TELEMETRIC MEASUREMENT OF THE BLOOD FLOW BY ULTRASOUND

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A radiotelemetric system, based on the use of the Doppler effect, and suitable for measuring the blood flow in dogs allowed to move freely is described.

Pulsed ultrasonic instruments accurately reproduce the form of a pulsating flux and have been successfully used in investigations with implanted sensors on experimental animals, and also during catheterization in clinical practice [1, 3]. However, to study the hemodynamics in freely moving animals or under other conditions preventing direct communication with the test object it is essential to have a compact and economic apparatus. This problem can be solved by using the properties of spread of continuous ultrasound waves in moving blood [2].

When ultrasound is emitted into a blood vessel, a signal of changed frequency reaches the receiver-transducer. The frequency of this signal depends on the velocity of blood flow through the Doppler effect and can be determined by the following arguments.

Ultrasound sent at an angle into a blood vessel undergoes changes of frequency. Initially, on entering the moving blood (in a direction away from the emitter), its frequency is determined by the formula:

$$F_1 = F\frac{C - V\cos\alpha}{C},$$

where V is the velocity of blood flow; C the velocity of spread of ultrasound in blood; F the frequency of the emitted ultrasound; and α the angle of inclination of the emitter.

Scattered radiation reflected from the blood cells is then received by the piezo-crystal receiver, arranged at the same angle. The frequency of ultrasound received is determined by the formula:

$$F_2 = F_1\frac{C}{C + V\cos\alpha}.$$

The velocity of the blood flow is proportional to the difference (ΔF) of frequencies of the ultrasound emitted and received, and can be determined by the formula:

$$V = \frac{\Delta F \cdot C}{2F \cdot \cos\alpha}.$$

The formula assumes that the greatest possible velocity of blood flow V (2 m/sec) is always much less than the velocity of spread of ultrasound C in blood (1500 m/sec).

Using this principle a radiotelemetric system has been developed and for 18 months it has been used to measure the blood flow in freely moving dogs.

The block diagram of the system is given in Fig. 1. The principal element of the system is a generator emitting with a frequency of 5 mHz. The matching cascade, consisting of a power amplifier, provides

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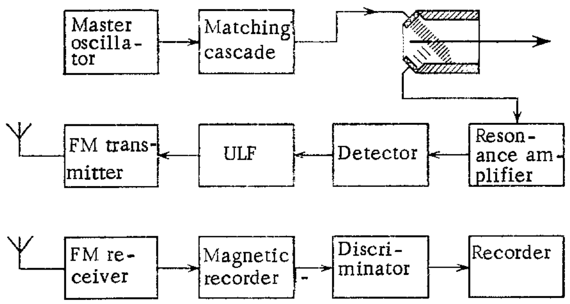

Fig. 1.

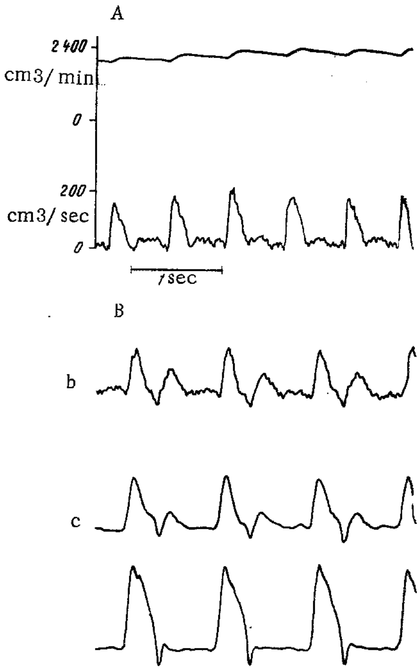

Fig. 2.

Fig. 1. Block diagram of telemetric system.

Fig. 2. Blood flow in descending aorta of a walking dog measured by the telemetric system (A) (curve above shows averaged value of flow) and comparative curve of blood flow in dog's carotid artery (B), recorded by the telemetric system (a) and with pulsed ultrasound (b), using implanted sensors (C – cardiac output reflected as pulsed ultrasound).

Fig. 3. Telemetric apparatus on experimental animal (consisting of a miniature Doppler flowmeter, an FM transmitter, a short rod antenna, and a power battery).

a voltage of 2-4 V and frequency of 5 mHz on the irradiated piezotransducer of the detector. The acoustic power thus developed is not more than 150 mW/cm^2.

Ultrasound reflected from the blood falls on the receiving piezo-crystal and, when mixed with the direct radiation as the result of its penetration, it is amplified by the resonance amplifier. This amplifier is based on a type IMM6.0 microcircuit employing planar silica transistors. The transmission band is 300 kHz and the amplification factor 60 dB.

The frequency of the oscillations detected is proportional to the velocity of blood flow, and is approximately 45 Hz/cm/sec. The low-frequency voltage from the detector is amplified and fed into a high-frequency generator (80 mHz), modulating the frequency of the oscillations produced by it. To change the frequency of generation by 150 kHz, 20 mV of low-frequency modulating voltage is required, and is applied to the base of the high-frequency transistor. The transmitter uses a power of about 70 mW. The high-frequency generator is loaded on a short rod antenna, emitting frequency-modulated waves. The velocity of the blood flow is thus frequency-modulated a second time.

The double frequency modulation used ensures high freedom of the telemetrized information from interference. The receiver is a portable radio receiver with an ultrashort waveband. In the experiments now described, a "Riga-103" radio receiver was used. To ensure reliable reception at a distance of 200-300 m, an antenna of the "wave channel" must be used. At a closer distance, the movable antenna of the radio receiver is adequate.

The telemetric information was recorded on magnetic tape (using the "Kometa-206" tape recorder) or fed directly into the input of a discriminator. The amplitude of the output signal of the discriminator is proportional to the frequency of the input signal, i. e., to the velocity of the blood flow. The scheme as used provides for one-way reproduction of flow. The blood flow was recorded on a "Mingograph-81" instrument.

The sensors consist of split half-cylinders, housing piezo-transducers. The angle of inclination of the piezo-crystals to the axis of flow is 45°. The material from which the sensors are made is protacryl. TsTS piezo-porcelain is used as the transducers.

During the implantation operations, performed by V. T. Selivanenko and S. A. Seliverstov, the sensors were fitted on the dog's ascending and descending aorta. The sensors worked normally under these conditions for 5-6 months.

The instrument measures the linear velocity of the blood flow. However, since the sensor is firmly applied to the blood vessel, and the cross section of the vessel at the point of measurement is constant, calibration in units of volume blood flow is possible (Fig. 2).

Preliminary investigations demonstrated that the Doppler frequency is a linear function of the volume of blood passing through the vessel, with deviations of not more than 6%.

In its construction the apparatus consists of three units: a master oscillator, an amplifier with detector, and a high-frequency generator. It measures 50 × 95 × 25 mm. When in use the apparatus was placed on the animal's back (Fig. 3). Its total weight together with the power source (2 "Krona VTs" batteries) is about 200 g.

LITERATURE CITED

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