A CONTACTLESS METHOD OF KINETOCARDIOGRAPHY

M. N. Tumanovskii, V. S. Postnikov,
V. M. Provotorov, and B. F. Filyakin

UDC 616.12-073.4-073.96

An electrometric transducer enabling contactless recording of low-frequency vibrations of the patient's chest wall is suggested. Circuits used in the instrument provide kinetocardiograms of stable amplitude. By altering the parameters of the transducer (time constant of the input circuit), kinetocardiograms of displacement or velocity can be obtained as the investigator wishes.

Existing contact methods of kinetocardiography [1-3, 5, 6] have a number of disadvantages due to the inconvenience of fixing the detector to the patient's body, to the distorting effect of the transducer converting mechanical waves into electrical, and to the psychological emotional influence of these methods on the patient.

An attempt to develop a contactless method of investigating the mechanical activity of the heart, based on recording changes in its volume and position with the patient in a high-frequency capacitor electric field, has been described in the literature [7]. Mechanical oscillations of the heart are transformed into electrical waves at high frequency, and the high-frequency potentials are subsequently converted into low-frequency.

The method of contactless free kinetocardiography now suggested enables low-frequency vibrations of the heart in the range 1-12 Hz to be reproduced without further transformations of the useful signal. The input electrometric transducer consists of an amplifier with high input resistance of the order of 10^9-10^{10} Ω and low input equivalent capacitor of the order of 1 pF, the input of which incorporates a probe electrode consisting of a metallic disk 30 mm in diameter.

The theoretical circuit of the input electrometric transducer is shown in Fig. 1. The probe electrode E is connected through the isolating capacitor Cs to the regulatory grid of an electrometric tube L_1. A stable voltage source B is connected through resistor R to the probe electrode. Resistor R_l is the leak resistor of the electrometric tube, to which the amplification cascade is connected. Capacitor Cs isolates the dc voltage source B from the circuit of the regulator grid. The variable voltage from the tube anode is fed through a connecting cable to a standard electrocardiograph of the ÉKPSCh type for further amplification and recording.

By means of the electrometric transducer, mechanical vibrations of a test area of the chest wall can be recorded at a distance by detecting the electric field due to natural or artificial charges on the patient's body. Since the natural charges, resulting from a polarization effect, are unstable, a stable source of constant voltage was used to supply the necessary energy for charging the parametric capacitor formed by the probe electrode and the surface of the patient's body. In this way, during transformation of mechanical oscillations into electrical, the voltage source B constantly charges the parametric capacitor. The magnitude of the charge on the capacitor is determined by its capacitance and the voltage of source B, which is chosen with the object of obtaining a useful signal of adequate strength, on the one hand, and freedom from clipping in the anode-grid circuits of the tube, on the other hand; its value is 10-20 V.

Department of Internal Medicine, Voronezh Medical Institute. Department of Physics of Metals, Voronezh Polytechnic Institute. (Presented by Academician V. V. Parin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 70, No. 11, pp. 121-123, November, 1970. Original article submitted September 13, 1969.

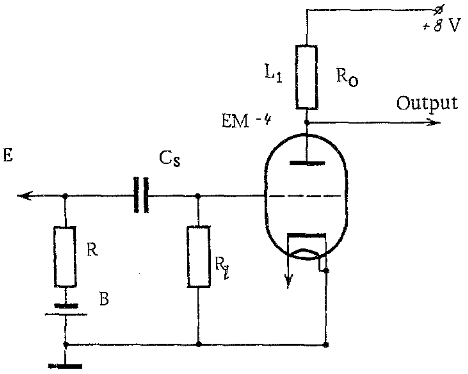

Fig. 1

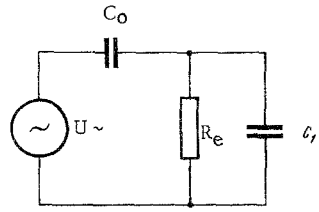

Fig. 2

Fig. 1. Theoretical circuit of input electrometric transducer (explanation in text).

Fig. 2. Equivalent diagram of input circuit of transducer (explanation in text).

During the investigation the patient lies on his back. The probe electrode together with the input transducer is fixed to a stand above the patient's chest. A standard gap (10 mm) is maintained between the patient's body and the probe electrode. The kinetocardiogram is recorded during voluntary expiration. The probe electrode is projected alternately on the desired points of the precardial zone. Movements of the test area of the patient's body generate an emf at the output of the electrometric transducer.

Mechanical vibrations (displacements) of the part of the body under the probe electrode are transformed into oscillations of the electric field of the parametric capacitor formed by this electrode and the surface of the patient's body beneath it. This capacitor can be called parametric, because its capacitance is a parameter of the recording system carrying out the conversion. Movements of the body cause changes in the distance between the plates of the capacitor, i.e., changes in its capacitance and the voltage on it. The necessary energy for transformation is provided by the stable dc source B, which charges the parametric capacitor to a voltage U_0. Let the mechanical displacement of the tested area of the body be described by the function: U(t). It can be shown that the voltage at the input of the electrometric transducer changes in accordance with the same law. The distance between the plates of the parametric capacitor is determined by the equation:

$$d = d_0 + \Delta d \cdot Y(t),$$

where d_0 is the mean distance between the plates and Δd is the maximum displacement of the tested part of the body from its mean position.

A change in distance between the capacitor plates leads to a change in its capacitance and in the voltage on it. The capacitance of the capacitor is determined by the formula:

$$C = \frac{\varepsilon S}{d},$$

where ε is the dielectric permeability of the dielectric between the capacitor plates, S the area of the plates, and d the distance between them.

The momentary voltage on the capacitor can be expressed through the charge q and capacitance C as follows:

$$U = \frac{q}{\dfrac{\varepsilon S}{d_0 + \Delta d \cdot Y(t)}} = \frac{q}{\dfrac{\varepsilon S}{d}} + \frac{q}{\dfrac{\varepsilon S}{d}} \cdot Y(t) = \frac{q}{C_0} + \frac{q}{\Delta C} \cdot Y(t). \qquad (1)$$

In the expression obtained above the first term is the constant voltage $U_0 = q/C_0$, and the second term the variable voltage $U\sim = (q/\Delta C) \cdot Y(t)$, which changes in accordance with the same law as the mechanical displacements of the test area of the body.

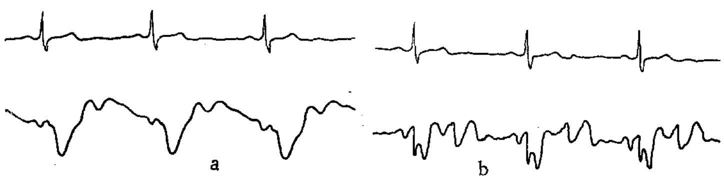

Fig. 3. Kinetocardiograms of displacement (a) and velocity (b) recorded in subject N., aged 29 years, from the region of the fourth intercostal space near the right border of the sternum, in phase with the ECG (lead II).

It also follows from expression (1) that the parametric capacitor can be replaced by a capacitor $C_0 = \varepsilon S/d_0$ with constant voltage U_0 and a capacitor $\Delta C = \varepsilon s/\Delta d$ with a charge varying in accordance with the law:

$$q(t) = q \cdot Y(t).$$

connected in series.

In accordance with the above description, an equivalent diagram can be drawn for the variable current of the input circuits of the input transducer which, for practical purposes, determines its frequency characteristics (Fig. 2). In it, the parametric capacitor is represented by a variable voltage generator U~ and a constant capacitor C_0 which (for a probe electrode 30 mm in diameter and a gap of 10 mm between it and the subject's body) has a value of the order of 18 pF. The capacitor ΔC is much larger in capacitance than C_0, and on the equivalent diagram, like the isolated capacitor Cs, it is therefore disregarded. The equivalent resistor R_e consists of the leak resistor R_l, the resistor R, and the input resistance of the tube, connected in parallel. Capacitor C_1 consists of the input capacitance of the tube, the distributed capacitance of the leak resistor, and the stray capacitance of the assembly, connected in parallel, has a value of the order of 1 pF.

To record the kinetocardiogram of displacement, parameters of the input circuit must be so selected that the useful signal is passed without distortion. It is known [4] that for distortionless reproduction by means of a linear quadripole of a signal with active spectral width from the lower limiting frequency f_{ll} to the upper limiting frequency f_{ul} the following relationship must hold good:

$$\tau_1 \geq \frac{1}{2\pi \cdot f_{ll}} \quad (2)$$

and

$$\tau_2 \leq \frac{1}{2\pi \cdot f_{ul}}. \quad (3)$$

where $\tau_1 = R_e \cdot C_0$ (4) is the time constant of the input circuit in the low frequency region, and $\tau_2 = R_e \cdot C$ (5) is the time constant of the input circuit in the upper frequency region. Taking $f_{ll} = 1$ Hz and $f_{ul} = 12$ Hz, we obtain from expressions (2) and (3) $\tau_1 \geq 0.16$ sec and $\tau_2 \geq 0.013$ sec. It is easy to find from expressions (4) and (5) that R_e must be of the order of 10 Ω.

In the case of recording the kinetocardiogram of velocity, the input circuit of the transducer must perform differentiation, i.e., it must satisfy the condition:

$$\tau_1 \cdot 2\pi \cdot f \leq 1. \quad (6)$$

For signals with a frequency spectrum with highest frequency f_{max}, condition (6) will be expressed by:

$$\tau_1 \leq \frac{1}{2\pi \cdot f_{max}}.$$

Since $f_{max} = 12$ Hz, for contactless recording of the kinetocardiogram of velocity, the time constant of the input circuit of the transducer must be:

$$\tau_1 \ll \frac{1}{2\pi \cdot 12 Hz} = 0.013 \text{ sec}.$$

Let τ_1 be chosen to be 0.001 sec. When $C_0 = 18$ pF, the equivalent resistance R_e must be $5 \times 10^7\ \Omega$.

By changing the parameters of the input circuit of the transducer, it is thus possible to record displacement (Fig. 3a) or velocity (Fig. 3b) of different points of the precardial zone separately and without distortion.

LITERATURE CITED

1. L. B. Andreev, in: Collected Transactions of Rostov Medical Institute [in Russian], Vol. 10, Rostov-on-Don (1959), p. 52.
2. L. B. Andreev, Collected Transactions of Rostov Medical Institute [in Russian], Vol. 12 (1960), p. 47.
3. L. B. Andreev, Klin. Med., No. 5, 12 (1961).
4. I. S. Gonorovskii, Radiotechnical Circuits and Signals [in Russian], Moscow (1963).
5. E. E. Eddleman, K. Willis, T. Reeves, et al., Circulation, 8, 370 (1953).
6. L. M. Rosa, Am. J. Cardiol., 4, 191 (1959).
7. L. M. Rosa, Cardiologia (Basel), 13, 33 (1948).