1 Introduction

Measurement of chest wall vibrations over the cardiac region has been of particular interest to scientists for the past several decades. These vibrations are produced by the mechanical activity of the heart and are transferred onto the chest. The characteristics of the chest tissues are such that these vibrations reflect a great deal of the activity of the myocardium (Verburg and Von Vollenhaven, 1979). The prominent techniques developed for this purpose are apex cardiography, in which a transducer is applied over the apex region and vibrations are recorded (Kesteloot, 1976), and displacement cardiography, a non-contact technique in which an electromagnetic field is employed to record tissue movements (Vas et al., 1976).

Recently Aubert et al. (1984) have developed a method in which a narrow beam of laser, focused on the apex region, is used for displacement measurement. Through their experiments on dogs, they have found that the general behaviour of the displacement curve of the left ventricular apex during open chest experiments is similar to the curve recorded near the same apical area with the intact chest. These techniques have provided valuable information on the mechanical activity, but the observations have been limited to a smaller region of the heart. Thus the displacement pattern of the entire heart as observed on the chest wall has not been obtained. Such data could be useful to assess the cardiac functioning during diseased conditions.

We have developed a new noninvasive and non-contact technique by which displacements of the chest wall due to cardiac action could be measured, and have successfully applied it to determine the displacement pattern in diseased conditions during the systolic phase of cardiac cycle. These results are in good agreement with that of two-dimensional echocardiography (Ramachandran et al., 1985). To introduce this technique, the speckles are formed due to interference of wavelets arising out of different microscopic projections of a surface when it is illuminated by laser light. When this surface is displaced in some manner, the speckle pattern also shows variation in proportion to the object's movement. The absolute values of the surface displacements could be measured either by double exposure method in which two exposures one before and one after the movement are recorded or by time average method in which a single exposure covering a part of the cycle of movements is recorded (Tiziani, 1978).

The time-average method is suitable for objects executing motion in a continuous fashion and has successfully been applied for mapping chest wall movements during the systolic phase of the cardiac cycle (Periasamy et al., 1983; Periasamy and Singh, 1985). A comparative study of these in-plane displacements during various phases of the cardiac cycle may provide information on the functional aspects of the heart. To the authors' knowledge this work has not been reported so far. Therefore, the aim of the present study is to reconstruct the displacement patterns due to cardiac action as observed on the chest wall for healthy male subjects, during the P, QRS and T-waves of the electrocardiogram (ECG) and to perform a comparative study of these displacements with that of a cardiac patient.
2 Method

The method consists of illuminating the chest wall of the subject by a collimated laser beam, recording of speckle patterns during the required phase of ECG by using the electronic shutter, analysing the recorded plate to obtain the displacements and to generate a three-dimensional plot from the displacement data.

2.1 Illumination

A beam of He/Ne laser ($\lambda = 632.8$ nm, power = 7.0 mW) was spatially filtered and collimated. Fig. 1 shows the area above the cardiac region which was illuminated by this collimated beam. This area consisted of the chest wall from II to V intercostal space with the sternum at the right side. The activity at various locations, which was maximum at the apex region, could easily be observed by the movement of speckles in the absence of breathing. To improve the reflectivity of this area a thin layer of water paint was applied.

![Fig. 1](Location on the chest wall for recording the specklegram)

2.2 Shutter operation

The ECG of the subject was continuously monitored and was used to operate a shutter placed in the path of the laser beam to allow illumination only during the required phase. The circuit diagram of the shutter is given in Fig. 2a. The ECG was fed to a filter and comparator to sense the R-wave peak. The output from the comparator in synchronism with the R-wave peak was fed to a pulse programmer (Yamuna Digital Electronics, India, Model 104-DO). The output pulse was supplied to a relay to allow the passage of the laser beam for the required duration during the desired phase of ECG by varying its delay time and width. A further check on this operation was performed by placing a light-dependent resistor (LDR) after the shutter (Fig. 2b). This output was also displayed along with the ECG of the subject.

2.3 Recording

The recording assembly is shown in Fig. 3. The subject was asked to sit in a vibration-free chair and advised to hold his breathing during recording. This was to ensure that the chest and abdomen wall did not suffer any respiratory movement. The recording was carried out in the image plane of the lens $L_2$ (placed at a distance $2f$ where $f$ is the focal length of the lens) on an Agfa-Gevaert Scientia 10E75 holographic plate. The painted region of the chest wall was illuminated during P, QRS and T-waves by employing the shutter described in Section 2.2. The recorded plates were processed with D-19 developer and IPC universal fixer. The processed plates will hereafter be referred to as specklegrams.

![Fig. 2](a) Circuit diagram of electronic shutter; (b) photodetector circuit

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