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Cage
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[54] METHOD AND APPARATUS FOR THE DETECTION AND RECORDATION OF HIGH FREQUENCY SOUND IN THE CARDIOVASCULAR SYSTEM

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[73] Assignee: **Hewlett-Packard Company**, Pala Alto, Calif.

[22] Filed: **Apr. 19, 1971**
[21] Appl. No.: **135,350**

[52] **U.S. Cl.** .... **128/2.05 S**
[51] **Int. Cl.** **A61b 5/02**
[58] **Field of Search** .... 128/2.05 R, 2.05 S, 128/2.06 R, 201 B, 2 K

[56] **References Cited**

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Moyer et al., "Transactions of the American Institute of Electrical Engineers", Vol. 80, Part I, 1961, pp. 717-721.

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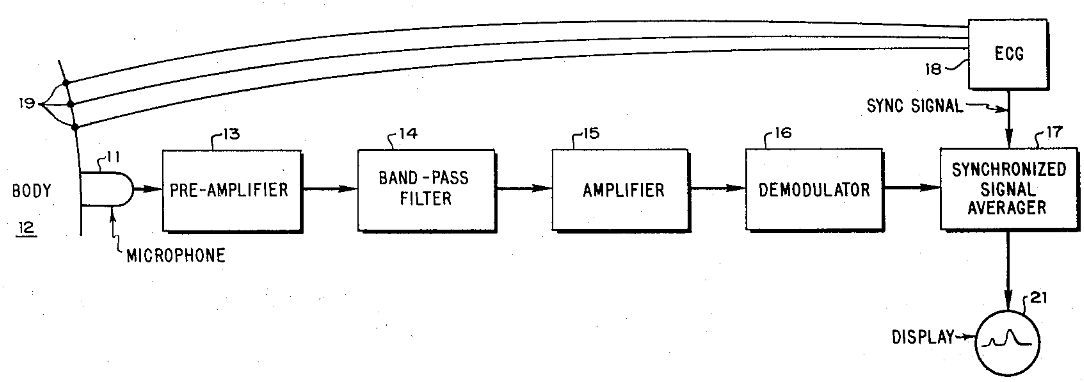
[57] **ABSTRACT**

High frequency sound, such as that produced by turbulence, in the cardiovascular system is sensed, amplified, demodulated, and filtered to produce an average of the amplitude of the sound, the demodulated signal being synchronously averaged over a plurality of successive cycles of the heart to produce a clear signature trace of the demodulated sound, even in the presence of background noise.

9 Claims, 6 Drawing Figures



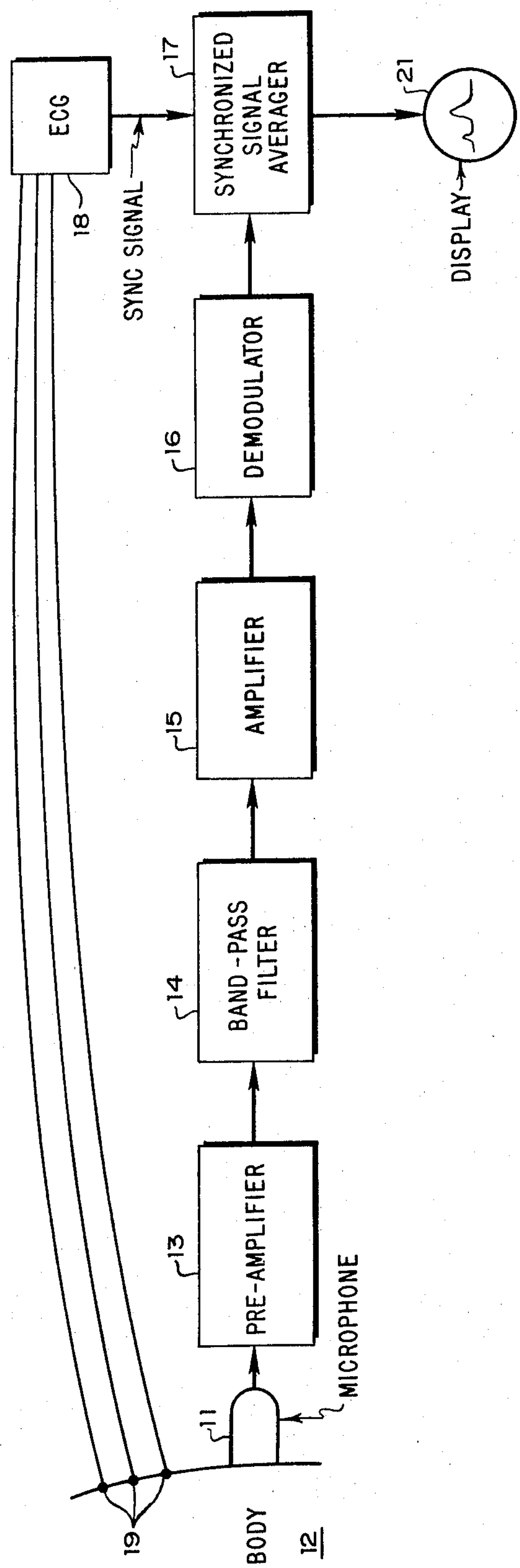


Figure 1

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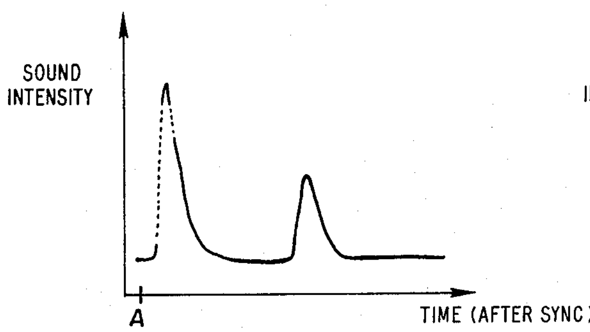

Figure 2

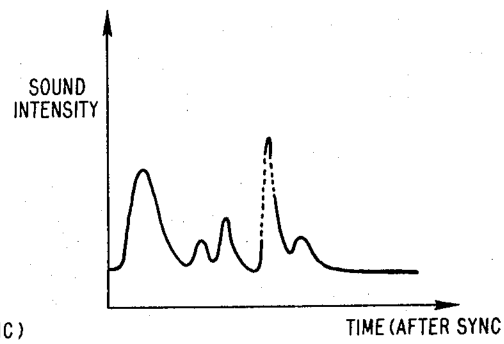

Figure 3

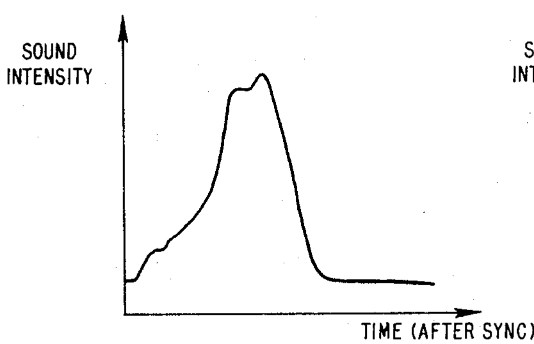

Figure 4

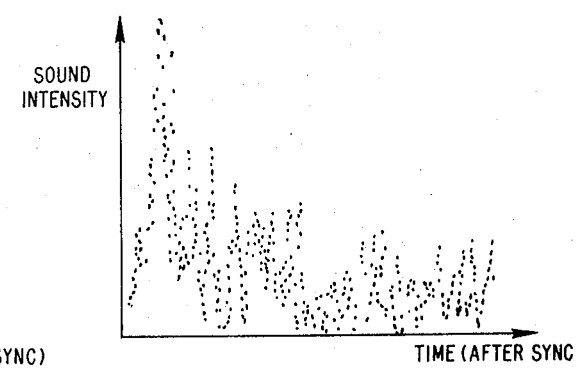

Figure 5

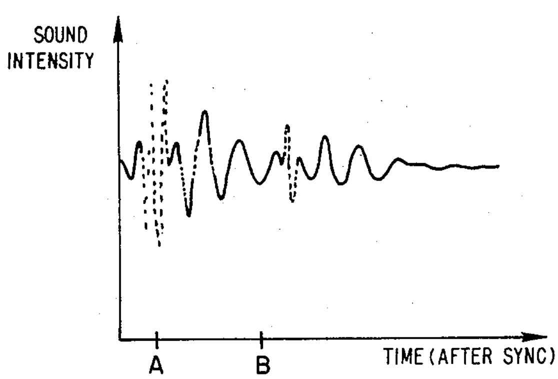

Figure 6

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METHOD AND APPARATUS FOR THE DETECTION AND RECORDATION OF HIGH FREQUENCY SOUND IN THE CARDIOVASCULAR SYSTEM

BACKGROUND OF THE INVENTION

Ausculation, i.e., the diagnostic monitoring of sounds made by internal organs or internal bodily parts, has been employed down through the years. The most widely used technique involves listening to cardiovascular sounds, generally with a stethoscope, and more recently with microphones, amplifiers and recording oscillographs.

Relatively loud, low frequency sounds are easily detected by modern stethoscopes, while very weak, higher frequency sounds are lost to the diagnostician.

In addition to listening to a successive number of heartbeats, gating techniques have been developed to listen to only portions of each cycle of the heart. Also, techniques have been employed wherein only the low frequencies of the sounds are detected, or only the high frequencies at any one time.

However, in addition to the typical sounds and vibrations produced by the pumping action of the heart, certain very weak, relatively high frequency sound is produced by turbulence in the blood flow, and this sound is not clearly detectable by present techniques. Even when the high-frequency sounds are loud enough to be heard by ausculation, the physician cannot accurately describe them.

The cardiovascular system of a human is so well designed that normal yound persons are relatively free of any turbulent sounds. However, even a healthy person with a good heart will usually produce very brief bursts of turbulent sound as the various heart valves close or open during each cycle of the heart. These sounds are produced by a short burst or leakage of blood through a valve just as it snaps shut or snaps open.

As the body ages, the blood system becomes less optimized and conditions appear which result in turbulence which in turn result in additional high frequency sounds. Most disorders of the heart will also produce turbulence symptomatic of the disorder. For example, a stenotic aortic valve or a mitral valve regurgitation will produce distinctive turbulence sound. A septal defect caused by congenital condition or by accident or disease permitting blood flow between the right and left cavities of the heart, either the atriums or the ventricose, will result in distinctive turbulence noise.

In addition, poor circulation due to stenosis of the arteries will produce turbulence in the blood flow through the blockage, and sound is produced in high frequency components. It has been found that over ninety percent (90 percent) of a coronary artery may be occluded before a heart attack occur. Since this closure builds up over a long period of time and produces turbulence noise during the development period, early diagnosis based upon the detection of the sound can lead to proper preattack treatment.

SUMMARY OF THE INVENTION

The present invention provides a novel method and apparatus whereby the relatively high frequency sounds produced by turbulence in the cardiovascular system, sounds heretofore lost to the diagnostician, may be detected and recorded.

A sound transducer, such as a microphone, is positioned to pick up the sounds from the body, and the relatively high frequency components in a selected band, say from 800 to 1,200 Hz, are separated out, amplified, and demodulated to obtain an envelope of the amplitude of this sound. The demodulated output is transmitted to a computer of average transients, or synchronized averager, which is synchronized with a specific repetitive condition of the cardiovascular system, such as the R wave of the electrocardiogram (ECG). The demodulated signal output is thus synchronously averaged over a plurality of sweep periods covering one cycle of the heart, for example, 2^6 or 2^7 sweeps, to obtain a clear, smooth average demodulated output trace of the sound. Environmental noise and unsynchronized body noise are thereby eliminated from the averaged signal.

The trace of the averaged signal will be a signature of the high frequency turbulence sound, which in turn will be distinctively related to the existing condition of the cardiovascular system.

In another embodiment, the sound signals are averaged without demodulation to give useful information about the low frequency sounds, even ones of subaudible frequency.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a preferred embodiment of the apparatus used in the present invention.

FIG. **2** is a trace of the demodulated high frequency sounds produced by turbulence in the cardiovascular system of an adult with a normal, healthy heart and obtained using the technique of the present invention.

FIG. **3** is a trace similar to that of FIG. **2** for a person that has had at least one heart attack.

FIG. **4** is a trace similar to that of FIG. **2** for a person with a late systolic murmur in idiopathic hypertrophic subaortic stenosis.

FIG. **5** is a trace of the demodulated high frequency sounds obtained for one cycle of the heart and without synchronous averaging over repeated cycles.

FIG. **6** is a trace of the low frequency sound from a normal person, without demodulation, averaged in a sycchronized signal averager.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, a microphone **11** is placed against the body **12** of the person being tested near the source of the noise to be detected. For example, for heart disorders the microphone is placed on the chest over the heart. If a stenosed artery is to be examined, the microphone is placed as near to the occlusion as possible.

The detected sound is amplified in pre-amplifier **13** and transmitted to a band-pass filter **14** which passes only frequencies within the selected high frequency rang of interest, for example 800 to 1,200 Hz. The frequency range is flexible and the limits are not critical; selected bands within an overall range of from 200 to 20,000 Hz appear to be most useful. Bands can be selected to give the best discrimination between one disease condition and another.

The selected band of sound frequencies is amplified in amplifier **15** and delivered to a demodulator circuit **16** which rectifies and filters the sound signal to produce an output signal proportional to the running average of the amplitude of the sound in the selected frequency band, this envelope having the form seen more clearly in the traces of FIGS. 2–4 described below.

The demodulated sound signal is transmitted to a standard form of synchronized signal averager **17** or computer of average transients, for example the model HP 5480A instrument manufactured and sold by Hewlett-Packard Co. of Palo Alto, Calif., the assignee of this patent application. The synchronizing signal for the averager **17** is obtained from a standard form of electrocardiograph instrument **18** coupled to the subject via three adhesive ECG electrodes **19.** The sync signal is delivered to the synchronous averager **17** from the ECG instrument preferably at the initial rise of the R wave in the heart cycle. Each demodulated sound signal averaged in the computer circuit will be synchronized with the R wave, and by averaging over a suitable number of sweeps or heart cycles, for example 2^6 or 2^7 sweeps, a very clean envelope signal is obtained for recording on the display instrument **21.**

It should be understood that the invention could take other forms; for example the sound signal could be synchronized with other periodic conditins, for example parts of the QRS complex other than the initial rise of the R wave. Where there is no built-in sync signal due to cyclic sound variations, as would be the case with a venous stenosis, cyclic venous flow rates may be produced artificially by mechanical means that repetitiously constrict the vein. The synchronous averager would then be synchronized with the mechanical means.

The synchronous averager could utilize analog or digital averaging techniques. An alternative to synchronized averaging is to cross-correlate successive scans of the demodulated high frequency sounds.

There is shown in FIG. **2** the trace obtained with the apparatus of the present invention from a person with a normal, healthy heart. The sounds were measured with a microphone placed on the chest directly over the heart. The beginning of the trace at point A on the left hand side is synchronized with the early rise time of the R wave of the ECG of the subject, and the total trace covers one beat cycle of the heart. The trace is the average computed over 2^7 successive heart beats.

The first peak is the envelope of the very brief turbulent sounds made by the closing and opening of various valves just before the ventricles of the heart commence pumping blood into the arteries. The second peak is the envelope of the turbulence sounds made by the valves as the ventricles cease pumping and begin filling.

The sounds are relatively high frequency and weak amplitude, falling typically within the range over 400 Hz, and of a type not heard with a stethoscope since they are well over the range in which a stethoscope is sensitive. The well defined curve results from the demodulation of the sounds and the repeated averaging of the envelope obtained by the demodulation.

The trace shown in FIG. **3** was obtained under operating conditions similar to those employed to obtain FIG. **2** except the subject was a person with a late systolic murmur in idiopathic hypertrophic subaortic stenosis. There was an overgrowth of heart muscle near the outflow tract. The high frequency sound begins gradually at about the time the heart begins to pump blood and builds up to its loudest point just before the finish of the ventricular contraction. Thus this slight constriction in the heart makes a substantial murmur that is clearly defined as shown, building up during systole to a late peak.

The trace of FIG. **4** was obtained from a person who has had at least one coronary occlusion. The envelope of the sounds due to the closing of the mitral and aortic valves are seen, although these two peaks are not as crisp as those of FIG. **2.** In addition, two smaller peaks appear between the two valve sounds, these two turbulent murmurs most probably being caused by damage left within the heart arteries.

These traces serve to illustrate the many possible forms of traces that can serve as signatures for the many different types of heart disease. These sounds can be detected during routine physicals and before serious damage occurs.

The advantage of synchronized time averaging over a relatively large number of sweeps, as utilized to obtain FIGS. **2** through **4,** is seen by reference to FIG. **5** which is a trace of a single sweep of the demodulated noise between 800 and 1,200 Hz obtained from a subject. Although there is the appearance of a relatively loud sound near the beginning of the sweeps, no peaks are very clearly defined and the signature contains very little useful information of the type obtained from repeated averaging of a plurality of sweeps. Actually, the subject has a murmur which produces a noise peak between the mitral and aortic valve peaks and which became clear when 2^7 sweeps were synchronously averaged.

Note that in this technique it is not necessary that a regular, periodic heart rate exist, since the measured noise is synchronized with the R wave which may itself be irregularly spaced.

The present invention will be most useful in the diagnosis of septal defects, coronary artery disease, faults in prosthetic valves, stenosis and regurgitation of valves, stenosis in peripheral blood vessels, including veins, and aneurisms and shunts. There is a definite possibility of the measurement of blood pressures through the use of cuffs and partial occlusions, rapid diagnosis of myocardial infarction by observing sound resonances, quantitative measurement of blood velocity and physical dimensions of biological structures, and improved display of phonocardiograms.

In some cases, the sound signals are averaged in the synchronized signal averager without demodulation, demodulator **16** having been eliminated from the system, to give useful information about the low frequency sounds, even ones of sub-audible frequency. A trace of this type from a normal person is shown in FIG. **6,** points A and B, being typically 40–50 cycle components of the sound of the heart valves, and the remaining sounds being the synchronously produced sounds within the chest cavity.

I claim:

1. The method of analyzing cardiovascular sound comprising the steps of:

- detecting the sound signals produced repetitively from a source within the body;
- detecting a periodic condition in the body synchronous with said repetitively produced sound signals;
- demodulating said detected sound signals to produce a data signal representative of the average of the amplitude over a selected past period of time;
- synchronizing the detected sound signals with said periodic condition in the body synchronous with said detected sound signals;

averaging a plurality of said demodulated signals over a plurality of successive time periods to obtain an average of the amplitudes of the demodulated signals; and

displaying said average of the amplitudes.

2. The method as claimed in claim **1** wherein the step of synchronizing the detected sound signals with a periodic condition comprises the steps of synchronizing with an electrocardiographic signal.

3. The method as claimed in claim **1** wherein the step of detecting the sound signals comprises selecting a band pass above 200 Hz and below 20,000 Hz.

4. The method as claimed in claim **1** wherein the step of averaging a plurality of sound signals comprises averaging over at least 2^6 signals.

5. Apparatus for analyzing cardiovascular sound comprising:

means for detecting the sound signals produced repetitively from a source within the body;

said periodic condition in the body synchronous with said detected sound signals;

means for demodulating said detected sound signals to produce a data signal representative of the average of the amplitude over a selected past period of time;

Means for synchronizing said detected sound signals with said periodic condition in the body synchronous with said detected sound signals;

means for averaging a plurality of said demodulated signals over a plurality of successive time periods to obtain an average of the amplitudes of the demodulated signals; and

means for displaying said average of the amplitudes.

6. Apparatus as claimed in claim **5** wherein said means for averaging comprises a time averaging computer.

7. Apparatus as claimed in claim **5** wherein said synchronizing means comprises means responsive to the electrocardiographic signal of said body.

8. Apparatus as claimed in claim **5** wherein said means for detecting said sound signals comprises a microphone positioned near said body.

9. Apparatus as claimed in claim **5** including means for filtering said detected sound signals to pass signals in selected bands above 200 Hz and below 20,000 Hz.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,762,397 Dated October 2, 1973

Inventor(s) John M. Cage

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 20, "said" should read -- means for detecting a --; line 21, "detected" should read -- repetitively produced --;

Column 6, line 3, "Means" should read -- means --.

Signed and sealed this 19th day of February 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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