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Interpretation of Ultrasonic Doppler-shift signals from arterial blood-flow.

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The ultrasonic Doppler-shift flow-velocity meter is a blood velocity measuring instrument and does not measure volume flow. This paper discusses the factors which must be considered when attempting to convert the instrument into a blood-flow device.

It can be shown that for coplanar emitting and receiving transducers the resultant Doppler-shift signal is given by:

$$\Delta f = \frac{2fV \cos \phi}{C}$$

- Δf = Doppler shift frequency
- f = incident frequency
- V = velocity of streamline in vessel
- C = velocity of sound in blood
- ϕ = angle of inclination of the probe to the direction of flow of blood.

In order that the instrument will read volume flow the following parameters must be known:-

(1) the mean velocity $\overline{V}$ across the cross-section
(2) the inclination of the probe to the blood-vessel
(3) the diameter of the blood vessel.

(1) Measurement of $\overline{V}$

It has been shown previously (Gosling et al 1969) that under certain conditions the velocity measured by the frequency-dc converter is close to but slightly higher than the mean velocity $\overline{V}$. The read out from the converter will approximate $\overline{V}$ if:

(i) there is no axial migration of the blood cells
(ii) there is no amplitude enhancement of the higher frequency signals due to beam/vessel geometry
(iii) there is no signal "drop out".
(iv) there is no distortion of the signal due to the audio band-pass characteristics of the converter.

There are two alternatives to a frequency-dc converter a) audio-frequency analysis (sonogram), b) a maximum frequency follower. These techniques are discussed.

(i) Axial migration:

Taylor (1955) and Bayliss (1959) have shown that in steady flow there is a migration of blood cells towards the axis of the flow tube. Goldsmith and Mason (1962) showed that for deformable liquid drops flowing in a non-uniform velocity gradient, both in steady and pulsatile flow, there is a migration of the drops towards the flow-

A method for finding Ø is discussed. Essentially this consists of mounting two small probes side by side, one inclined upstream and the other downstream. By consideration of the velocities measured by each probe it is possible to find Ø.

(3) Measurement of vessel diameter

Pulsed sonar techniques have been used to measure the diameters of the carotid artery and the abdominal aorta and it is hoped to extend the measurements to other major vessels such as the common femoral, popliteal and posterior tibial arteries.

References

Taylor, M. The flow of blood in narrow tubes II
Aust. J. Exp. Biol. & Med. Sci. 33, 1-15 (1955).

Bayliss, L. L. The axial drift of red cells when blood flows in a narrow tube. J. Physiol. London, 149, 593-613 (1959).

Goldsmith, H. L. and Mason, S. G. The flow of suspension through tube. Proc. Roy. Soc. A, 282, 569-591 (1964).

Gosling, R. G., King, D. H., Newman, D. L. and Woodcock, J. P. Transcutaneous measurement of arterial blood-velocity by ultrasound. Ultrasonics 1969 U.S.I. Conf. Papers 16-23.

tube axis. Such a migration of the red blood cells could account for the observation that the maximum amplitude Doppler-shift signal is obtained from the fastest moving blood-cells. It has been shown (Gosling et al, 1969) that the frequency-dc converter read out is weighted towards the frequency with the maximum amplitude and as a result the converter will read higher than the mean velocity $\bar{V}$, except when the velocity profile is flat across most of the tube lumen when $V_{max} \sim \bar{V}$. The sonagraph read out will show a banding effect at the maximum frequencies present for either condition.

(ii) Amplitude Enhancement due to beam/vessel geometry:

The case is considered in which the emitting transducer and therefore the ultrasonic beam width is small compared with the vessel diameter and the probe is directly over the axis of the vessel. Under these conditions and with a parabolic velocity profile, if there is an even distribution of scatterers across the cross-section it is shown that from purely geometrical considerations the maximum amplitude of the scattered signal is from the fastest moving particles. This again causes the converter to read higher than $\bar{V}$, and the sonagraph to show banding at the maximum frequencies. The amplitude weighting function of the converter is discussed experimentally and theoretically.

(iii) Signal drop-out:

It has been found that in conditions of steady flow at high velocities there is a tendency for signal 'drop-out' to occur. If one considers equal velocity increment annuli across the vessel cross-section and an even distribution of scatterers it can be shown that as the velocity gradient increases the number of scatteres in a given annulus decreases. Since the scattered intensity is proportional to the number of scatterers the intensity decreases for any given velocity annulus as the velocity gradient increases. This "drop out" will be seen as an equal decrease in amplitude at all frequencies up to that corresponding to the highest velocity. Thus the signal to noise ratio in the doppler shifted signal received from each annulus is decreased. This may degrade the converter output signal or cause complete loss of signal as signal to noise ratio approaches unity.

(iv) Audio band-pass characteristics:

The converter velocity/output response is only linear from zero flow to a value corresponding to a 'drop-out' frequency F, which is dependent on the audio characteristics of the converter. As the velocity increases above that which produces a Doppler-shift frequency F the converter output tends towards a plateau. The converter will not be able to follow frequencies above F and so the resulting velocity as given by the converter will read lower than the true value (Gosling et al 1969).

(v) Measurement of steady flow using the spectrum analyser:

In a steady flow parabolic regime it can be shown that V_{max} is twice $\bar{V}$, (Gosling 1969), hence $f_{max}/2$ is related to $\bar{V}$ and by substituting in the usual Doppler shift equation will yieldvolume flow if diameter and angle are known. This will be independent of signal enhancement providing only that the ultrasound beam cuts V_{max} at some point. A spectrum analyser can be used to detect fmax or a maximum frequency follower used (Gosling, 1969, Flax 1970).

(2) <u>Angle of inclination of the probe to the direction of flow</u>

When the instrument is used transcutaneously it is very difficult to measure the angle of inclination Ø of the probe to the direction of flow. Ø must be known before the volume flow can be calculated.