A cardiac pre-ejection period monitor for foetal assessment during labour*

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Abstract—*The design of a practical instrument for measurement of the value of the pre-ejection period (p.e.p.) of the cardiac cycle in real time is presented. This arrangement has the capability of determining the p.e.p. in the presence of relatively large amounts of biological-origin noise. A commercial Doppler ultrasound technique is used to obtain the aortic-valve velocity profile. An electrocardiographic (e.c.g.) trigger circuit provides a synchronising signal which is required to establish the beginning of the p.e.p. interval.*

Keywords—*Pre-ejection, Frequency-sweep detection, P.E.P. monitor, Foetal assessment, Ultrasound*

Introduction

The pre-ejection period is an index of left ventricular function and reflects changes in myocardial contractility, left ventricular end-diastolic volume and aortic diastolic pressure (NIMURA *et al.*, 1968; METZGER *et al.*, 1970; ORGAN, MILLIGAN *et al.*, 1973; GOODLIN *et al.*, 1972). From experimental studies on the behaviour of p.e.p. in stressed mature foetal lambs, it appears that, in the field of obstetrics, this parameter can be used to indicate foetal hypoxia and umbilical-cord occlusion (ORGAN, BERNSTEIN *et al.*, 1973). It is desirable, then, to have a clinical instrument to automate the measurement procedure that is currently being performed off line. A technique for obtaining an on-line readout of p.e.p. which is resistant to the noise and signal problems associated with the Doppler signal will be presented here.

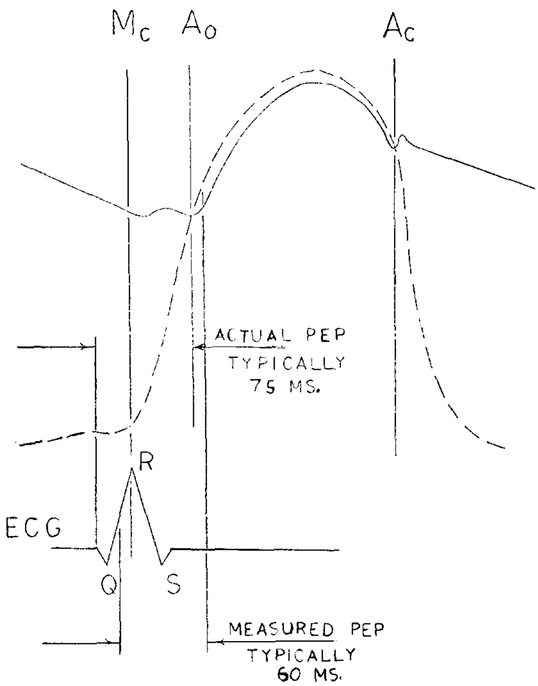

Fig. 1 Actual and measured pre-ejection period

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Signal-detection fundamentals

The p.e.p. is defined as the interval from the beginning of the QRS complex until the opening of the aortic valve (Fig. 1). It is relatively easy to obtain a trigger circuit that responds to the slope of the R wave (WINTER and TRENHOLM, 1969). However, it is not as easy to determine electronically the *beginning* of the QRS complex. Thus, at present, the initiation of the measurement interval contains a systematic error term. This error term can be considered constant.

The time of opening of the aortic valve is determined by detecting the velocity of the aortic valve using a standard Doppler ultrasound technique. The actual opening time of the aortic valve is not obtainable, as this corresponds to zero frequency in the demodulated signal. Only velocities considerably above 80 mm/s (this corresponds to 200 Hz with a carrier frequency of 2 MHz) are detected following suitable filtering to sufficiently attenuate the dominantly lower frequencies produced by other myocardial structures (NIMURA *et al.*, 1968). Some error is introduced as the valve opens in about 10 ms out of a typical p.e.p. value of 75 ms, but the beat-to-beat error introduced here is low as well because detection occurs at approximately the same point within the 10 ms period. Since interest is primarily in changes in the p.e.p. from a steady state value, the measured p.e.p., which is a relative measurement with respect to the physiologically defined interval, provides the required information.

It should be noted that the sweep rate involved as a result of the valve opening is of the order of 100 kHz/s. Because this is a relatively high rate of change, and because there is the need to distinguish sweep signals from transient signals, a new technique is required that can detect the fast frequency sweep immersed in noise. The scheme to be presented incorporates both a tracked time window in which the sweep must occur to be detected and a circuit which detects swept signals within upper and lower frequency rate limits.

Sequential transient filtering technique

A block diagram of the detection scheme is shown in Fig. 2. The Doppler-shifted signal (demodulated) is applied to two fourth-order fixed frequency bandpass filters driven in parallel. Each fourth-order bandpass filter channel consists of a cascade of two identically tuned second-order bandpass filters with characteristics noted in Fig. 2. It can be demonstrated that, by maintaining the *bandwidths* of the two channels equal, the output of the lower-frequency filter occurs first as well as forcing the amplitude of the two output channels to be equal. (This is true under the assumption that the Doppler signal maintains a constant amplitude over the frequency interval of interest.) This filtered output is then envelope detected and compared with an exponentially decaying peak value of the previously detected signal. When the present signal reaches an adjusted percentage of the previous one, delay D_1 is initiated. After D_1 seconds, the same procedure occurs through the envelope detector, peak detector and comparator of the higher-frequency filter. If there is an output of this comparator, flip–flop A is set.

In addition, a time window is initiated at the transition of the first comparator. This prevents flip–flop A from being set after a delay of D_2 seconds ($D_2 > D_1$). Thus flip–flop A is set if the output of the second comparator occurs after D_1 but before D_2 seconds. This system comprises essentially a swept-frequency rate discriminator that will detect swept signals occurring between two controlled rates.

If flip–flop A is properly set, a counter is interrogated that has been counting since the beginning of the e.c.g. trigger signal. The result then represents the relative p.e.p. value.

The function of the exponentially decaying peak detectors is to allow the system to follow changing-amplitude signals. These have been observed to occur because of ultrasound transducer movements, foetal or maternal movement etc., and will typically change from subject to subject and, to a lesser extent, beat to beat. By varying the time constant of the peak detector, it is possible to compensate for amplitude variations with reasonably small transient errors. In all cases, however, it is possible to compensate for a step change in amplitude within one heart cycle.

Owing to the large levels of background noise, it was necessary to incorporate a background-noise sample, hold and comparator configuration. This

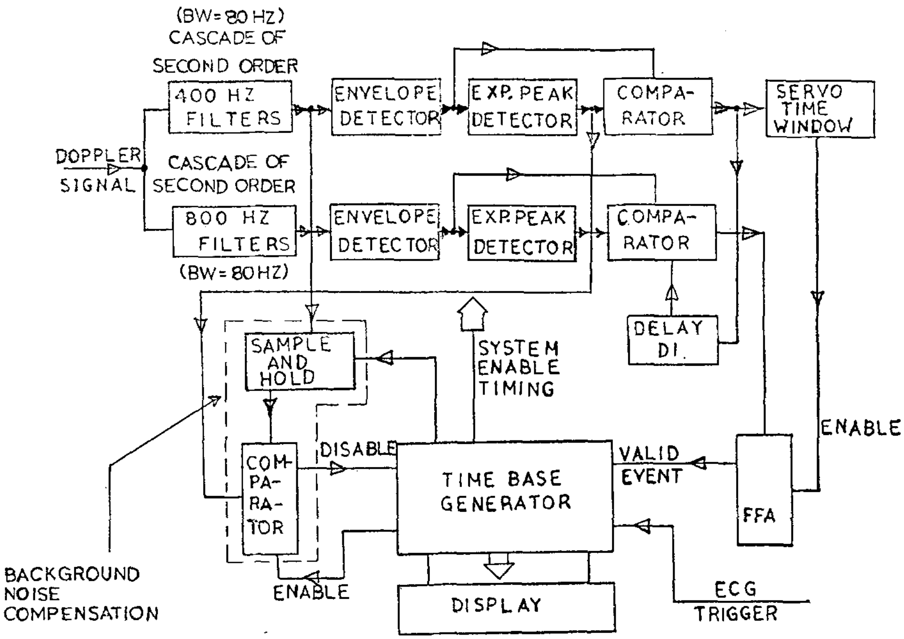

Fig. 2 Block diagram of p.e.p. monitor

prevents the circuit from making a decision on aortic opening time if the transient filter response is not an arbitrary percentage greater than the background steady-state noise within that band (chosen when the frequency sweep is assumed not to be present).

Results

Figs. 3 and 4 illustrate the clinically obtained signals. It should be noted that the Doppler signal

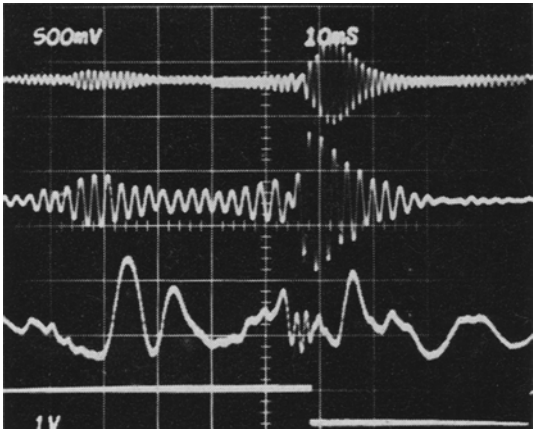

Fig. 3 Photograph of detection of p.e.p. from clinical signal
Top trace: Output of 400 Hz filter
Second trace: Output of 800 Hz filter
Third trace: Clinical input signal (Doppler detected)
Bottom trace: Indicates detection and end of p.e.p. interval on negative edge

shown in Fig. 4 represents some of the best data available and is not typical of the normal signal/noise ratio. The level transition (high to low) of the fourth trace in Fig. 3 and the third trace in Fig. 4 indicates detection of the previously defined aortic opening time. From the photographs, the p.e.p., measured from the left edge of the trace, is approximately equal to 58 ms. The time from the beginning of the QRS complex to the trigger signal was 14 ms, giving a corrected p.e.p. of 72 ms.

Long-term clinical testing is currently under way to confirm the effectiveness of the instrument.

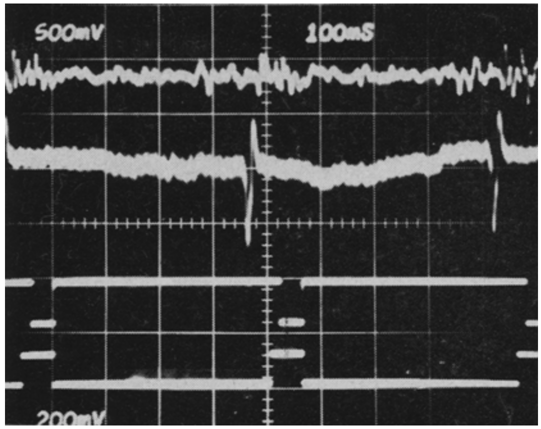

Fig. 4 Photograph of clinical signals and resultant system-generated reference signals
Top trace: Clinical input signal (Doppler detected)
Second trace: Clinical foetal electrocardiogram
Third trace: Detection and end of p.e.p. interval on negative edge
Bottom trace: Physiologically maximum p.e.p. decision window

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Moniteur de la période de pré-éjection cardiaque pour la surveillance des foetus pendant la période de travail des accouchements

Sommaire—Les auteurs présentent un modèle d'instrument pratique permettant de mesurer la valeur de la période de pré-éjection du cycle cardiaque en temps réel. Cette configuration permet de déterminer la période de pré-éjection en présence d'un volume important de bruits d'origine biologique. Pour obtenir le profile de vélocité de la valve aortique, on a fait appel à une technique commerciale d'ultrasons Doppler. Un circuit de déclenchement électrocardiographique fournit le signal de synchronisation nécessaire pour établir le début de l'intervalle de la période de pré-éjection.

Überwachung der Herztätigkeit vor der Geburt zur Beurteilung des Fötus während der Wehen

Zusammenfassung—Es wird Konstruktion eines praktischen Instruments zum Messen der Herztätigkeit des Fötus vor der Geburt (p.e.p.) in Realzeit vorgestellt. Das Gerät kann durch relativ große Mengen biologisch verursachter Geräusche die Zeit bis zur Geburt bestimmen. Ein kommerzielles Ultraschall-Dopplerverfahren wird eingesetzt, um ein Geschwindigkeitsprofil der Aortenklappe zu erhalten. Eine EKG-Impulsauslösung liefert das synchronisierende Signal, das erforderlich ist, um den Anfang der P.E.P.-Strecke festzulegen.