THE USE OF HALL's EMF PICK-UP IN EXPERIMENTAL PHYSIOLOGY

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In some physiological and clinical investigations it is necessary to record the mechanogram of biological objects which it may be difficult or undesirable to attach to the recording device, or to connect with it by means of a beam of light (the human eyelids, the gills of fishes, the jaws of small mammals in long-term experiments). In such cases there are objections to the use of most of the pick-ups presently available for biomechanical measurements (pneumatic mechanotrons, ohmic and reluctance, capacitive, inductive, piezo, magnetic, photoelectric, etc.), for they must all be coupled to the object by one of the methods mentioned above [1, 11, 13, 16, 17, 19].

Physiologists are naturally interested in other forms of pick-up by means of which mechanograms could be recorded graphically (from various organs, muscles, etc.), without the need for contact with the test object or for fixation of a beam of light upon it. One such pick-up suitable for the no-contact recording of the mechanogram is Hall's emf pick-up, which is manufactured in the Soviet Union, but which at present is used only in physical experiments and for various technical purposes [2, 5, 14, 18].

Hall's emf is the name given to the transverse emf arising in conductors transmitting a current in a magnetic field. This emf is produced by deviation of the charges moving along the wire under the action of the Lorenz force. In the case of Hall's pick-ups, consisting of disks of semiconducting material with four electrodes soldered at their edges, Hall's emf may be expressed by the equation

$$E = 10^{-8}\,RHJ/t,$$

where E is Hall's emf (in volts); R* is Hall's constant (in cm^3/coul); H is the intensity of the magnetic field (in oersteds); I is the density of the current passing through the pick-up (in amperes); and t is the thickness of the disk (in centimeters).

Hence, other conditions being equal, Hall's emf is proportional to the ratio $\sin\varphi/r^2$, where φ is the angle in degrees formed by the vector of the magnetic field with the plane of the pick-up, and r is the distance from the pick-up to the magnet (in centimeters).

Using this relationship between Hall's emf and the position of the pick-up in relation to a constant magnet, distant recording of the position of a miniature permanent magnet fixed to a biological object (organ, muscle) and moving together with the object can be carried out. In our experiments we used n-germanium Hall's emf pick-ups, made by the special construction office of the Institute of Semiconductors of the USSR Academy of Sciences. The specification of these pick-ups is shown in the table. In order to protect the pick-up from moisture and mechanical injury, we sealed it in a hermetic cover of organic glass with four durable electrodes on the outside and two holes for attachment of the pick-up by screws to a stand or to the object (Fig. 1). In our experiments a thin, flexible wire was soldered to the electrodes, and miniature permanent magnets, weighing about 50-100 mg, made of barium alloy with high magnetic properties, were fixed to the objects. The size and shape of these magnets and also the method of fixing them and the pick-ups depended on the purpose of the investigation (Figs. 2 and 3). In every case we tried to

* The value of Hall's constant R depends on the material from which the pick-up is made, and it reaches its greatest value in indium-antimony, germanium, and certain other semiconductors, distinguished by the low concentration and high mobility of the charge carrier.

Specification of Hall's emf Pick-Ups Made by the SCO of the Institute of Semiconductors of the USSR Academy of Sciences

Characteristics of pick-ups	Material of Pick-ups		
	crystalline germanium	crystalline indium-antimony	mercury-selenium film
Input (and output) resistance (in Ω)	500-5,000	0.1-1.0	5-50
Maximal dissipation power in air (in watts)	0.1 + 0.15	0.1-0.15	0.05-0.1
Sensitivity (in μV/1 oe)	120-200	150-200	40-60
Maximal current (in A)	0.03-0.05	0.5-1	0.05-0.1
Maximal voltage (in V)	5-10	0.5-1	1-2
Mobility of carriers (in cm^2/sec)	$2\text{-}3, 10^3$	$3\text{-}50, 10^3$	$2\text{-}4, 10^3$
Concentration of carriers (in cm^{-3})	10^{14}	10^{16}	10^{17}
Temperature coefficient of resistance (in % per 1°)	0.4-0.5	0.5-1.5	0.1-0.05
Limits of practical application	From 0.1 oe to 20,000 gauss		
Coefficient of nonequipotentiality (in %)	Less than 2	Less than 2	Less than 1
Dimensions (in mm)	From 5 × 3 × 0.5 to 8 × 5 × 0.5	From 5 × 3 × 0.5 to 8 × 5 × 0.5	From 5 × 10 × 0.1 to 15 × 25 × 0.1

create conditions which would permit considerable changes in the power of the magnetic flux crossing the pick-up in response to a small displacement of the object with the magnet in relation to the pick-up.

After compensation of the nonequipotentiality of the Hall's electrodes and amplification (by means of a direct current amplifier or an alternating current amplifier with conversion at the input and rectification at the output), the Hall's emf was recorded on an oscillograph (see Fig. 2). Specimen tracings of various physiological processes produced by this method are shown in Fig. 3. Ink recordings were made by means of the OCh-2 oscillographic apparatus, constructed by the experimental group of the V. M. Bekhterev State Psychoneurological Institute, with a direct current pre-amplifier, the total sensitivity of the whole apparatus being 5 μV/mm of the ink tracing.

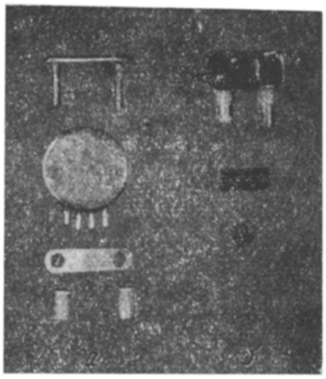

Fig. 1. Hall's emf pick-up in exploded (on the left) and assembled forms and the nuts and bolts for fixing the pick-ups to a stand or to the object (natural size).

From working with this apparatus it may be concluded that the use of this suggested method of recording by means of the Hall's emf pick-up as applied to several physiological processes is more efficient than methods previously used.

For example, recording the respiratory movements of the fish by means of Marey's capsules [4], Engelmann's levers [10], and so on, can be done only if the fish is fixed, which may affect its respiratory rhythm. The same applies to pneumatic transmission from a mask, as is usually used to record the movements of mastication [9, 6], which not only is unsuitable for recording mastication in small mammals in chronic experiments, but may also exhibit spring resistance to the lower jaw movements of larger animals or man. The noncontact method of recording the blink reflex does away with the need to fix the pick-up in a carefully selected position on the object and to connect it to the upper eyelid of the subject to be investigated, as must be done if Marey's capsules are used for this purpose [7, 3], or microphone pick-ups [13], contact transformers [1], and so on. Finally, the recently constructed inductive pick-up for noncontact tracing of the mechanogram of the internal organs in acute experiments [16] reacts, like the Hall's pick-up, to the displacement of a ferromagnetic disk connected to the object, but it is much larger and more complicated to construct than the Hall's emf pick-up.

The Hall's emf pick-up has a number of disadvantages: sensitivity to the earth's magnetic field, shown only after high amplification and movement of the pick-up in relation to the earth; the photoelectric effect; dependence on temperature (see table), requiring the use of a thermocompensatory scheme [5]; some difficulty in calibrating the readings when the distance to the magnet and the vector of the field created by it change simultaneously. At the same time, this pick-up possesses essential advantages. These include: 1) absence of inertia; 2) high sensitivity to the magnetic field, enabling changes in its intensity of 10^{-3}-10^{-7} oe to be detected by means of certain (indium-antimony) pick-ups of this type [2, 5, 14]; 3) the linear relationship between the signal obtained and the intensity of this field, and its suitability for static and dynamic measurements [2, 5, 14]; 4) the possibility of operation from both direct and alternating current [2, 5]; 5) its small size; and 6) its suitability for noncontact recording of the mechanogram from a distance of up to 5-10 cm or more. Because of these advantages of Hall's emf pick-ups, they may be used in certain medical and biological apparatuses (for example, apparatuses for ballistocardiography, cardiac catheters, and phonocardiographs) as detectors of displacement, pressure, vibration, etc., instead of the pick-ups of the various types in use at the present time, especially the magnetoelectric.

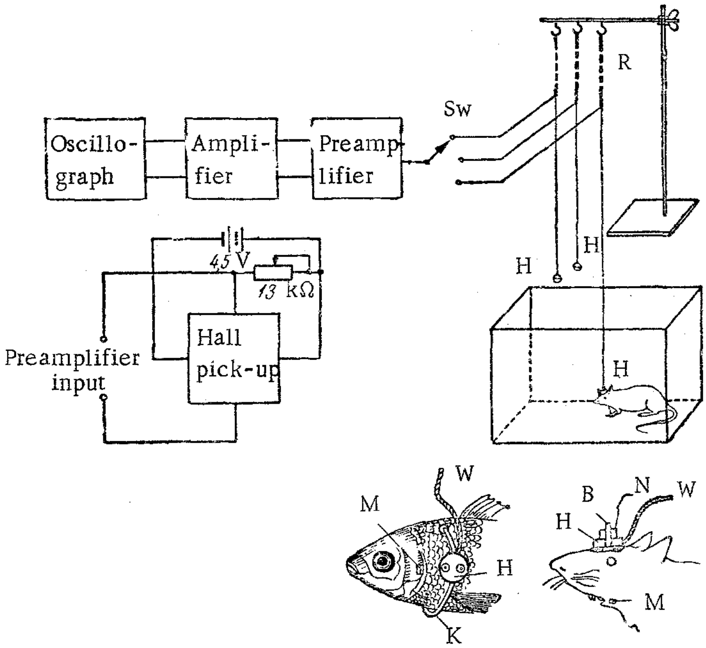

Fig. 2. Scheme of the apparatus, the compensation scheme for the pick-ups, and the method of fixing them to certain objects. Sw–switch; H–Hall's pick-up; B–bolt to fix pick-up to object; N–nut for this bolt; M–magnets fixed to object; W–wire to pick-up; R–long (1.7 m) rubber band preventing entangling of the wires; K–double wire hoop.

There is reason to suppose that the field of application of the Hall's emf pick-up in experimental biology is not restricted to biomechanical measurement, and will be considerably expanded in the future. For instance, the use of magnetometers with sensitive Hall's emf pick-ups may lead to the development of new methods of large-scale labeling of small animals (commercially bred fish, insects, etc.) with miniature magnetic tags.

Finally, it would seem to be of considerable scientific interest to measure the Hall's effect on biological objects themselves [8]. Although on account of the low mobility of ions this effect cannot usually be observed in conductors of the second order [8, 15], according to the most recent data [12] it may attain a perceptible magnitude in nerve tissue, in which it shows a quantitative relationship to its functional state.

Although it is obvious that these results require confirmation, they can justifiably be regarded as evidence that besides the electrolytic mechanism of conduction of current in the tissues there is also an electric mechanism. It must be supposed that in such a case further parallel measurements of the electrical conductivity and the Hall's emf of different biological objects would provide information of the utmost value to biophysics concerning certain properties held in common by semiconductors and living matter, and primarily in relation to the type, concentration, and mobility of the carriers of the current in tissues in various functional states.

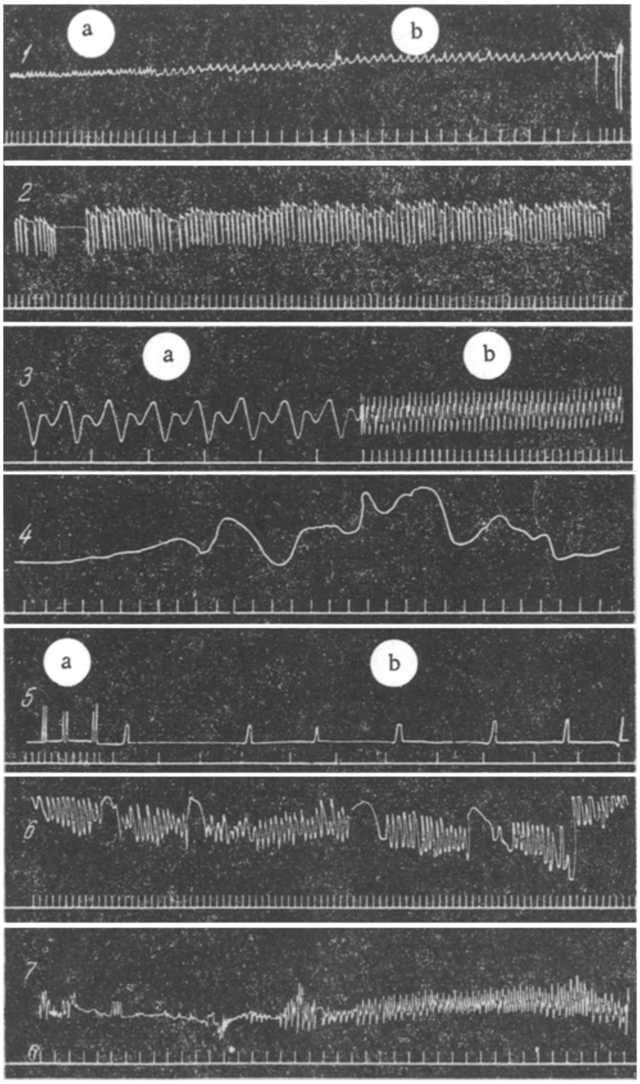

Fig. 3. Specimen tracings of various physiological processes obtained by means of Hall's emf pick-ups. 1) Tracing of the respiratory movements of the golden carp (time marker – 1 sec). A magnet, impressed into a piece of foam rubber (3 × 2 × 1 mm with transverse magnetization) is sutured to the gill cover of the experimental fish, and the pick-up, suspended from its rubber shock-absorber by a thin, flexible wire, is fixed by two small screws to the corresponding side of a wire hoop passing through the muscle tissue of the dorsum of the fish and surrounding its body at the level of the beginning of the dorsal and pectoral fins (see Fig. 2); 2) pneumogram of a frog (Rana temporaria) (time marker 1 second). The pick-up is placed beneath a small box with a notch cut out for the head, in which the frog is placed; a magnet (3 × 2 × 3 mm with transverse magnetization is glued to the frog's respiratory membrane; 3) mechanocardiogram of a frog (time marker 1 sec). The magnet (2 × 3 × 3 mm) was fixed to the exposed heart of the immobilized animal and the Hall's emf pick-up, fixed to a stand, was brought to a position 3 cm above the magnet; 4) motor activity of the small intestine of the frog (time marker 5 sec). The magnet (2 × 3 × 3 mm) was placed on the alimentary tract of an immobilized, laparotomized frog. Method of fixation of the pick-up as in the preceding experiment; 5) blink reflex in man (time marker 1 sec). The magnet (2 × 2 × 1 mm) with transverse magnetization was fixed with adhesive tape to the subject's upper lip. The pick-up was fixed to the spectacle lens; 6) tracing of movements of mastication in man (time marker 1 sec). The magnet (5 × 3 × 8 mm with transverse magnetization) was glued to the subject's chin and the pick-up to his upper lip; 7) lower jaw movements of an albino rat (tracing made in an animal behaving freely) (time marker 1 sec). The magnet (3 × 2 × 1 mm with longitudinal magnetization) was implanted beneath the skin of the lower jaw of the experimental rat and the Hall's emf pick-up was fixed by nuts on two bolts secured to a small brass plate, embedded in dental cement, poured over the animal's skull exposed by removal of the skin. The wire to the pick-up hung from a rubber shock-absorber above the box, open at the top, in which the rat was kept, and did not restrict its movements.

SUMMARY

In mechanographic recording of some physiological functions (masticating movements of small mammals, blinking reflex) it is difficult and undesirable to connect the object with the recording device. This connection may be avoided by attaching to the object a miniature constant magnet (weighing about 50-100 mg) and conducting a remote recording of the shifts of the latter by means of the Hall's e.m.f. pickup. The value of the galvanomagnetic e.m.f. occurring in the pickup, which is proportional to the intensity of the magnetic flow crossing it, may be recorded on the oscillograph after amplification and transformation. Remote recording of the following was performed: the motions of the lower jaw of small rodents in chronic experimental conditions, respiratory motions of the freely moving fish, blinking reflex of man, mechanocardiogram of frog, etc.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.