The Use of Change in Capacity to Record Cardiac Volume in Human Subjects[1]

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A completely satisfactory method of determining cardiac output in man has not yet been devised. The direct Fick procedure and the various concentration methods, while theoretically sound, require considerable technical ability and facilities and are not applicable in the average laboratory or clinic. The ballistocardiograph, having the advantage of technical simplicity, is open to criticism on theoretical grounds and cannot be applied in situations where tachycardia or abnormal types of cardiac ejection are present. In a search for a method, both simple and widely applicable, we have begun investigations utilizing the change in capacitance of a condenser as a means of recording the volume changes of the intact heart; a method first used by Atzler and Lehmann in 1932 (*1*).

The condenser consists of two aluminum plates 15 cm in diameter placed before and behind the thorax so as to include the cardiac region in their field. The capacity of such a condenser is given approximately by:

$$C = 0.0885 \frac{AK}{K\ (D-T)} + T$$

where C = capacity; A = area of plates; K = dielectric constant of the chest; D = distance between plates; and T = thickness of the chest (*2*). The dielectric value of the chest is determined by the tissues and tissue fluids of the thoracic contents and by the air in the lungs. Under the conditions of measurement used, the dielectric constant for blood has been shown experimentally to be about 1.75 as compared with 1.00 for air. Varying amounts of blood in the field during the phases of the cardiac cycle thus change the dielectric value sufficiently to cause measurable changes in capacity. It should be noted that blood in the auricles and great vessels as well as in the ventricles contributes to these changes. In addition, movements of the heart will cause some change in capacity by moving blood closer or farther from the condenser plates, and respiratory movements of the chest wall will, likewise, produce capacity changes.

Atzler and Lehmann (*1*) placed their condenser in a resonant circuit, excited by an oscillator near its resonant frequency and connected to a diode detector. Thus, changes in capacity which would shift the frequency of the resonant circuit from that of the oscillator caused a change in the output of the diode which was amplified and recorded on a string galvanometer. A plot of output versus frequency for such a detector reveals a linear relationship over only a small region of the curve, resulting in difficulties of adjustment. To overcome these, we have used the frequency modulation discriminator to convert the changes in frequency to a measurable form. This has the advantage of simple adjustment and linearity of response, and allows the use of a limiter circuit to prevent amplitude changes from affecting the output.

The condenser is used as a portion of the frequency-determining circuit of an oscillator, the output of which is amplified by a broadband, high frequency amplifier and then by a pentode with low plate and screen voltages so

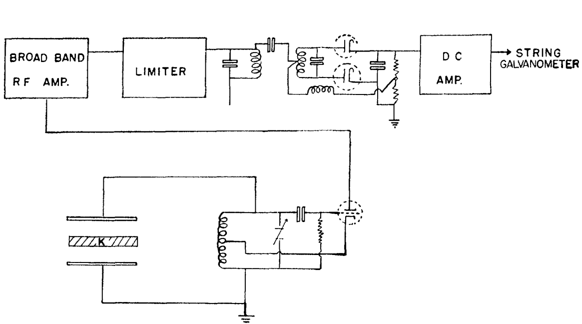

FIG. 1. Block diagram of circuit for recording capacitance changes accompanying the cardiac cycle.

that limitation of output with freedom from amplitude changes is accomplished. The output is fed to the discriminator which converts the changes in frequency to a d-c voltage that linearly represents the capacitative variations. This voltage is then amplified by a push-pull, direct-coupled amplifier and applied to a string galvanometer of the usual e.k.g. type. Fig. 1 presents a block diagram of the apparatus.

The choice of frequency is determined by several considerations. The chest is a poor dielectric substance and loss current as well as capacitative displacement current will be present.

The derivation from Roberts and Von Hippel (*3*) shows that the power factor $(\tan \delta) = \frac{\sigma}{\omega K}$; where σ is the conductivity of the medium, K is the dielectric constant and ω is the angular frequency. At low frequencies $\tan \delta$ is large and the loss current is maximized. At high frequencies not only are the power factor and loss current minimal, but a greater shift in frequency for a given change in capacity is present, with a resultant larger output. However, at ultrahigh frequencies absorption of the oscillator's energy takes place. As a compromise, for simplicity of circuits, we have chosen a frequency of 10.7 megacycles.

The apparatus is simple in adjustment and operation and gives consistent and reproducible records in both model and human experiments. Representative "cardio-dielectrograms" of normal human subjects are pictured

[1] Preliminary reports covering this work were presented at the Fall Meeting of the American Physiological Society, Minneapolis, Minnesota, September 16 and 17, 1948.

[2] The authors wish to acknowledge the assistance of Dr. Fred A. Hitchcock, Dr. Theodore Wang and Mr. George Jacobi during preliminary phases of this work conducted in the Laboratory of Aviation Physiology and Medicine, The Ohio State University, Columbus. They are also indebted to Mr. Craig Goodwin of the Department of Psychiatry, University of Illinois College of Medicine, Chicago, for helpful advice and the use of equipment in the course of the investigation.

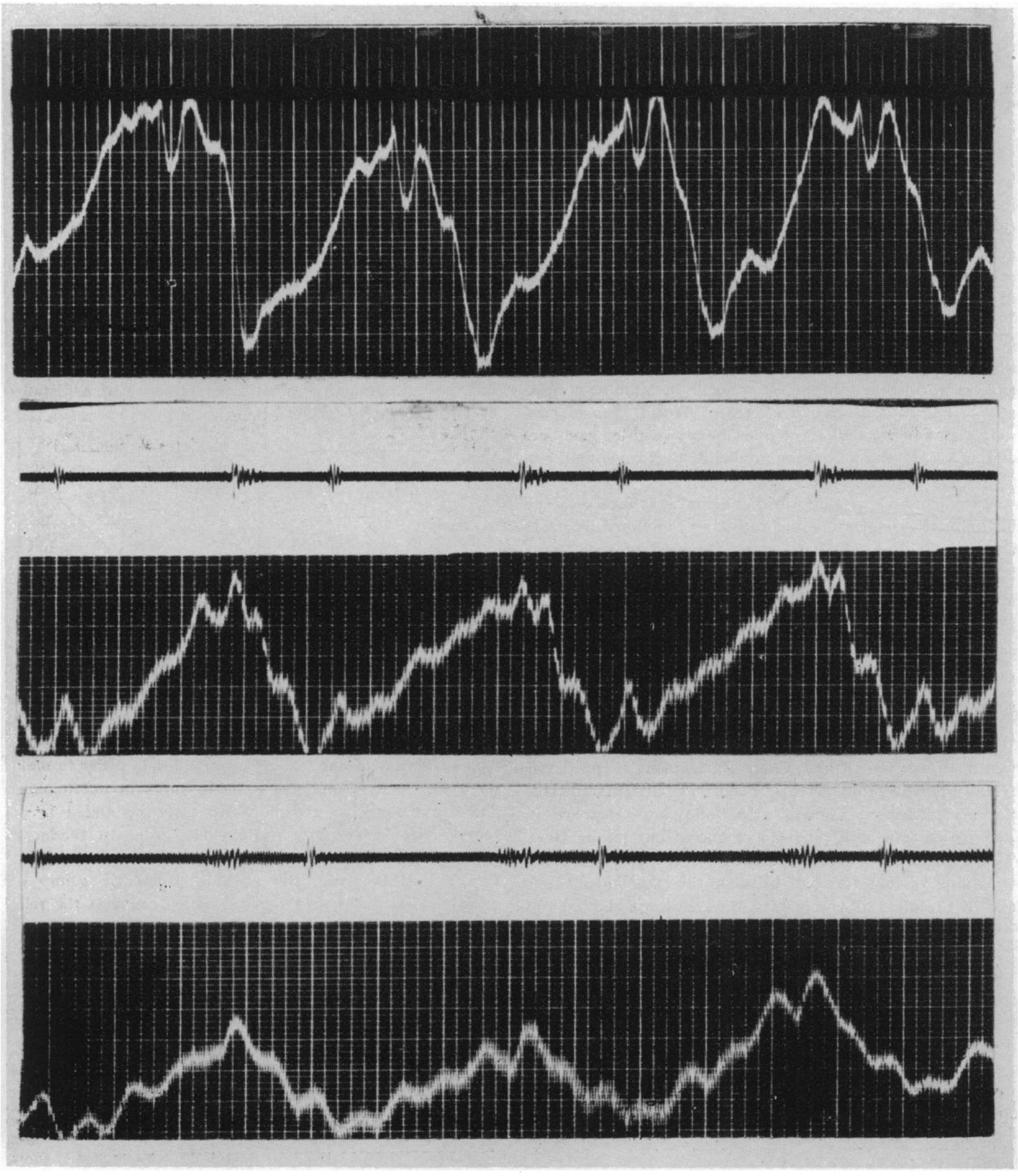

FIG. 2. Simultaneous recordings of phonocardiogram (above) and dielectrocardiogram (below) from normal human subjects. Time intervals are 0.4 sec. Downward deflection indicates a decrease in the volume of blood in the field.

in Fig. 2. Values for stroke volumes, cardiac output, and cardiac indices calculated from such records on the basis of preliminary calibration of the instrument by introduction of known volumes of saline between the plates, fall within the range of accepted normal values, but conclusions as to validity of the method are not yet possible.

Finally, it is obvious that the method is basically applicable to the study of movements and volume changes in other regions of the body.

References

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