ULTRASONIC METHOD OF MEASURING CIRCULATION TIME

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D. D. Matsievskii

Laboratory of Physiological Electronics (Head—V. S.Sinyakov), Institute of Normal
and Pathological Physiology, Academy of Medical Sciences of the USSR, Moscow
(Presented by Active Member of the Academy of Medical Sciences of the USSR V. V. Parin)
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The principle of operation of an ultrasonic flowmeter consists of measuring the time difference of the transmission of ultrasonic oscillations with and against a flow between two similar piezoelectric sensors. In 1958 Franklin and Ellis [3] proposed an impulse ultrasonic flowmeter. This instrument measures the time shift occurring upon propagation of a pulsed ultrasonic signal with and against a flow. The impulse method makes it possible to synchronize several instruments in time, which permits simultaneous recording of the blood flow in closely situated vessels. As a consequence, Franklin improved the instrument so much that he successfully recorded a circulation time of less than 1 cm/sec [4]. Hence, we used the principles proposed by Franklin when designing an instrument.

The principle of action of the instrument is as follows. Piezoelectric sensors placed on opposite sides of a vessel at an angle to its axis are alternately switched to the transmitter and receiver. The frequency of switching is 400 cps. Thus, during one half-period of the switching frequency, the ultrasonic wave is propagated along the blood flow and during other half-period, counter to it. A special circuit generates sawtooth pulses whose duration is determined by the traveling time of the ultrasonic wave between the transmitting and receiving piezoelectric sensors.

Propagating along the flow, the ultrasonic wave reaches the receiving piezoelectric sensor more quickly than when propagating against the flow. Thus, the sawtooth voltage is a modulated signal of the switching frequency. The sawtooth voltage is fed to the peak detector at the output of which is the signal of the switching frequency amplitude characterizes the value of the blood flow and whose phase, the direction. The circulation time is determined by the formula:

$$V \approx \frac{\Delta t C^2}{2S \cdot \mathrm{Cos}\,\alpha},$$

where Δt is the difference of travel time of the ultrasonic wave along and against the flow; S is the distance between piezolectric sensors; α is the angle at which the ultrasonic wave intersects the axis of the vessel; C is the velocity of the ultrasonic wave in tissues and blood equal to 1,500 m/sec.

The block diagram of the instrument is shown in Fig. 1 and the diagram of the voltages acting in the circuit of the instrument is shown in Fig. 2.

The main element synchronizing the work of the instrument is the master oscillator (1) which generates a sinusoidal voltage with a frequency of 800 cps and controls the operation of the synchronizing circuit (4,7,9). The latter sends out the following signals:

pulses with a frequency of 800 cps for triggering the transmitter (2, 3);

pulses with a frequency of 800 cps for cutting off the receiver (10) during operation of the transmitter;

pulses with a frequency of 800 cps for discharging the reservoir capacitor of the peak detector (15);
square-wave voltage with a frequency of 400 cps, for powering the vibroswitches (6);

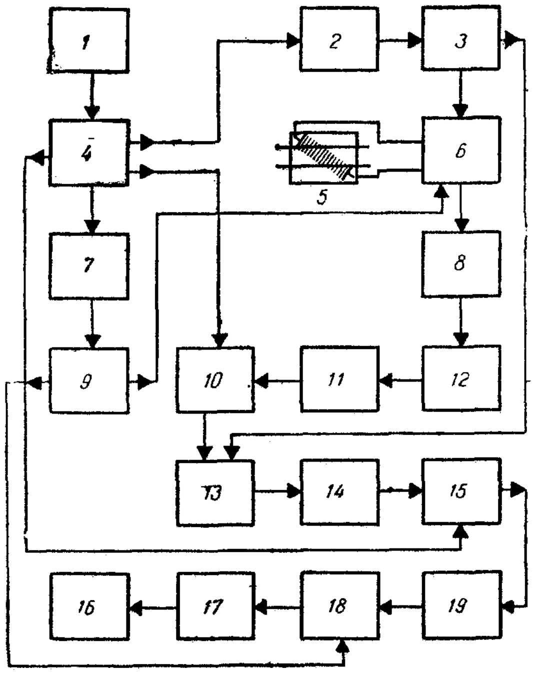

Fig. 1. Block diagram of instrument. Explanation in text.

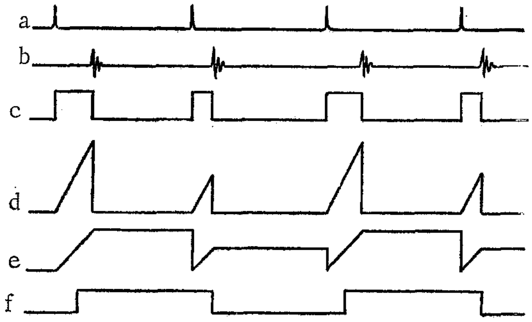

Fig. 2. Tension diagram. a) Transmitter pulse; b) receiver pulse; c) trigger signal; d) sawtooth voltage; e) peak-detector signal; f) signal at input of phase-sensitive bridge.

square-wave voltage with a frequency of 400 cps, which is the reference signal for operation of the phase-sensitive bridge (18).

The transmitter (2, 3) generates pulses with a duration of 0.2 μsec, a frequency of 800 cps, and an amplitude of 850 V (Fig. 2a) for exciting the piezoelectric element. Flopover of the trigger (13) is accomplished by this pulse. The pulses are fed to the receiver (8, 10, 11, 12) through the vibroswitches (6). The receiver includes the following elements: amplifier V4 (8), detector (12), video amplifier (11), key (10). Data of the receiver: tuning frequency 2.5 Mc/sec, pass band 1 Mc/sec, amplification factor 30,000.

The trigger (13) generates a pulse (Fig. 2c) whose duration is determined by the traveling time of the ultrasonic pulses between the two piezoelectric sensors. During the first cycle (see Fig. 2) the ultrasonic wave is propagated against the blood flow and during the second cycle with the flow. The trigger controls the operation of the sawtooth voltage generator (14) so that its pulse duration (Fig. 2d) is determined by the duration of the trigger pulse. The sawtooth voltage is fed to the peak detector (15) whose reservoir capacitor is discharged before each new cycle of operation of the transmitter. Thus, the voltage across the output of the peak detector (Fig. 2e) is the modulated signal of the switching frequency.

The selective amplifier (19) is loaded on a phase-sensitive bridge. The output signal of the phase-sensitive bridge (Fig. 2f) is a direct-current voltage whose magnitude is proportional to the circulation time and whose polarity is proportional to the tension of the flow. This signal is amplified (17) and fed to the recorder (16).

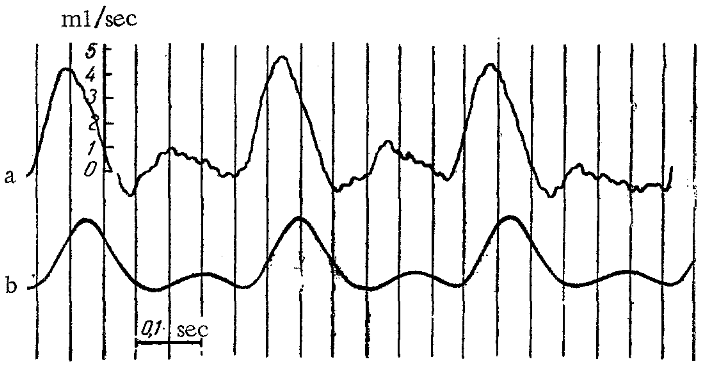

Fig. 3. Interrelationship between blood flow in right carotid artery (a) and pressure in front of sensor (b).

The sensor is a cuff made of styracryl (dental plastic) in which the piezoelectric elements are placed. Ceramic material of barium titanate with the addition of cobalt are used as the piezoelectric elements. On the side surface of the cuff is a longitudinal slit through which the blood vessel is brought inside. Since the cuff limits the distention of the vessel and the diameter of the vessel in the cuff is not changed, the instrument can be calibrated in volume units of circulation time (in ml/sec). The frequency response of the instrument is above 50 cps.

The described instrument was tested under an acute experiment on a dog. The blood flow was recorded in the right artery and the pressure in the vessel in front of the blood-flow sensor. The interrelationships between blood flow and pressure are shown in Fig. 3. The curve was calibrated in volume units of blood flow. The pulse value of the linear rate of blood flow was in this case about 20 cm/sec.

LITERATURE CITED

1. D. K. Franklin and R. M Ellis, Fed. Proc., 17, No. 1, Pt. 1 (1958) p. 49.
2. D. L. Franklin, D. W Baker, and R. F. Rushmer, IRE Trans. bio-med. Electronics, 9 (1962), p. 44.

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.