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Abstract

An investigation of the preejection period (PEP) of the heart is described. A procedure for dynamic analysis of valvular events is achieved with the results obtained forming the basis for a novel automated measuring technique. This scheme has the capability of determining the PEP in the presence of relatively large amounts of biological-origin noise. A commercial Doppler ultrasound technique is used to obtain the aortic valve velocity. An electrocardiographic (ECG) trigger circuit provides a synchronizing signal required to establish the beginning of the PEP interval.

The clinical viability of a prototype instrument of a practical nature incorporating the new scheme is demonstrated.

Introduction

There is much emperical evidence that tends to establish the PEP as an indicator of the degree of myocardial contractility, left ventricular end diastolic volume, and aortic diastolic pressure (1,2,3,4). In the field of obstetrics, the PEP could be especially important since a number of potentially healthy newborns are compromised during labour as they undergo hypoxic conditions which can lead to brain damage and, in some cases, death. By having a relatively harmless method of monitoring the PEP, the fetal status can be determined before the possible effects of hypoxia become detrimental and thus, appropriately early measures can be taken. Although most of the initial work in this area has been done in the field of obstetrics, the PEP also holds potential for true noninvasive real time confirmation of cardiac disease and performance in adults.

The PEP is defined as the interval from the beginning of the QRS complex until the opening of the aortic valve (Figure 1). A circuit which looks for a section of the QRS wave is used to obtain a trigger signal from the ECG which establishes the beginning of the PEP interval. The difficult task is to find the time of opening of the aortic valve (Ao). Doppler ultrasound is used to provide a signal that contains swept frequency components proportional to the velocities of all moving objects as well as various phases of carrier frequency components due to reflections from stationary surfaces and transducer crosstalk. The component due to aortic valve opening is contained within this composite signal and the remainder of the paper will describe how it is obtained.

Dynamic Analysis of Valvular Events

From the previous paragraph, it can be realized that the composite Doppler signal has a spectrum which changes as a function of time. A practical method of handling complex signals of this type is through the use of a spectrograph. Its output simultaneously displays frequency and time, normally plotted along planar axes, and amplitude, coded as intensity.

To sufficiently attenuate the carrier frequency components as well as the large Doppler components due to heart wall movements, blood flow, etc., the Doppler signal is demodulated and then processed through a high pass filter. A spectrogram which illustrates a strong Ao component is shown in Figure 2. The spectrogram is shown on the bottom half of the photograph while the top half represents an envelope detected plot of the amplitude-time characteristics. In Figure 3, several valvular components are present (Mc,Ao,Ac). The dark horizontal lines result from noise present in the recording area - most notably the tenth harmonic of the power line frequency.

The two significant conclusions to be reached from these spectrograms are 1) the valve velocities are notably higher than those of the other reflecting structures 2) the amplitude of the valvular signal is relatively constant over a good deal of the frequency sweep. What now remains is to devise an automated method of detection of the frequency sweep corresponding to Ao.

Sequential Transient Filtering Technique (5)

It should be noted, that the sweep rate resulting from the opening of the aortic valve is greater than 100Khz/sec. In addition the signal begins its sweep from zero Hertz. As these specifications are normally not reached with conventional phase locked loops and voltage tunable filters, a new technique is required.

Generally, the scheme provides a transiently adaptive piecewise approximation to the resultant time domain signature of the frequency sweeping event. A conceptual block diagram is shown in Figure 4. Specifically, it consists of processing the demodulated Doppler signal through two equal bandwidth filters arranged in parallel. The resonant frequencies of the filters are fixed with one located at a higher frequency than the other. By maintaining equal bandwidths, the output of the lower frequency filter occurs first while the amplitudes of the filter outputs are equal. The output from the lower filter enables its neighbor. Thus, the output from the high frequency filter indicates that a swept frequency event has occurred. By employing controllable delays between the two filters, one can tailor the technique to detect a range of swept frequencies. The system comprises essentially a swept frequency rate discriminator that will recognize swept signals occuring between two controlled rates.

Although developed specifically for measuring valvular velocities, the system can easily be generalized to enable detection of any swept frequency signal. In particular, by using more parallel filters with attendant enabling circuits, this technique can be used for detection of a wide variety of nonlinear swept frequency events.

Results

Figures 5 and 6 illustrate the clinically obtained signals. It should be noted that for clarity the Doppler signal shown in Figure 6 represents some of the best data available and is not typical of the normal signal to noise ratio. The level transition (high to low) of the third trace in Figure 5 and the fourth trace in Figure 6 indicates detection of Ao. Long term clinical testing is currently underway to confirm the effectiveness of the instrument.

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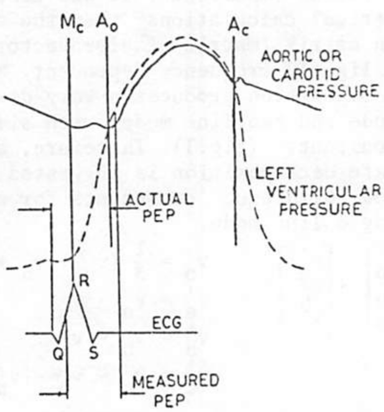
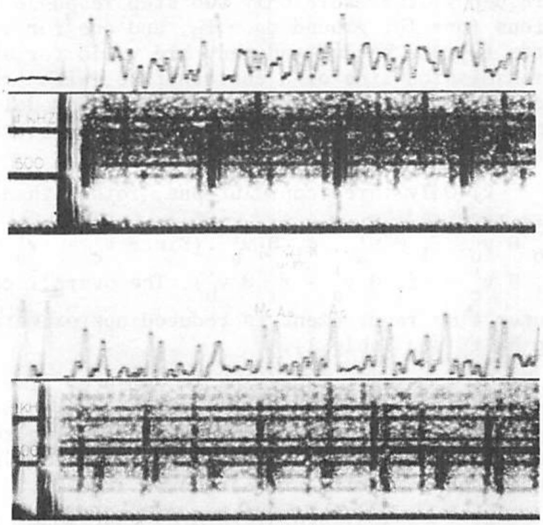


FIGURE 1

MEASURED AND ACTUAL PEP



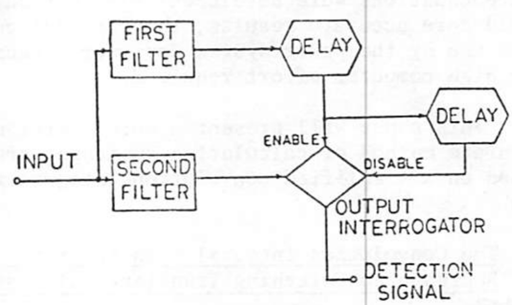


FIGURE 4

SEQUENTIAL TRANSIENT FILTERING TECHNIQUE