ROHINI
COLLEGE OF ENGINEERING AND TECHNOLOGY
Approved by AICTE and affiliated to Anna University Chennai (An ISO Certified Institution)
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DEPARTMENT OF BIOMEDICAL ENGINEERING

BM3491 Biomedical Instrumentation

UNIT-IV MEASUREMENT OF BIO SIGNALS

4.5 Blood Flow Measurement

- Blood flow measurements can yield cardiac output data. Such instruments measure the blood flow rate, and the cardiac output is determined by integrating the blood flow signal over a known period of time.
- The problem with this method, however, is that most blood flow transducers capable of delivering meaningful quantitative data must be applied directly to the blood vessel being measured.
- It is not possible to obtain valid cardiac output data from blood vessels taken far downstream in the arterial system; thus, none of the easily accessible peripheral arteries (i.e., an arm or leg) can be used.
- The measurement must be done either in the pulmonary artery or in the aorta immediately after these vessels leave the heart.
- This requirement limits cardiac output measurement via blood flow measurement to thoracic surgery procedures, whenever the vessels are normally exposed anyway.
- The average velocities of blood flow vary over a wide range in vessels with diameters ranging from 2 cm to a few millimetres

4.6.1 Electromagnetic Blood Flowmeter:

Why Electromagnetic Blood Flow Meter is Popular among other methods ?

1. It measures volume flow rate independent of velocity.
2. It produces accuracies up to +5 per-cent.

3. The technique can accommodate blood vessels of diameters from 1 to approximately 20 mm diameter.

The operating principle:

The operating principle underlying all electromagnetic type flowmeters is based upon ***Faraday's law of electromagnetic induction*** which states that when a conductor is moved at right angles through a magnetic field in a direction at right angles both to the magnetic field and its length, an emf is induced in the conductor.

- In the flowmeter, an electromagnetic assembly provides the magnetic field placed at right angles to the blood vessel (Fig. 10.1) in which the flow is to be measured.
- The blood stream, which is a conductor, cuts the magnetic field and voltage is induced in the blood stream.
- This induced voltage is picked up by two electrodes incorporated in the magnetic assembly.
- The magnitude of the voltage picked up is directly proportional to the strength of the magnetic field, the diameter of the blood vessel and the velocity of blood flow,

$$e = CB\,l\,v$$

Where,

e = induced voltage

B = strength of the magnetic field

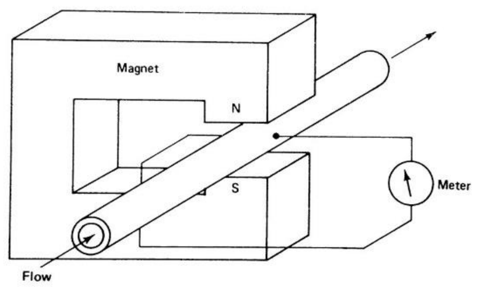
v = velocity of blood flow

l = length of the conductor (diameter of the blood vessel)

C = constant of proportionality

If the strength of the magnetic field and the diameter of the blood vessel remain unchanged, then the induced voltage will be a linear function of the blood flow velocity.

Principle of Electromagnetic Blood Flow Meters



- If the strength of the magnetic field and the diameter of the blood vessel remain unchanged, then the induced voltage will be a linear function of the blood flow velocity.

  Therefore, $e = C_1 V$

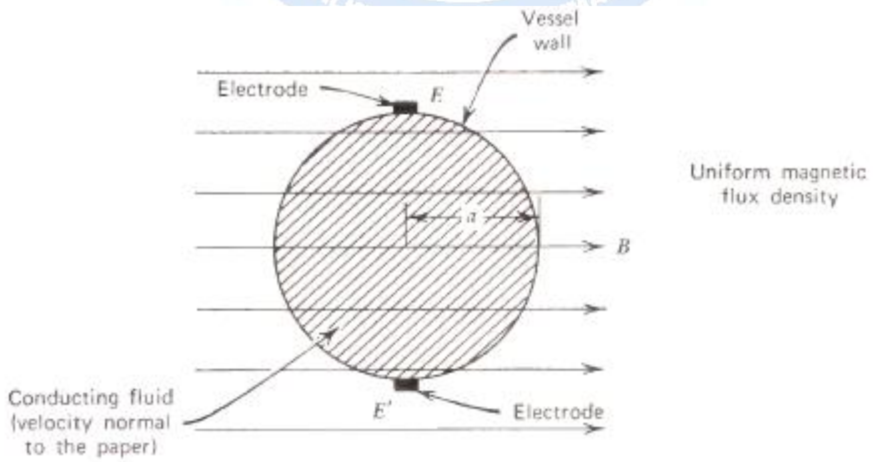
  where C1 is a constant and equal to CBl

- Further, the flow rate Q through a tube is given by Q = VA

  Therefore, V = Q/A

  where A is the area of cross-section of the tube, hence

$$e = C_1 \frac{Q}{A} = C_2 Q$$



Cross-sectional view of EM Flow meter

Construction of Electromagnetic Blood Flow meter:

- **Flow Tube**:

  The section of the pipe through which the fluid flows. It is usually lined with a non-conductive material such as rubber, Teflon, or ceramic to prevent the fluid from short-circuiting the electrodes.

- **Electrodes**:

  Two electrodes are typically mounted opposite each other on the interior walls of the flow tube. They are in direct contact with the fluid and detect the induced voltage. The electrodes may be in contact with either the flowing blood or the outer surface of the blood vessel carrying the flowing blood.

  The former is called '***Cannulating flowmeter'*** and the latter '***Cuff flowmeter'***

- **Magnetic Coils**:

  Coils or magnets generate a magnetic field perpendicular to the direction of the fluid flow. These coils are mounted outside the flow tube. Today, we have electromagnetic flowmeters whose magnetic coils work on sine, square or trapezium current waveforms.

- **Transmitter**:

  The electronic unit that processes the signal from the electrodes, converts it to a flow rate, and displays or transmits this information. The transmitter may also provide additional features such as signal conditioning, data logging, and communication interfaces.

- **Liner**:

  The inner lining of the flow tube, which must be non-conductive and compatible with the fluid to prevent short circuits and corrosion.

- **Housing**:

  The outer casing that protects the internal components and provides structural integrity.

Working Principle

1. **Magnetic Field Generation**:
   - The magnetic coils generate a magnetic field across the flow tube. This field is usually perpendicular to the direction of the fluid flow.
2. **Fluid Flow**:
   - As the conductive fluid flows through the magnetic field, it acts as a moving conductor.
3. **Induced Voltage**:
   - According to Faraday's Law, the motion of the conductive fluid through the magnetic field induces a voltage between the two electrodes. The magnitude of this induced voltage is directly proportional to the flow velocity of the fluid.
4. **Voltage Detection**:
   - The electrodes detect the induced voltage, which is then sent to the transmitter.
5. **Signal Processing**:
   - The transmitter processes the voltage signal, converting it to a flow rate based on the known dimensions of the flow tube and the characteristics of the magnetic field.
6. **Output**:
   - The flow rate is displayed on a digital readout, recorded, or transmitted to a control system.

Key Points for Accurate Measurement

- **Conductivity**: The fluid must have a minimum level of electrical conductivity for the magmeter to work correctly.
- **Flow Profile**: The flow profile should be uniform; therefore, straight pipe runs upstream and downstream of the meter are recommended.
- **Grounding**: Proper grounding of the flow meter is essential to avoid noise and interference in the voltage signal.

Advantages of Electromagnetic Flow Meters

- **Accuracy**: They provide highly accurate flow measurements.
- **No Moving Parts**: They have no moving parts, reducing maintenance and the risk of wear and tear.
- **Versatility**: They can measure a wide range of fluid types, including slurries, corrosive fluids, and wastewater.
- **Low Pressure Drop**: They cause minimal pressure drop compared to other types of flow meters.

Limitations of EM Blood Flow Meter:

- **Sensitivity to Electromagnetic Interference**:
  Electromagnetic blood flow meters can be affected by external electromagnetic fields, which can introduce noise and affect the accuracy of measurements.

- **Calibration and Maintenance**:
  These devices require careful calibration to ensure accurate readings. Regular maintenance is necessary to maintain their precision and functionality.

- **Conductive Fluid Requirement**:
  The measurement principle relies on the conductive properties of blood. This means that the device might not work properly with non-conductive fluids or in conditions where the conductivity of blood is altered.

- **Installation Complexity**
- **Cost**
- **Physical Space requirement**
- **Temperature sensitivity**

- **Biocompatibility Issues**:
  There may be concerns about the biocompatibility of the materials used in the sensor when it comes into contact with blood, which can potentially affect the patient.

4.6.2 Ultrasonic Blood Flow Meters:

- There are basically two types of ultrasonic blood flow-velocity meters.
  - ✓ The first type is the ***transit- time velocity meter*** and
  - ✓ the second is the ***Doppler-shift*** type.

Doppler-shift Flow-velocity Meters:

- It is a non-invasive technique to measure blood velocity in a particular vessel from the surface of the body.
- It is based on the analysis of echo signals from the erythrocytes in the vascular structures.
- Because of the Doppler effect, the frequency of these echo signals changes relative to the frequency which the probe transmits.
- The Doppler frequency shift is a measure of the size and direction of the flow velocity.
- The principle is illustrated in Fig. 4.6.2. The incident ultrasound is scattered by the blood cells and the scattered wave is received by the second transducer.
- The frequency shift due to the moving scatterers is proportional to the velocity of the scatterers.
- Alteration in frequency occurs first as the ultrasound arrives at the 'scatterer' and second as it leaves the scatterer.
- If the blood is moving towards the transmitter, the apparent frequency f_1 is given by

$$f_1 = \frac{(C - v\, cos\theta)}{C}$$

where f = transmitted frequency
C = velocity of sound in blood
q = angle of inclination of the incident wave to the direction of blood flow
v = velocity of blood cells

- Assuming that the incident and scattered radiations are both inclined at θ to the direction of flow as shown in **Fig.** 4.6.2

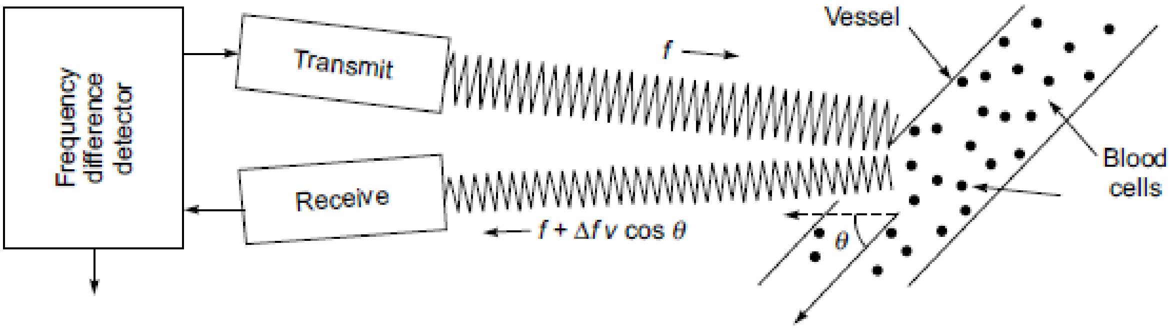


Fig. 4.6.2 *Principle of ultrasonic Doppler-shift flow velocity meter*

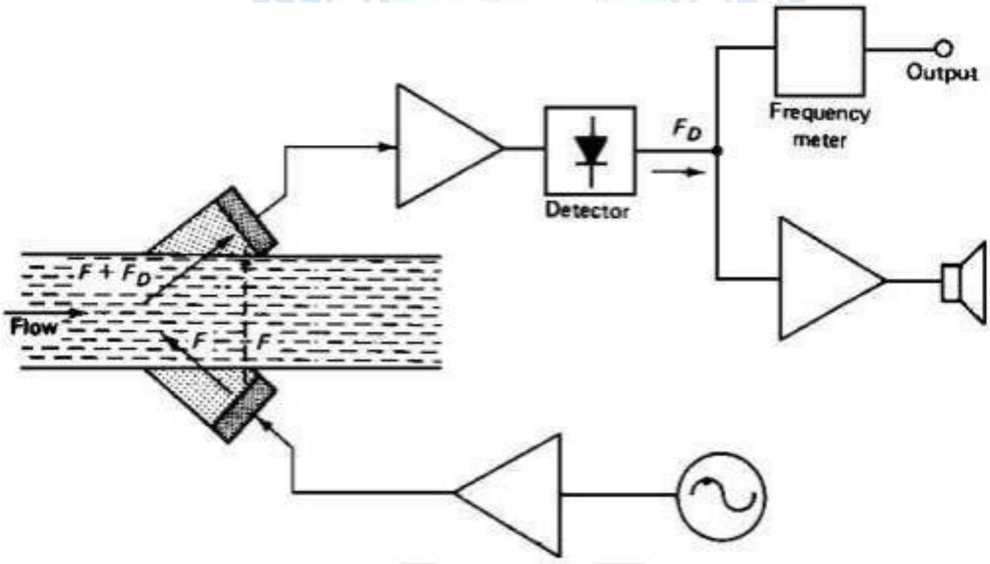


Fig. 4.6.3 *ultrasonic Doppler blood flow meter*

- More common are ultrasonic flow meters based on the Doppler principle. An oscillator, operating at a frequency of several megahertz, excites a piezoelectric transducer (usually made of barium titanate).
- This transducer is coupled to the wall of an exposed blood vessel and sends an ultrasonic beam with a frequency F into the flowing blood.

- A small part of the transmitted energy is scattered back and is received by a second transducer arranged opposite the first one. Because the scattering occurs mainly as a result of the moving blood cells, the reflected signal has a different frequency due to the Doppler effect.
- Its frequency is either F + FD or F - FD, depending on the direction of the flow.
- The Doppler component FD is directly proportional to the velocity of the flowing blood. A fraction of the transmitted ultrasonic energy, however, reaches the second transducer directly, with the frequency being unchanged. After amplification of the composite signal, the Doppler frequency can be obtained at the output of a detector as the difference between the direct and the scattered signal components.
- With blood velocities in the range normally encountered, the Doppler signal is typically in the low audio frequency range. Because of the velocity profile of the flowing blood, the Doppler signal is not a pure sine wave, but has more the form of narrow-band noise.
- Therefore, from a loudspeaker or earphone, the Doppler signal of the pulsating blood flow can be heard as a characteristic "swish-swish-." When the transducers are placed in a suitable mount (which defines the area of the blood vessel), a frequency meter used to measure the Doppler frequency can be calibrated directly in flow-rate units. Unfortunately, Doppler flow meters of this simple design cannot discriminate the direction of flow.
- More complicated circuits, however, which use the insertion of two quadrature components of the carrier, are capable of indicating the direction of flow.

$$f_2 = \frac{C}{(C + v\cos\theta)}$$

The resultant Doppler shifts

$$\Delta f = f_1 - f_2 = \frac{C}{(C + v\cos\theta)}$$

substituting f_1, we get

$$= f_1 - \left[\frac{f\,(C - v\cos\theta)}{C}\right]\left[\frac{C}{C + v\cos\theta}\right]$$

$$= f\left[1 - \frac{(C - v\cos\theta)}{(C + v\cos\theta)}\right]$$

Since $C >> v$,

$$\Delta f = \frac{2 f\, v \cos\theta}{C}$$

$$v = \frac{D\, f \cdot C}{2 f\, \cos\theta}$$

This relationship forms the basis of measuring blood velocity.

Advantages of Doppler Blood flowmeter:

- **Non-invasive Measurement**:
  Doppler blood flow meters provide a non-invasive way to measure blood flow and velocity, reducing the need for surgical procedures and lowering patient risk.
- **Real-time Monitoring**:
  They allow for real-time monitoring of blood flow, which is crucial during surgeries, in critical care, and for assessing ongoing treatment efficacy.
- **Portable and Convenient**:
  Many Doppler devices are portable, making them convenient for use in various settings, including bedside, outpatient clinics, and remote locations.
- **Accurate and Reliable**:
  Doppler ultrasound technology is highly accurate and reliable for assessing blood flow in various vessels, including arteries and veins, providing essential data for diagnosing vascular conditions.
- **Assessment of Blood Flow Velocity**:
  They can measure blood flow velocity and direction, which is vital for diagnosing conditions like arterial blockages, venous insufficiencies, and other vascular disorders.

- **Detection of Vascular Abnormalities**:
- Doppler blood flow meters can detect vascular abnormalities such as stenosis, occlusions, aneurysms, and plaques, facilitating early diagnosis and intervention.

Limitations of Doppler flowmeters:

- ✓ Liquids to be metered must have an excess of approximately 2% suspended solids by volume.
- ✓ Liquid linear velocities must exceed 0.15 m/s.
- ✓ Piping material must be of a homogenous composition Pipe wall thickness cannot be greater than 1.91 cm.

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