# THE PHONOCARDIOGRAPHY OF HEART MURMURS

## PART I.—APPARATUS AND TECHNIQUE

BY

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It was considered important to subject the points made by William Evans (1947) to further examination by phonocardiography. We hoped to define the sphere of usefulness of this instrument in aiding the clinician in the diagnosis of patients presenting with murmurs of the heart.

The Cambridge Instrument Company kindly supplied a standard phonocardiograph outfit in every way similar to that used by Evans. It was decided to attempt a rough estimate of the suitability of this instrument by taking gross clinical examples of organic heart disease and subjecting them to phonocardiography, since it was considered axiomatic that the instrument must be able to record all the murmurs that could be heard on simple clinical auscultation. It was soon found that the standard instrument was incapable of recording the majority of relatively high pitched systolic and diastolic murmurs.

The Research Department of the Cambridge Instrument Company then kindly agreed to develop a modern apparatus from the new physical data that have been made available over the last twenty years; it was agreed that the clinical and scientific aspects should be closely co-ordinated. The apparatus is described later.

Those concerned with the visual recording of the heart sound vibrations must be grateful for the work of Rappaport and Sprague (1941 and 1942) in amplifying the basic data on which a reliable phonocardiograph should be constructed.

The heart sound vibrations are modified by the thoracic tissues as they radiate to the chest wall. This distortion will vary from person to person and is probably dependent largely on the amount of adipose tissue of the thoracic organs and of the chest wall itself and must remain an indeterminate variable in clinical phonocardiography.

Once the heart sound vibrations have reached the chest wall they are further modified for a clinician listening to the sounds with a stethoscope, by the stethoscope, which produces a certain degree of attenuation of sounds of low frequency, and by the human ear, which in the auscultatory range has a practically logarithmic low frequency attenuation response (see Fig. 2).

There are therefore three phonocardiographic records that may be considered physiological.

(1) A linear phonocardiogram. This is a visual record of the heart sound vibrations as they occur at the chest wall without any modification other than undistorted amplification, hence the term linear. The heart sound vibrations consist of an intense low frequency component (palpable but not audible) and a faint higher frequency component (audible). The linear phonocardiogram, however, resembles a jugular venous pulse record for it only shows the intense low frequency component. This component is 100,000 to 1,000,000 times more intense than the higher frequency vibrations which consequently cannot be shown on the same scale (see Fig. 9A and B, 11A and B, Part II).

(2) A stethoscopic phonocardiogram. This is a visual record of the heart sound vibrations from the chest wall as modified by an average stethoscope, that is as presented to the human ear. Such records will show low frequency events such as the third and fourth heart sounds as well as the whole range of murmurs and are the most generally useful phonocardiograms (see Fig. 4–8 and 10A and B, Part II).

(3) A logarithmic phonocardiogram. This is a visual record of (2) above, plus the additional modification of the average normal human ear. In other words it is a visual representation of the vibrations as presented to the sensorium of a listening clinician. The advantages of this type of record are firstly that its amplitude corresponds to the loudness heard by the clinician (a sound heard twice

as loud as another sound will be twice the amplitude of the other on the record); and secondly that as the low frequencies are extremely attenuated, a record taken from a patient with heart murmurs may be easier to interpret than one in which low frequency events are also recorded. Such a record should therefore be used to add to the information of a stethoscopic tracing (see Fig. 3, 9B, 10C, 11A and B, Part II).

It is necessary to record simultaneously some other manifestation of cardiac activity to provide a reference tracing for interpreting the phonocardiogram. The following tracings have been used for this purpose—the electrocardiogram, the subclavian or jugular venous pulse, the apex beat cardiogram and in special cases the arterial pulses.

The electrocardiogram has been used extensively because it can be recorded easily, but the only reliable reference point it gives is that mechanical ventricular systole never precedes the QRS complex of the electrocardiogram.

Since the electrocardiogram gives no reference points in diastole it is misleading to use it to determine the phase of the cardiac cycle of any diastolic event, either sounds or murmurs (see Fig. 5); it is, however, a valuable additional reference tracing to an apex beat or venous pulse recording, particularly when auriculo-ventricular dissociation is present or when there is some abnormality of propagation of the cardio-excitatory impulse.

The subclavian or jugular venous pulse gives, in addition to the onset of ventricular systole, the onset of auricular systole, the beginning of the second sound and a fair indication of the site of the third heart sound.

The apex beat tracing (linear phonocardiogram) gives the onset of ventricular systole, the beginning of the second sound and the third heart sound; it is as a rule easier to record by electrical means than the venous pulse and requires no time correction for vessel transmission of vibrations as does the venous pulse.

The heart sounds and most murmurs are noises in acoustic terminology, which means they are conglomerations of sound vibrations of various frequencies harmonically unrelated. In some cases, therefore, it is impossible to determine the exact onset of a murmur that follows a heart sound. Moreover, there is some variation in the vibrations recorded from one heart cycle to the next.

### The Phonocardiograph

The apparatus used consists of a crystal microphone, a two-stage valve amplifier, and a Cambridge double-string Einthoven galvanometer. One fibre of this galvanometer is used for the electrocardiogram in the normal way; the other, which is used for the phonocardiogram, is tightened to its full extent in order to raise its high-frequency response. In this condition its sensitivity is about 1 mV/mm.

From examination of our phonocardiograms it will be noted that large excursions of the phonocardiographic fibre displace the electrocardiographic fibre. It has been proved experimentally that this is an air pressure phenomenon and not an electromagnetic interference, and that the phonocardiographic fibre is not affected by large excursions of the electrocardiographic fibre. The explanation of this effect lies in the greater sensitivity of the loose electrocardiographic fibre when it is calibrated for clinical use.

The microphone used is a Cosmocord Mic-6. This microphone was originally chosen because of its high sensitivity and high internal capacity. It has the disadvantage of being nearly 2 inches in diameter, so that good contact between the microphone and the chest is not always easy to attain. The sensitivity is stated by the makers to be about 10 mV/dyne/sq.cm. in the phonocardiographic frequency range.

The microphone is placed in a brass case which forms the chest piece. A ring of sorbo rubber is cemented to the case to assure good contact with a chest wall of irregular contour. The volume of the air chamber coupling the chest wall to the diaphragm is about 14 ml. The case is not intended to have any selective frequency properties; the intention is that the microphone and amplifier should have a fundamentally flat response, any other type of response being produced by controllable electrical filters in the amplifier.

The amplifier circuit is shown in Fig. 1. As the output has only to operate a string galvanometer the gain is not high, the voltage gain from the input to the galvanometer terminals being 100. A switched attenuator, placed between the two stages, controls the gain in steps of 2: 1, and a universal shunt connected across the galvanometer gives continuous control of gain at any setting of the attenuator. In phonocardiography, calibration of the controls is of little value, but they must cover a very wide range in order to deal with the varying levels of heart sound vibrations encountered.

In order to make the fundamental response as flat as possible, a 10-megohm resistor is placed across the microphone, which has a capacity of 0·002 $\mu$F. This gives a time constant of 0·02 second which, since it is the shortest time constant in the whole system, will control the low-frequency response; it should result in the response being down to half at about 8 c/cs. As explained later, such a response was not obtained.

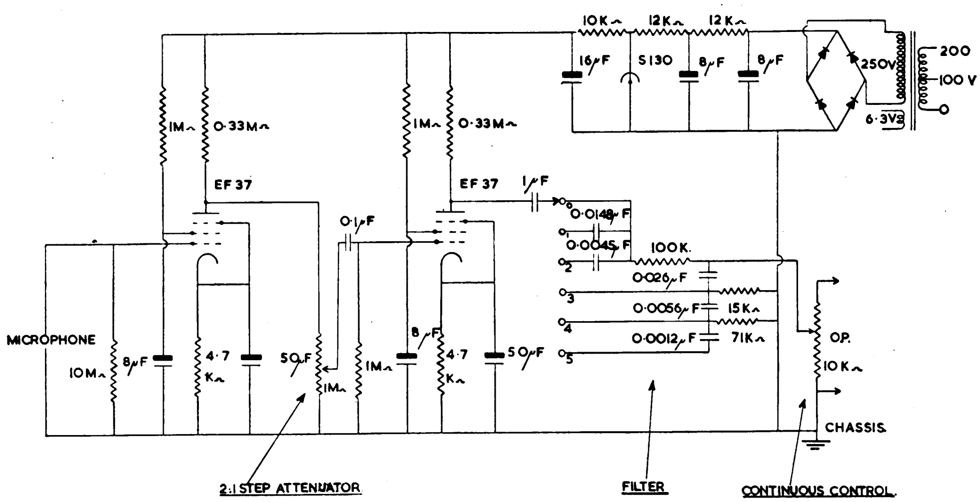


FIG. 1.—Amplifier circuit of phonocardiograph.

A 6-position filter, controlling the low-frequency response, is placed between the output stage and the galvanometer. At setting 0 the amplifier response is flat. At settings 1, 2 and 3 single-stage condenser-resistance filters, giving time constants of 0·0064, 0·002 and 0·0004 seconds respectively, are provided. These values give a loss of 3 db at 25, 80 and 400 c/s respectively, and a loss approaching 6 db/octave below these frequencies (stethoscopic phonocardiogram settings).

At settings 4 and 5, a 2-stage and 3-stage filter respectively are introduced, the time-constant of each additional section being 0·0004 seconds. These filters begin to cut off between 400 and 500 c/s (like that of setting 3) and give a loss approaching 12 and 18 db/octave respectively below these frequencies (logarithmic phonocardiogram settings).

Fig. 2 shows measured frequency responses for the assembly of microphone, amplifier, and galvanometer. These results were obtained by applying a variable frequency sound stimulus to the microphone with a pistonphone calibrator. Two points require comment. First, the low-frequency response at setting 0 is not flat; this is the result of accoustic leakage in the microphone assembly. The chief cause of this leakage is a felt ring which the makers fit round the rim of the microphone case. It is proposed in future to work without this ring, so that the response can be entirely controlled by the electrical circuit. Secondly, the response begins to fall above 500 c/s. This is the result of the galvanometer properties. The microphone has a resonance at about 2500 c/s, but the low galvanometer response at this frequency entirely masks this resonance. The high-frequency response attained is probably sufficient for the purposes of phonocardiography.

Conventional mains power supplies are provided. Rough HT stabilization is obtained by an S.130 gas tube, and the valve heaters are run on a.c. HT variations and heater pick-up are not unduly troublesome, but improvements in both these respects are desirable.

Special cable, type K.16 G.M. made by Telegraph Construction and Maintenance Co. Ltd., is used for the microphone input lead. This gives a very considerable reduction in the extraneous voltages produced when the microphone cable is moved in any way.

The advantages of a string galvanometer over other methods of recording high frequency phenomena are not great when an amplifier is essential. It was used in the research detailed in Part II because it was available. Comparative experiments have therefore been made with a double Duddell oscillograph, which has a wider frequency range and is more robust. This instrument, used in conjunction with appropriate amplifier circuits and a smaller microphone free from acoustic leakage, has been tried with promising results; Fig. 9A and B, 11A and B, Part II were taken with such an apparatus. The addition of an electrocardiographic channel is under consideration, but the whole of the apparatus is regarded as purely experimental at the moment.

The tracings are photographed at a speed which facilitates the accurate reading of phonocardiograms.

(References will be found at the end of Part II.)

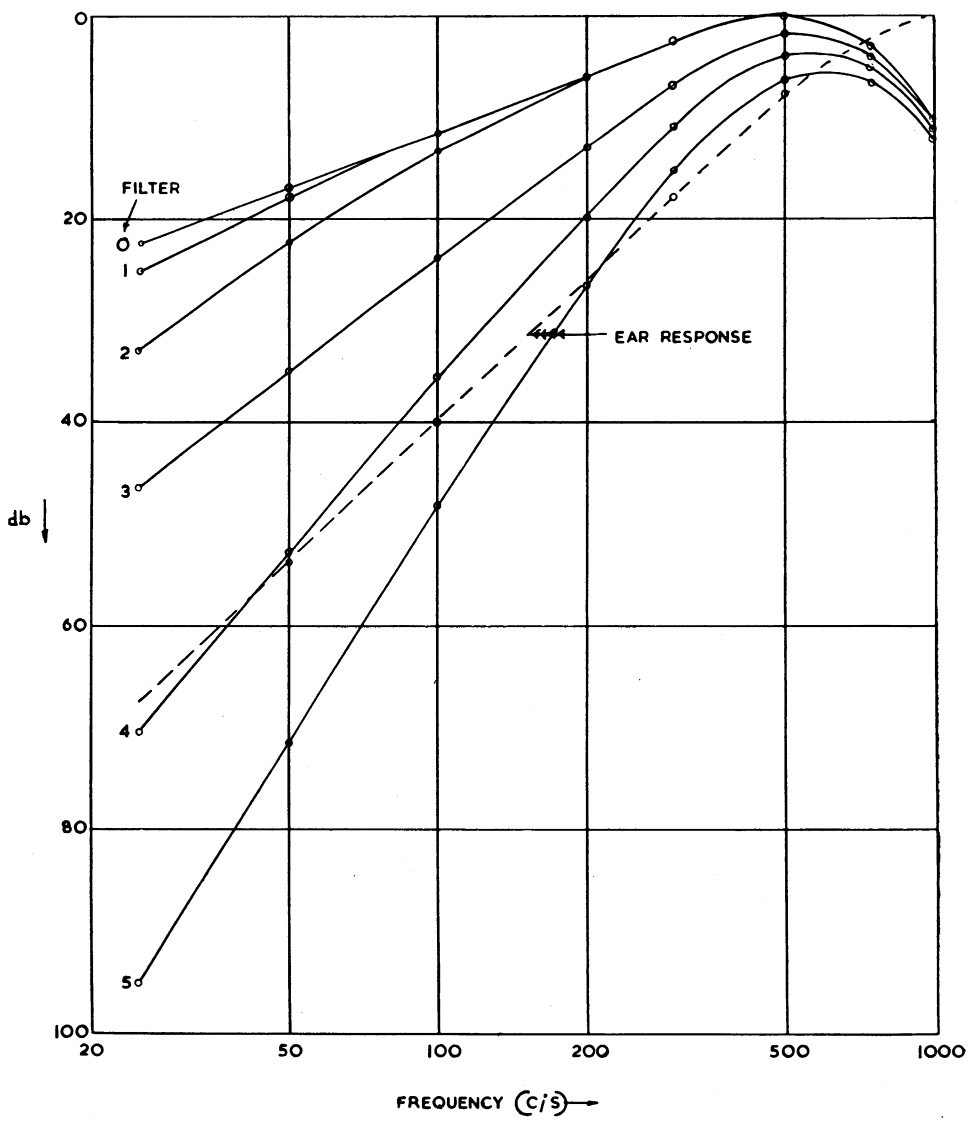


FIG. 2.—Frequency response curves of phonocardiograph and of "normal" human ear (audiogram).