Published in the Scientific Instrument Manufacturers' Association BULLETIN January & March 1956.

Electronics and the Human Heart

H. V. Beck

(Research Department) Cambridge Instrument Co. Ltd.

ELECTRONIC devices of one sort or another seem to have entered into most fields of human activity; in some, such as navigation and entertainment, rather spectacularly, and in others, such as medicine, almost without notice by the general public. Nonetheless, the results obtained by the application of electronic techniques in the medical field are having a far reaching effect, and the purpose of this article is to describe some of these applications and the results obtained in one small part of it - that of measurements associated with the human heart.

Until a few years ago, measurements were made on a small scale by means of non-electronic instruments. In some cases instruments of fifty years ago were giving results comparable with those obtained now, but, on the whole, a great deal of time and trouble was necessary to obtain the good results.

In recent years, the progress made in the treatment of heart disorders has brought about a marked increase in the number of patients requiring extensive investigation. At the same time as the number of patients has increased, the extent of the investigation, or diversity of measurements on any one patient, has also increased and as a result of all this extra activity there has been the demand for apparatus that will measure one or more phenomena with the minimum of preparation and skill, and in the shortest possible time. It is in this connection that electronics has become so useful. On the whole, it is true to say that, so far, electronic techniques have not made any fundamental contribution to the type of measurement made, but they have improved on the convenience with which they can be made.

Electrocardiographs

Perhaps the most widely used electronic instrument for measurement on the heart is the electrocardiograph, an instrument which records the electrical activity of the heart.

The heart behaves rather like an electrically-operated pump, in which the pumping action is obtained by the contraction and relaxation of the four chambers of the heart. The control of the sequence of mechanical activity is achieved electrically by an electrical stimulus, which starts in one of the two small chambers, causing them to contract, and then travels along the dividing wall between the two large chambers and spreads over their surfaces. The muscular activity caused by the stimulus gives rise to an electrical impulse which is conducted to the surface of the body; electrical connections to certain points on the body, notably the limbs and the chest, will pick up an electrical signal of characteristic shape. A study of this shape will yield information not only of the state of the electrical 'circuit', but also to some extent the mechanical activity: for example, the shape of the wave may be changed by discontinuities in the bundle of nerves carrying the stimulus, or a lengthening of the path that the stimulus has to travel, or an abnormal initiating stimulus. *Fig.1a* shows a normal record of electrocardiogram taken between the left arm and right arm. The excursion P is caused by the contraction of the small chambers, QRS by the contraction of the large chambers, and T by the relaxation of the large chambers. T-P is the resting state of the entire heart.

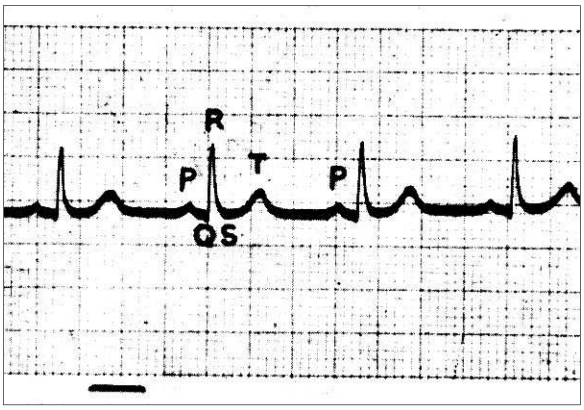

Fig.1a. Normal electrocardiogram.

Fig.1b shows the shape associated with auricular fibrillation, a condition in which the small chambers contract independently and more rapidly than the large chambers and which is caused, amongst other things, by excessive tobacco and alcohol, by emotional stress and by infections such as pneumonia.

Einthoven's Galvanometer

The electrical signal picked up at the surface of the body is extremely small; so small, that it would take some ten thousand million people, or five times the population of the world, to light a small torch bulb. In spite of this, the signal was successfully recorded towards the end of last century by several scientists, the most successful of whom was Einthoven, a Dutchman, using an extremely sensitive string galvanometer of his own design. This type of galvanometer consists essentially of a very fine wire stretched in a strong magnetic field, the movement of the wire being recorded photographically after optical magnification. It is the simplest of instruments and is still in widespread use today, but it has several disadvantages. Although it will give a faithful recording of the shape of the wave on adult humans, its sensitivity could not be greatly increased to allow, for example, electro-cardiograms of an unborn child to be taken without distorting the wave shape.

A second disadvantage of the Einthoven string galvanometer is that when it is connected to the patient, the electrical signal falls perhaps to half its original value. This is quite unimportant if only one electrocardiogram is being taken from the patient at any one time since the fall in signal can be compensated by a corresponding increase in sensitivity. If, however, two or more electro-cardiograms are being taken simultaneously, for example, one between the left arm and left leg, at the same time as one between left arm and right arm, some distortion would be present that could not be eliminated by altering the sensitivity. The string galvanometer cannot, therefore, be used for accurate simultaneous recording. Other disadvantages arise from the method of recording. With the photographic method the record is not available immediately, and the use of moving paper or film makes observation of the wave shape before and during recording impossible.

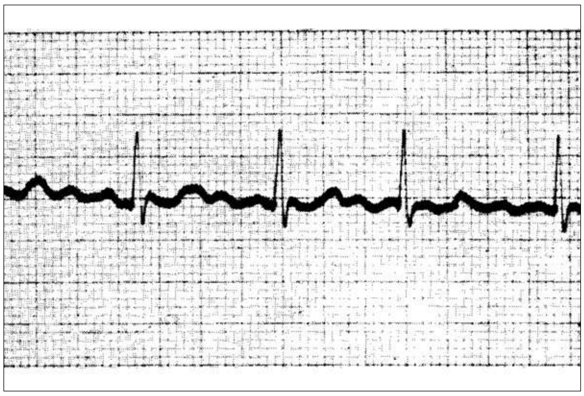

Fig.1b. Electrocardiogram showing auricular fibrillation (see text).

Electronic techniques have been employed to overcome one or more of these disadvantages. Thus, an electronic amplifier feeding a string galvanometer has been used to increase the sensitivity, while another apparatus has three amplifiers each feeding a galvanometer with less sensitivity but smaller and lighter than the string type, enabling three records to be taken simultaneously without distortion. An instrument has also been made in which an amplifier feeds a cathode ray tube, thus giving the facility of observation before and during recording, but retaining the photographic feature.

Perhaps the greatest advance has been the development of direct writing instruments that overcome all these disadvantages as a result of the power that can be made available by electronic amplification. To record faithfully the electrical signal from the heart, the recording mechanism must be made to move very rapidly. The success of the string instrument lay in the use of a very fine wire, which required almost infinitesimal power to move it rapidly; a pen mechanism on the other hand in direct contact with paper requires a very much greater power and electronic amplification is a very convenient means of providing it. An example has already been given of the minuteness of the electrical signal by reference to the number of persons that would be required to light a torch bulb. The effectiveness of electronic amplification can be seen from the ease with which the signal from only one person can be amplified to achieve the same result. A signal of the order of 10^{-3} of a volt, at a maximum power of $10^{-11}$of a watt, can be made to deliver power of the order of 1 watt into the pen of a direct writing instrument.

Fig.2. Direct-Writing-Electrocardiograph.

There are several makes of direct writing electrocardiographs available and *Fig.2* shows a typical outfit. The whole instrument is made small and portable so that electrocardiograms can be taken by a specialist in a patient's home or in the hospital ward. It may be pointed out in passing that instruments made for measurement on the human heart are frequently used on animals and the illustration shows the actual instrument recently presented to Her Majesty the Queen for use on her horses.◄

Cathode Ray Monitor

Even though the direct writing electrocardiograph has solved the main problems, there has in recent years been a new demand, that of seeing the electrocardiogram and possibly the waveform of another phenomenon at a distance. A surgical operation of any sort throws a strain on the heart and it is often helpful for the anaesthetist or surgeon to see the electrocardiogram during its progress. The effect of the administration of drugs and anaesthetics on the rhythm of the heart can readily be ascertained, and when the operation is on the heart itself, the associated waveform can convey a great deal of information on how the stages in the operation are progressing, often more than a visual examination of the heart itself.

The observation of the electrocardiogram can be made with the minimum of inconvenience and disturbance of the work in hand by its display, several times larger than usual, on a screen placed some distance away; the anaesthetist or surgeon has only to look up to check the waveform and proceed accordingly. A viewing unit designed for this purpose is shown in *Fig.3*. A cathode ray tube, similar to the type employed in most television sets, is mounted vertically in a cone and is viewed through a mirror. A spot of light is made to move slowly from left to right across the screen and is deflected up and down by the amplified signal from the patient, so that the wave shape is traced out. The amplified signal is obtained from a direct writing instrument so that a permanent record may be made if required of the wave appearing on the screen.

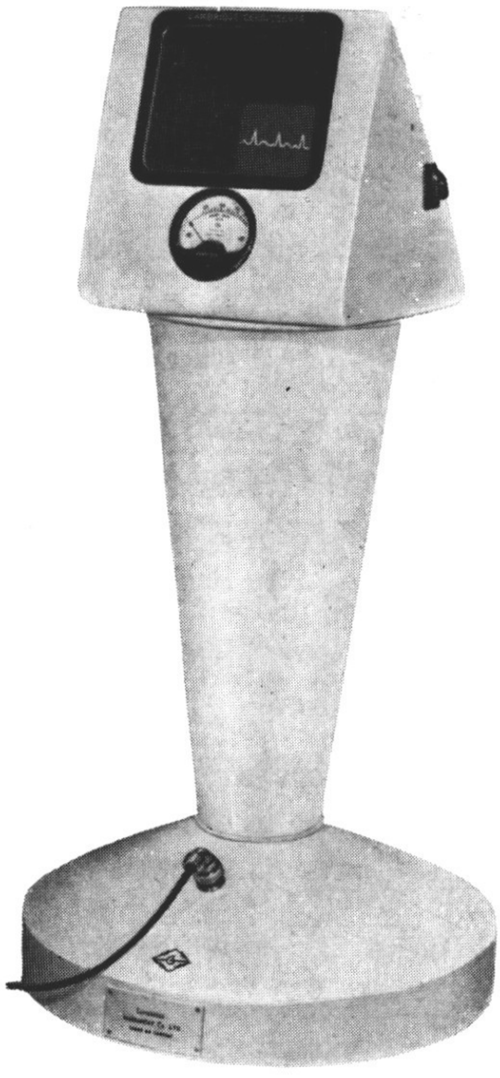

Fig.3. Viewing unit for operating theatre.

Heart Rate Indicator

The cathode ray monitor equipment also contains a heart rate indicator circuit feeding a meter mounted on the face of the viewing hood.

Probably all of us have had our heart or pulse rate taken at some time or other. Some occasions arise when taking the pulse with the finger is not very practicable. During a long operation it is desirable to keep a check on the pulse, but the time, or, more particularly, the space taken up by a nurse to do this could be put to a better use. Thus the need for an automatic 'pulse taker' or heart rate indicator has arisen.

One obvious way is to make the movement due to the expansion of the artery generate an electrical signal just as the nerves in the tips of our fingers do, in transmitting the information to the brain. An electronic circuit, like the brain, requires an electrical signal for its operation, and many devices exist that convert various quantities to electricity. The microphone which converts sound to electricity is perhaps the best known example of this. Once the electrical signal has been obtained, it can very easily be changed from one form to another to suit the particular measurement by being distorted, chopped up, amplified and so on.

Some heart rate indicators employ this principle, that is a 'pick-up' device on the wrist but, when an electrocardiogram is being recorded or observed, we can use the electrical signal generated by the heart itself. The QRS part of this signal (*Fig.1a*), when amplified, can be applied to an electronic circuit that, in effect, pours exactly one bucketful of electricity per pulse into an electrical storage tank which has a leak in it. The amount of electricity in the tank is dependent on the rate at which the bucketfuls are being poured in, and this can be shown on a meter. The anaesthetist or surgeon has only to glance at the meter to read the pulse rate, and take action when the rate increases or decreases to a dangerous level. On one instrument of this type, it is not necessary to look at the instrument or even the patient to see that the pulse or the heart has stopped altogether - an alarm device is fitted and a bell is rung if this event occurs!

Phonocardiographs

One of the most frequent and time-honoured measurements made on the heart is that of listening to the sounds made by it. This measurement is made so widely, indeed it is probable that most of us were subjected to it before we were born, that it is perhaps not surprising that electronic techniques have been applied to it.

The heart sounds arise mainly from the closing of the valves; first the valves between the small and large chambers and then the valves on the exit sides of the larger chambers. This gives a characteristic 'lub-dub' sound. It is also commonly found that perfectly normal hearts give other sounds that can be recognised with some practice. Certain defects in the heart do, however, give rise to other sounds, notably murmurs, which are due, amongst other things, to valves not closing properly, obstructions by growths, and deposits in the blood stream, each type giving a characteristic sound. These sounds can be heard quite easily with the aid of an acoustical stethoscope, but very much more information can be obtained if the precise timing of them in relation to other phenomena such as the electrocardiographic signal could be determined. The ear cannot judge time relationships very accurately. This can best be done by recording a wave shape representing the sounds, together with waves representing other activities.

The first attempts to record the wave shape of the sounds were by means of non-electronic instruments, and it was soon found that results were not as valuable as had been hoped. The reason was to be found in the selective characteristics of the ear. The 'lub-dub' sound appeared very prominently on the record, and because its intensity was very great it completely masked the murmurs which were of such less intensity. The ear, however, is more sensitive to the murmurs, which contain mostly high notes than to the 'lub-dub' sound, which contains mostly low notes, so that the murmurs appeared much more prominently to the ear than on the record.

It was not until the invention of an electronic stethoscope incorporating a circuit which, in effect, superimposed the selective characteristics of the ear on the overall response, that a wave shape representative of the sounds apparent to the ear was obtained.

The electronic stethoscope collects the sounds and directs them to a microphone which gives out an electrical signal representing the sounds. The signal is amplified, and then passed through a filter circuit, which gives the characteristics of the ear, and is then fed to an oscillograph which traces out the wave shape on film or photographic paper. The electrical signal is also converted back to sound so that the sounds may be heard at much greater intensity. *Fig.4* shows a typical three-channel tracing in which two sounds, A and C, are recorded with an electrocardiographic signal B. The effect of superimposing the characteristics of the ear can be readily seen by comparing A (fully super imposed) with C, which is the same sound but with the characteristics only partially superimposed. The 'lub' (1) and 'dub' (2) can be seen in both, but the opening snap (OS) of a valve, readily observed in A, is masked in C. The murmur (MDM) is also more apparent in A than C.

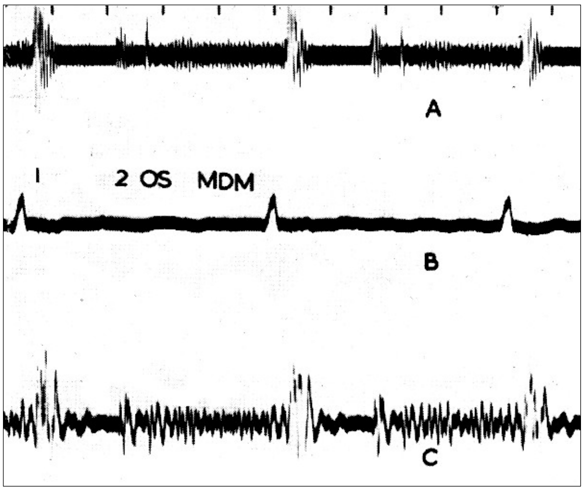

Fig.4. Three-channel record. Two phonocardiograms recorded with an electrocardiogram.

Fig.5. Audio-Visual Heart Sound Recorder.

An interesting development is the employment of magnetic disc or tape recorders for 'storing' the sounds. The record can be played back for detailed study and comparison with records of sounds from other patients, for teaching purposes, and for the comparison of sounds before and after treatment. A portable magnetic disc recorder (*Fig.5*) has been designed especially for this work. The sound being recorded can be heard in stethophones and the shape of the electrical signal representing the sound can be examined on a cathode ray tube built into the instrument.

Blood Pressure Measurements

Another measurement to which electronic techniques is being increasingly applied is that of blood pressure. The form of this measurement with which most of us are familiar is the rubber bag on the arm which is inflated to give the maximum and minimum pressure reached in the arteries in the arm during each heart beat.

It is sometimes necessary to measure not only the maximum and minimum pressures, but also the way in which the pressure varies with time, that is the shape of the pressure wave form and not just one or two values in it. It is also sometimes necessary to measure the pressure waveform in the heart itself or in the arteries and veins directly leading to it. This would give information about blockages in the arteries or leakages in the valves, and other mechanical defects in the heart. Measurements inside the heart have been made by inserting a long thin and flexible tube into a vein in the arm and pushing the tube through the vein, up the arm, past the shoulder and into the heart. The tube is filled with liquid which transmits the pressure at the tip to the other end where it causes a small flexible disc to distort.

Until a few years ago, the movement of the disc was measured by fixing a small mirror on it and shining a beam of light on to the mirror. Movement of the beam of light due to pressure at the remote end of the tube was recorded on a camera placed several feet away, but the difficulty with this arrangement was that the slightest vibration caused an interference on the record so that for satisfactory operation massive concrete supports were required and movement of persons in the vicinity could not be tolerated. These requirements were, of course, not practicable in an operating theatre and electronic techniques have therefore been applied to the measurement of the movement of the disc. To mention but one method, based on the original, a beam of light shines into a photocell placed six inches or so from the mirror. The photocell converts the light into an electrical signal which is amplified electronically and then applied to the recorder.

Multi-channel instruments

For the purpose of simultaneously recording several phenomena, electronics has a definite, but, perhaps, subtle advantage in its ability to convert all the phenomena to the same form. The heart sounds, the pressures in the blood vessels, and the pulse rate, are all represented by electrical signals similar to the electrocardiographic signal itself, and all may be amplified electronically to similar power levels. Thus the same, or very similar, recording mechanism can be used for each phenomenon, instead of the cumbersome mixture of recording systems required by the corresponding nonelectronic methods. The application of electronic techniques has thus brought about the development of very compact and versatile instruments for measuring simultaneously several phenomena.

The instruments described are in widespread use in hospitals or consulting rooms in all parts of the world. Others such as the vector-cardiograph which traces a loop that represents the electrical activity of the heart, the ballistocardiograph which measures the force exerted by the heart on the blood in each heartbeat, the oximeter which measures the change in colour of the blood due to changes in the amount of oxygen in it, are in use on only a small scale, but may well be laying a foundation for routine measurements in years to come. Some of these newer measurements are completely dependent on electronics, and when they have come into widespread use, electronics will have become fully established in the field of measurements on the human heart.

◄ The presentation was made by the Municipality when H.M. The Queen visited Cambridge on 20th October 1955 to mark the granting of City status.