CHAPTER 2

GENERATION AND DETECTION OF ULTRASOUND

2.1 The piezoelectric phenomenon

Although a number of different methods are available for the production of high frequency mechanical vibrations, the most common method of generating ultrasound, and the one employed in the devices used in clinical ultrasound, relies on a phenomenon called the piezoelectric effect. This phenomenon is exhibited by some crystalline materials, and involves the reversible conversion of two forms of energy from one to the other, namely mechanical and electrical energies.

The prefix piezo means pressure. When crystals of piezoelectric materials are compressed or stretched (i.e., when mechanical stress is applied upon them), electrical charge will appear on their surfaces. Mechanical energy will have been transformed into electrical energy. This process is called the **piezoelectric effect**. Figure 2.1 illustrates this effect, and also shows that the polarity of the induced surface charge is reversed between compression and stretching.

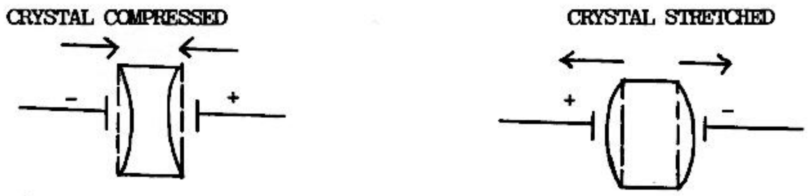

Fig. 2.1 The piezoelectric phenomenon

Conversely, when a potential difference is applied between the faces of a piezoelectric crystal, the crystal will respond by expanding or contracting. Electrical energy will have been converted to mechanical energy. This is the **reverse piezoelectric effect.**

2.2 Production and detection of ultrasound

Recalling that ultrasound is a mechanical form of energy, we can deduce that to produce ultrasound using the piezoelectric phenomenon we must rely on that process which converts electrical energy into mechanical energy, i.e. the reverse piezoelectric effect. On the other hand, we can use the same phenomenon to detect high frequency mechanical vibrations, by converting them into an electrical signal (the piezoelectric effect). In summary, the generation and detection of ultrasound is done by using crystals of piezoelectric materials. **Production of ultrasound relies on the reverse piezoelectric effect, while detection is based on the piezoelectric effect.** Because of the reversibility of this phenomenon, it is possible to use the same crystal to produce ultrasound, and subsequently to detect echoes returning to the crystal from a reflector at some distance away.

2.3 Ultrasonic transducers

Devices which convert one form of energy into another are called transducers. The probe assembly used to generate and detect ultrasound is therefore aptly called a transducer. There are several different designs of ultrasonic transducers. First, we consider a transducer made with a single piezoelectric crystal. Multi-crystal transducers will be discussed in Chapter 7.

2.3.1 The single crystal transducer

The essential components of the single crystal transducer are shown in Fig 2.2

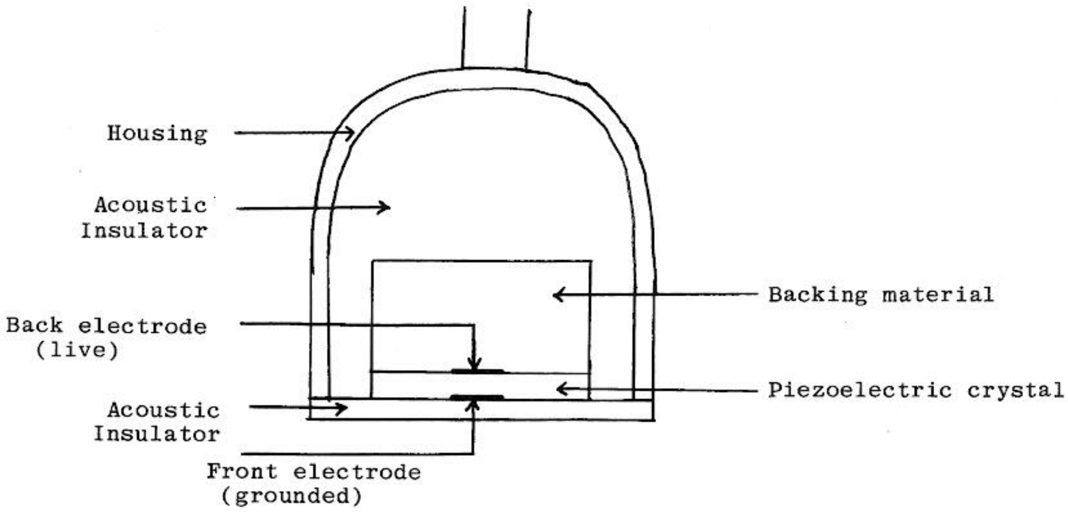

Fig 2.2 Components of a single crystal (T)

The crystal element

The crystal element is the most important component of the transducer. It is a thin disc of piezoelectric material near the front surface of the transducer. The crystal material may possess its piezoelectric properties naturally, but more commonly, the piezoelectric properties are artificially induced using a combination of thermal and electrical treatment. It is important to note that the piezoelectric properties of an artificial crystal can be destroyed if the crystal is heated to high temperatures. For this reason, **the sterilization of ultrasonic transducers should not be done by autoclaving.**

The crystal thickness controls the frequency of vibrations. A vibrating crystal will transmit ultrasound in both directions from its two surfaces. The crystal thickness is chosen such that the vibrations at the two surfaces will reinforce each other every time the ultrasound makes a round trip internally from one face to the other and back to the first face. Reinforcement takes place if the distance covered by the ultrasound during the round trip equals a whole wavelength of the ultrasound wave. The wave then arrives at a crystal face in exactly the same phase of the wave cycle as the preceding disturbance which caused it. Consecutive vibrations on the crystal faces will then reinforce each other through what is known as **constructive interference** in wave theory. The reinforcements result in prolonged self-sustenance of vibrations, a condition called **resonance.**

Fig 2.3 shows that conditions of resonance are met when the thickness, t, of the piezoelectric crystal is equal to one half of the wavelength corresponding to the desired frequency of vibrations.

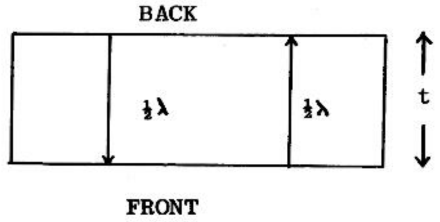

Fig. 2.3 Thickness of a crystal determines vibrational frequency

The relationships used to determine the thickness corresponding to a particular frequency are:

(i) $$\text{frequency} = \frac{\text{velocity of ultrasound in crystal material}}{\text{wavelength}}$$

(ii) wavelength = 2 x thickness (t)

Therefore, $$\text{frequency (f)} = \frac{\text{velocity (v)}}{2t}$$

or $$t = \frac{v}{2f}$$

Example

The velocity of ultrasound in a commercial preparation of lead zirconate titanate, a commonly used piezoelectric ceramic material, is 4,000 metres per second. If a vibration frequency of 5 MHz were desired, what would be the crystal thickness?

$$\text{Thickness} \quad t = \frac{v}{2f} = \frac{4{,}000\ \text{m/s}}{2 \times 5 \times 10^{6}/\text{s}}$$

$$= 4 \times 10^{-4}\ \text{m}$$

$$= 0.4\ \text{mm.}$$

In practice, crystal thicknesses for diagnostic ultrasound transducers range typically from 0.1 mm for high frequencies to 1.0 mm for low frequencies. **The thinner the crystal, the higher the frequency.**

The size (diameter) and shape of the crystal have an effect on the shape of the ultrasound beam as it travels outwards from the transducer. This is discussed in Chapter 5.

2.3.1.1 Electrical connections

The front and back surfaces of the crystal are coated with thin films of electrically conducting material to facilitate connections to the electrodes which supply the potential difference for pulsing the crystal. The back electrode serves as the live connection, while the front electrode is earthed to protect the patient from electrical shock. In addition to pulsing the crystal during the generation of ultrasound, the electrodes also serve to pick up the piezoelectric signal generated when returning echoes strike the crystal. The front side of the transducer, which makes direct contact with the patient, is covered with an electrical insulator.

2.3.1.2 Backing material

The backing block behind the crystal is made of a material which absorbs ultrasound heavily. Absorption of ultrasound is discussed in Chapter 3. The purpose of the backing block is to absorb ultrasonic energy transmitted back into the transducer, and hence to quickly damp the oscillations of the crystal following a pulsation. This is important in pulsed -wave techniques in which the transducer sends out a short burst of energy (a pulse) followed by a comparatively much longer "listening" phase during which the transducer does not emit ultrasound but is instead tuned to detect returning echoes. Damping also controls the pulse length, which in turn affects image resolution (see Chapter 8). Transducers for continuous wave ultrasound are allowed to vibrate freely at the resonant frequency, and do not require damping.

2.3.1.3 Acoustic insulator

The acoustic insulator prevents vibrations originating from the crystal from being transmitted into the transducer housing. It also insulates the crystal from extraneous sources of ultrasound. It should be made of a material which transmits ultrasound poorly, such as rubber.

2.3.1.4 Transducer housing

The internal components of the transducer are covered by a robust housing.