. A type EI-1 instrument was used for this purpose. A system was introduced into its circuit enabling the synchro pulse fed into the oscillograph to be retarded behind the stimulus fed into the NGPK-3M. In some cases it was necessary to stimulate the mechanoreceptors by means of a second EMS. Sometimes, in addition, the nerve fiber of the receptor had to be stimulated electrically. In these cases either a second NGPK-3M or a GI-2A apparatus was used as generator.*

LITERATURE CITED

1. O. B. Il'inskii, Fiziol. Zh. SSSR, No. 2, 201 (1963).
2. R. Alvarez Buylla and J. Remolkina, Acta physiol. lat.-amer., Vol. 7 (1959), p. 178.
3. J. A. B. Gray and J. L. Malcolm, Proc. roy. Soc. B., Vol. 137 (1950), p. 96.
4. Idem., J. Physiol. (London), Vol. 115 (1951), p. 1.
5. J. A. B. Gray In the book: Handbook of Physiology. Sect. I. Neurophysiology, Washington, Vol. 1 (1959), p. 123.

*The authors are grateful to S. A. Evdokimov for his valuable advice and help.

6. R. H. Kay, Experimental Biology; Measurement and Analysis, New York (1964).
7. U. F. Lindblom, Acta physiol. scand., Vol. 44, 153 (1958).
8. W. R. Loewenstein and R. Altamirano-Orrego, J. gen. Physiol., Vol. 41 (1958), p. 805.
9. W. R. Loewenstein and M. Mendelson, J. Physiol. (London), Vol. 177 (1965), p. 377.
10. M. Mendelson, Med. Electron, Vol. 2 (1964), p. 185.
11. M. Ozeki and M. Sato, Physiol. (London), Vol. 170 (1964), p. 167.
12. Idem., Ibid., Vol. 180 (1965), p. 186.
13. M. Sato, Ibid., Vol. 159 (1961), p. 391.
14. L. Wendler, Z. vergl. Physiol., 47, 279 (1963).