

Aug. 7, 1962

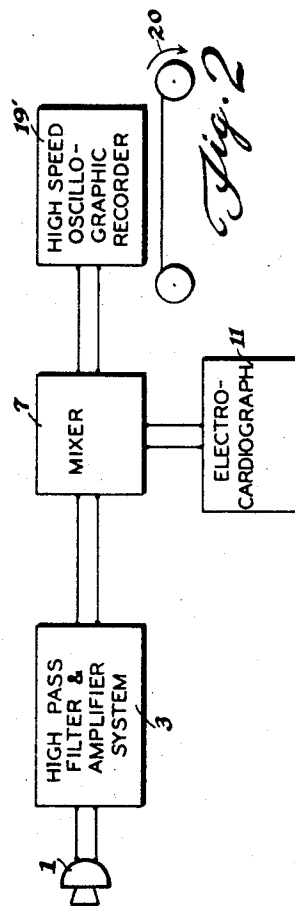
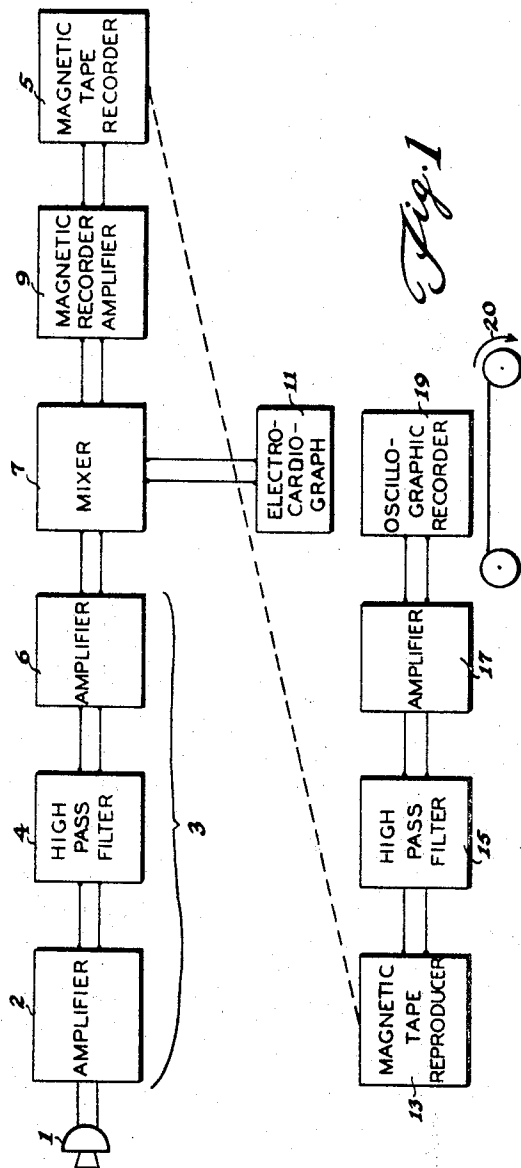
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3,048,166

PHONOCARDIOGRAPHIC METHOD AND APPARATUS

Filed March 29, 1955

2 Sheets-Sheet 1



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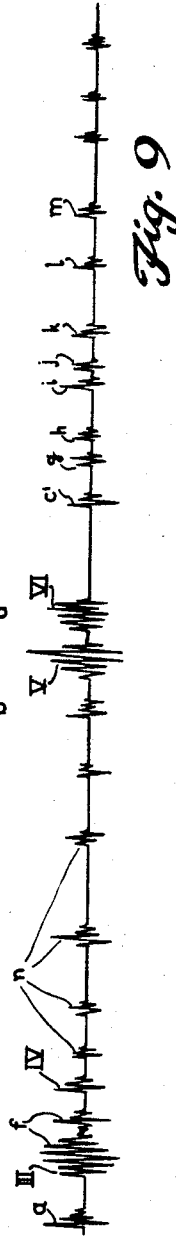
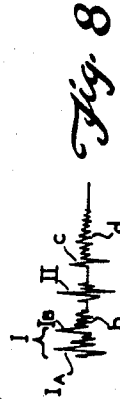
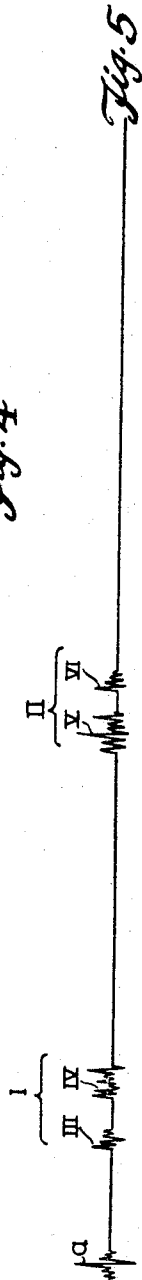
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PHONOCARDIOGRAPHIC METHOD AND APPARATUS

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3 Claims. (Cl. 128—2.06)

The present invention relates to phonocardiographic methods and apparatus for aiding in the analysis and diagnosis of heart condition through a study of the sounds associated with cardiac activity.

It has heretofore been customary to utilize oscillograms of heart sounds to aid in diagnosing heart conditions. The art has heretofore considered that for this purpose, the only useful sound frequencies generated by the heart are those lying well below about five hundred or six hundred cycles per second, which lower frequencies contain the principal energy of the heart sounds. This is explained in the recognized treatises on this subject, such as, for example, in articles by Maurice B. Rappaport and Howard B. Sprague, entitled "Physiologic and Physical Laws That Govern Auscultation, And Their Clinical Application" and "The Graphic Registration Of The Normal Heart Sounds," appearing, respectively, in volume 21, pages 257-318, March 1941, and volume 23, pages 591-623, May 1942, of The American Heart Journal; and in "Calibrated Phonocardiography and Electrocardiography," by Edgar Mannheimer, published in 1940, Acta Paediatrica, vol. XXVIII, Supplementum 11. The diagnostician and researcher alike have therefore concentrated on the high-energy low-frequency sounds, and various phenomena associated with heart operation can be observed in present-day low-frequency phonocardiograms that aid in the making of diagnoses.

It has now been discovered, however, that there is certain useful diagnostic information contained in frequencies well above about 500 cycles per second, and more specifically in the range above about 800 cycles per second, which is normally entirely masked by the much higher energy low-frequency heart sounds, and is accordingly entirely undetectable in conventional phonocardiograms. In particular, it has been discovered that when the presently utilized high-energy low-frequency sounds are discarded, through filtering or similar operations, and the presently ignored and masked low-energy high frequencies thereabove are recorded and properly displayed with far greater signal resolution than is presently employed in phonocardiography, as later more fully discussed, startling new results can be attained. In particular, important diagnostic information relating to the condition of the heart can be obtained from an examination of such properly displayed high-frequency sounds that cannot be gleaned from the conventional present-day phonocardiogram.

An object of the present invention, therefore, is to provide a new and improved method of and apparatus for receiving and indicating heart sounds and, in particular, the high-frequency sounds associated with cardiac activity.

A further object is to provide such a method and apparatus that enables the attainment of novel diagnostic information concerning the condition of the heart.

Other and further objects will be explained hereinafter, and will be more particularly pointed out in the appended claims.

The invention will now be described in connection with the accompanying drawings, FIG. 1 of which is a

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block diagram illustrating a preferred apparatus for practicing the present invention;

FIG. 2 is a similar diagram of a modification;

FIGS. 3 and 5 to 9 are reproductions of actual clinically obtained phonocardiograms; and

FIG. 4 is a reproduction of a timing signal corresponding to simultaneously recorded electrocardiographic information.

A microphone 1 may be utilized to transduce the sounds associated with cardiac activity into electrical signals of corresponding frequencies. The microphone may be of any desired type such as, for example, a moving coil-and-magnet-type microphone having adequate response to frequencies above the before-mentioned five-hundred cycles per second. Piezoelectric, capacitance, magnetic and other types of transducers may, of course, similarly be employed. The microphone 1 may be placed on the body of a patient, not shown, in the desired location to pick up the sounds associated with cardiac activity, as is well known. The electrical signals transduced from the heart sounds are preferably fed to an amplifier system 3 which may comprise a preamplifier stage 2, a high-pass filter 4, and a further amplifier stage or stages 6. The high-pass filter 4 is employed to eliminate the presently utilized high-energy low-frequency sound components of the heart sounds picked up by the microphone 1, as before described, and to select only the frequencies above, say, 500 cycles. It may be desirable in some cases to achieve this filtering action directly at the microphone 1 as by appropriate design of the same. The requirement of the amplifier system 3 is that it be capable of responding and amplifying with substantially uniform gain, sound frequencies transduced by the microphone 1 and passed by the filter 4. As an illustration, Model 62-type phono-amplifiers manufactured by the Sanborn Company and an RC high-pass filter have been successfully utilized in the system of FIG. 1. Filters of any other desired type and similar amplifiers may, of course, also be employed.

The filtered amplified high-frequency signals fed from the amplifier stage 3 are preferably applied to the amplifier 9 of a conventional magnetic tape-recorder 5, 9. The connections from the amplifier 3 to the tape recorder 5, 9 may be effected through a mixer 7. The mixer 7 permits the simultaneous injection of timing signals derived from electrical potentials of the heart of the patient, as detected by a conventional electrocardiograph 11. Similarly, any other type of impulse from any other cardiovascular event, after being transformed into corresponding electrical potentials, may be fed to the mixer 7 for timing or reference purposes. The electrocardiograph 11 may, for example, be of the Cardiette type marketed by the Sanborn Company and having in its output circuit a multivibrator that may be triggered to produce a sharp timing signal in response to, for example, the R-wave detected by the electrocardiograph. The magnetic recorder amplifier and tape recorder 5, 9 may, as an illustration, be of the Magnecord PT-106 type. The tape recorder 5 may operate at a rate of 15 inches per second, thereby making a magnetic record of electrical signals corresponding to the transduced high-frequency heart sounds in the frequency range above about 500 cycles per second, and the timing or reference signals corresponding to the electrocardiograph R-wave. These signals may be displayed either upon a common oscillographic channel, as hereinafter described, or upon separate channels, one or more for the signals corresponding to the heart sounds and one or more for the timing or reference signals.

If these signals were to be displayed directly upon an oscillographic recorder 19, 20, however, such as the phonocardiographic channel of the photographic Sanborn Twin-Beam Cardiette, which is commonly employed in conventional phonocardiography, operating with a time scale or rate of movement of the film 20 of about 3 inches per second, they could not be interpreted in accordance with the present invention. This is true for two principal reasons. In the first place, the oscillographic-recording equipment which would commonly be available for this purpose to a physician or physiological laboratory would normally have been designed primarily for conventional electrocardiographic or physiological work. The response of such oscillographic apparatus would thus be entirely too slow to handle the high-frequency signal components, corresponding to the high-frequency heart sounds, present on the magnetic tape, if that tape were to be played back at its original speed. Secondly, in order to be able to resolve small time intervals on the record to the precision or resolution demanded by the present invention, as later explained, the time scale or base of the oscillographic display would have to be expanded to something of the order of 24 inches per second.

If, however, it is desired to utilize this type of recording equipment, which, as before stated, is readily available to the physician or laboratory, the tape recording may be played back or reproduced by the reproducing head 13 of the magnetic recorder-and-reproducer 5, 9, 13, at a much slower speed than the speed of recording, thus artificially to shift the entire frequency spectrum of the heart-sound tape recording downwards. As an illustration, if the original tape recording is taken with the recorder 5 operating at the before-mentioned speed of about 15 inches per second, and is played back by the reproducer 13 at a tape speed of $1\frac{1}{4}$ inches per second, all frequencies in the playback system will appear at approximately one-eighth of the original recorded frequencies. Thus a relatively slowly responding oscillographic recording instrument 19, 20, which might have a 1,000 cycle pass band, would be rendered capable of recording frequencies up to approximately 8,000 cycles on the original recording. The reproduction of the recorded signals thus simulates their occurrence in a period of time longer than the actual time of their occurrence, thereby increasing the signal resolution. It is preferable that, in this transcription process, the reproduced signals be again filtered, as at 15, in order to complete the rejection of the low frequencies which may not have been sufficiently accomplished by the initial high-pass filter 4. Further amplifying stages 17 may also be employed. The further filter 15 may be made adjustable for providing maximum clarity and resolution of the bursts of the heart-sound signals shown in the final record on the film 20. The use of such a further filter 15 in conjunction with the magnetic tape recorder 5, 9, 13, furthermore, makes it possible to provide a number of oscillographic records of a particular heart-sound recording, each covering a different portion of the audio spectrum, if desired. The availability of the heart-sound signals on the magnetic tape makes it possible, moreover, to edit the tape and pick a suitable portion of the record containing only a few heart cycles for final transcription upon the oscillographic recorder 19, 20, without the use of an inordinate amount of photographic paper.

If, on the other hand, a high-speed oscillographic recorder is available, the preselected high-frequency electrical signals, corresponding to the high-frequency sounds associated with cardiac activity, may be directly displayed upon such a recorder. Thus, in FIG. 2, the film 20 of the high-speed recorder 19', 20 may be operated at, for example, 24 inches per second, to display the selected signals on an expanded time base. This serves the same purpose as the system of FIG. 1, though without the before-mentioned advantages of magnetic recording or other storage processes. While in the system of FIG. 1,

as before stated, the reproduction of the selected signals is effected in a period of time far longer than the actual time of occurrence of the signals, thereby to provide a high degree of signal resolution, in the system of FIG. 2, the signals are displayed directly upon a more rapidly moving film, thus to achieve similar high signal resolution.

It is to be understood that other types of displays than those herein-mentioned, including cathode-ray oscilloscopes and direct-writing oscillographs, may also be utilized in the systems of FIGS. 1 and 2, as may other well-known recorders, reproducers or storage devices be employed in the system of FIG. 1.

The discoveries underlying the present invention may perhaps be most strikingly illustrated through an analysis of novel information obtainable with the aid of a system designed in accordance with the present invention, but entirely unobtainable with the prior-art phonocardiograph systems. In FIG. 3, a conventional phonocardiogram of a normal patient is reproduced, illustrating the well-known low-frequency heart sounds below about 500 cycles per second that are presently recorded and used for diagnostic purposes. The first heart sound is shown comprising what appears as a continuous train of oscillations I and is believed to be associated with the closing of the mitral and tricuspid valves and the opening of the aortic and pulmonic valves of the heart, as discussed in the before-mentioned treatises. The second heart sound II, which also appears as a continuous train of oscillations, is believed to be associated with the closing of the aortic and pulmonic valves and the opening of the mitral and tricuspid valves.

In order to establish the time sequence of the phonocardiogram, without the necessity for adding a second channel to the recorder, which, as previously stated, may be done, if desired, the before-mentioned timing signal, in the form of a sharp rectangular pulse triggered by the R-wave pulse I' of FIG. 4 that is detected by the electrocardiograph 11, may be injected into the mixer 7.

In accordance with the present invention, the novel phonocardiogram of FIG. 5 is produced with, for example, the system of FIG. 1, for the same patient whose conventional phonocardiogram is shown in FIG. 3. The timing signal is shown at *a* in FIG. 5, serving to identify the beginning of electrical systole of the cardiac cycle. With the benefit of this orientation, the first heart sound can now be properly identified and it is clearly shown to be constituted of spaced, separated, discrete, transient bursts of oscillations III and IV. The second heart sound is shown to be constituted of somewhat similar discrete, transient bursts V and VI. While a study of the conventional low-frequency phonocardiogram would lead one to consider each of the heart sounds I and II as a continuum of oscillations, as discussed in the said treatises and as before mentioned, the apparatus of the present invention demonstrates that the heart sound I is actually composed of two distinct transient bursts III and IV, and the heart sound II, of two distinct transient bursts V and VI. This discovery is extremely useful for diagnostic purposes as later explained.

The conventional phonocardiogram of a patient with a pathological heart condition is reproduced in FIG. 6. Nothing unusual can be seen in the first heart sound I. There can be seen a murmur represented by a train of oscillations VII following the first heart sound I. One cannot tell, however, whether this murmur starts with the closure of the mitral and tricuspid valves or whether it follows the opening of the aortic and pulmonic valves. In accordance with the present invention, on the other hand, the high-frequency phonocardiogram of FIG. 7 shows murmurs constituted of two transient bursts VIII between the first two components III and IV of the first heart sound. This observation, which is entirely masked in the conventional low-frequency phonocardiogram of FIG. 6, suggests abnormality of closure of the mitral and

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tricuspid valves. Similarly, a further series of bursts continues through systole at IX in FIG. 7, the discrete transient nature of which is again not discernible in the conventional phonocardiogram of FIG. 6. A diagnosis of improper mitral or tricuspid valve action can thus be obtained by observation of the discrete bursts VIII and IX of FIG. 7. This entirely masked in the low-frequency heart-sound reproductions of FIG. 6 where it is impossible to determine whether the murmur VII stated upon the closure of the mitral and tricuspid valves or with the opening of the aortic and pulmonic valves. The present invention, therefore, among other things, permits the physician to determine which valves are improperly operating.

Another example of heart pathology that is detectable by means of the present invention is illustrated by contrasting FIGS. 8 and 9. In FIG. 8, the conventional phonocardiogram of a patient suffering from rheumatic heart disease is illustrated. From the conventional phonocardiogram it can only be stated that there is a first heart sound which is divided into two connected groupings IA and IB, but there is no distinct division therebetween, and there is insufficient clarity of the baseline to draw any conclusions as to what may or may not exist therebetween. A systolic murmur of low amplitude trails off the first heart sound at *b* and persists through most of systole. A distinct second heart sound is visible at II, and a short interval thereafter, a so-called opening snap of the mitral valve is distinctly recorded at *c*. Following the opening snap *c*, however, there is present a diastolic murmur *d* which becomes minimal a short interval prior to the beginning of the first heart sound of the next cycle, not shown. From this conventional phonocardiogram of FIG. 8, the only conclusion that can be drawn is that the patient may be suffering from mitral stenosis which is characteristic of the distinct opening snap *c* of the mitral valve and the diastolic murmur *d*. Due to the fact that this particular patient had auricular fibrillation, a presystolic accentuation of the murmur in diastole, which generally is present in this type of heart disease, is not present.

Turning, on the other hand, to FIG. 9, which shows the novel phonocardiogram of the present invention, taken upon the same patient, it is evident that in the region of the first component III of the first heart sound there are a considerable number of transient bursts *f* which are entirely masked in the conventional phonocardiogram of FIG. 8. These bursts *f* indicate improper operation of the mitral valve with probable insufficiency. The second component IV of the first heart sound is followed by a plurality of further bursts *n*, again indicating fluttering of the mitral or tricuspid valves. The second heart sound components V and VI are very noticeably prolonged, indicating further improper action of the valves. A snapping effect due to mitral valve closure appears to be indicated by a series of high-frequency transient bursts *c'*, demonstrating faulty closure of that valve. It has been found that in the case of mitral stenosis, as contrasted with the normal operating mitral valve, these high-frequency transients *c'* are characteristically observed clinically. Following the transient burst *c'* is a phenomenon that is also not at all discernible in the normal phonocardiogram of FIG. 8, namely, a plurality of substantially uniformly spaced transient bursts or flutters, representing subsequent fluttering operation of the mitral valve as shown at *i*, *j*, *k*, *l* and *m*. This enables a definite diagnosis of the valve action.

It is thus evident that, by eliminating the masking low-frequency sounds of the conventional phonocardiogram, and by presenting, instead, the high-frequency sounds above about 500 cycles on a display with sufficient signal resolution to separate the components of the first and second heart sounds, which, as before stated, have previously been believed to occur in a continuum, diagnostic informa-

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tion can be obtained that is entirely unattainable with conventional phonocardiograms. The oscillograms of FIGS. 7 and 9, are, of course, but two illustrations of pathological conditions that may be detected through the use of the present invention, and it is to be understood that the present invention may similarly cast light on a large variety of other pathological conditions. In all cases, the important result is that the high-frequency sounds are displayed in their transient separated-burst character and are thus available for diagnostic interpretation.

A preferred time resolution of the order of 1 millisecond or less was employed in the phonocardiograms of FIGS. 5, 7 and 9. As before stated, this cannot be attained through the utilization of customary phonocardiographic paper speeds, such as 3 inches per second, but, rather, through the expanded trace or time base of FIGS. 5, 7 and 9. This expansion is approximately eight times the time duration of the time bases of FIGS. 3, 6 and 8. In the system of FIG. 1, this expansion is achieved by a reproducing-to-recording speed ratio of about one-to-eight, though ratios of between about 1/4 and 1/10 may be employed for some purposes. In FIG. 2, the high-speed oscillographic recorder 19' may operate with a speed of about twenty-four inches per second to produce similar expansion and signal resolution, as previously explained. The apparatus utilized in producing the phonocardiograms reproduced in FIGS. 5, 7 and 9 employed the Sanborn Company equipments before mentioned in connection with the system of FIG. 1. That apparatus had a maximum over-all response near 1500 cycles and an over-all frequency response that provided about 10 decibels of attenuation below this maximum response at about 800 cycles, 25 decibels of attenuation at 500 cycles, and rapidly increasing attenuation there-below. Useful information of the character above described in the range including the frequencies within from about 800 to 1800 cycles has been obtained, and still higher frequency components have also been utilized.

Further modifications will occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A method of diagnosing the functioning of the heart that comprises transducing the sounds associated with cardiac activity into electrical signals having a relatively low intensity high frequency component of frequencies above substantially 500 cycles per second and including frequencies in the range of from substantially 800 to substantially 1800 cycles per second and a relatively high intensity low frequency component of frequencies below 500 cycles per second masking the low intensity high frequency component, filtering said electrical signals to remove said high intensity low frequency component and retain said low intensity high frequency component, thereby unmasking said low intensity high frequency component, and producing an output corresponding to the retained unmasked low intensity high frequency component as an amplitude-versus-time transient wave having sufficient resolution to separate each of the portions thereof corresponding to the first and second heart sounds, for normal heart function, into first and second separated bursts of transient oscillations.

2. The method as in claim 1 in which the step of producing an output comprises the steps of magnetically recording the retained unmasked low intensity high frequency component at a predetermined recording speed and magnetically reproducing the recorded signals at a slower speed to provide said sufficient resolution.

3. Apparatus for diagnosing the functioning of the heart that comprises means for transducing the sounds associated with cardiac activity into electrical signals having a relatively low intensity high frequency component of frequencies above substantially 500 cycles per second and including frequencies in the range of from substan-

tially 800 to substantially 1800 cycles per second and a relatively high intensity low frequency component of frequencies below 500 cycles per second masking the low intensity high frequency component, means for filtering said electrical signals to remove said high intensity low frequency component and retain said low intensity high frequency component, thereby unmasking said low intensity high frequency component, means for substantially simultaneously detecting the electrical potentials corresponding to the R-wave of an electro-cardiogram, means for producing a timing signal corresponding to said R-wave electrical potential, means for combining the timing signal with the retained unmasked low intensity high frequency component, and means for producing a permanent record displaying the combined retained unmasked low intensity high frequency component and timing signal as an amplitude-versus-time transient wave having sufficient resolution to separate each of the portions thereof corresponding to the first and second heart sounds, for normal heart func-

tion, into first and second separated bursts of transient oscillations.

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