

BEAM DISTORTION IN DOPPLER ULTRASOUND FLOW TEST RIGS: MEASUREMENT USING A STRING PHANTOM

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Abstract-The tube in flow rigs used for testing Doppler ultrasound instruments can attenuate and distort the beam and sample volume by refraction, reflection, absorption and mode conversion. The attenuation and degree of distortion has been measured by using a moving string test object and candidate tubes have been compared. Tubes of rubber, TFE-Teflon, Perspex, heatshrink and C-Flex have been tested leading to the choice of 0.8mm wall C-Flex.

Keywords- Doppler, ultrasound, test, flow

The TMM is normally gelatine or agar based and although tubeless test objects have been built and their geometric stability over periods up to four days studied [2,3], their long-term stability is unknown and thus it is usual for the flow channel to be the lumen of a tube separating BMF and TMM. This tube, usually made from a plastic or rubber, will have acoustic characteristics different from BMF and TMM and can distort the instrument's beam and sample volume [4-6]. A different ultrasound propagation speed g

I. INTRODUCTION

Doppler ultrasound devices are routinely used for the assessment of flow characteristics in patients and for clinical research. They can take the form of a stand-alone instrument or be incorporated into an ultrasound scanner and can be either continuous wave (CW) – sensitive to flow within the region of overlap of the beams of transmitter and receiver transducers - or pulsed wave (PW) – sensitive to flow within a sample volume defined by the beam width, transmitted pulse duration and received signal gating. Testing these devices as part of a quality control programme is normally carried out by the use of moving string test objects, which simulate single streamlines and can be used to determine spatial resolution (eg. beam width, sample volume size) and flow test objects which simulate flow in a blood vessel [1]. The general form of a flow test object is a flow channel within a tissue mimicking material (TMM) having an ultrasound propagation speed, absorption and scattering characteristics typical of soft tissue. A blood-mimicking fluid (BMF) having an ultrasound propagation speed, absorption and scattering characteristics similar to blood flows steadily through the channel from an upper to a lower reservoir or under the action of a pulsatile pump (Fig. 1).

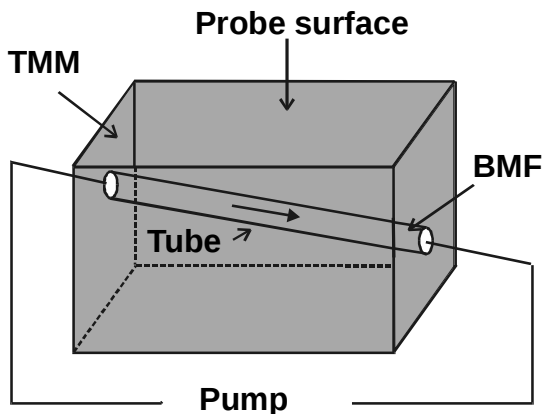


Fig. 1. Flow test object. TMM – Tissue mimicking medium; BMF – Blood mimicking fluid.

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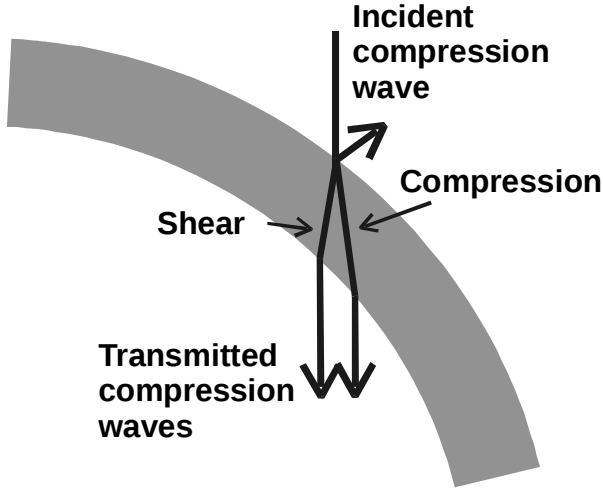


Fig. 3. Effect of mode conversion at wall of hard tube.

II. METHOD

The effect of different wall material and thickness has been assessed by measuring the sensitivity variation within the beam of a 4MHz continuous wave Doppler instrument using a string phantom with and without a tube present. The relative positions of the Doppler instrument probe, tube and moving string are shown in Fig. 4.

The string and tube are within a water bath and the section of tube is mounted in the test-rig such that it can be moved along the string to allow measurements without the tube being in the beam path.

For the measurements reported here the beam/vessel angle was 62.5° and the string (1mm rubber O-ring) speed was 0.6ms^{-1} . All measurements were made with the string on the horizontal mid-line of the tube and running parallel to the tube axis.

In practice it was found to be more convenient to keep the string in a fixed position and, by means of micro-manipulators, to move the Doppler probe and tube together during a measurement. The Doppler signal from the CW instrument together with tube and probe position signals from

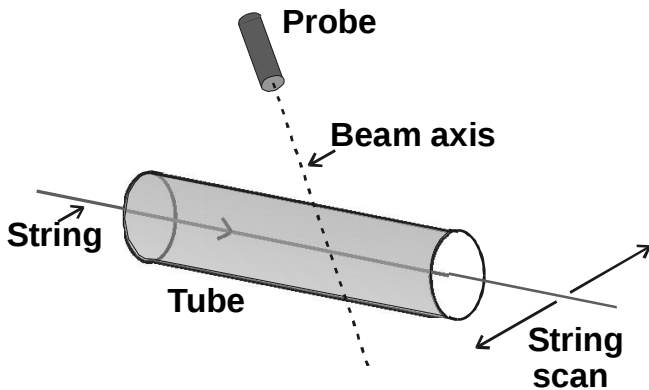


Fig. 4. Measurement of beam sensitivity variation within a tube.

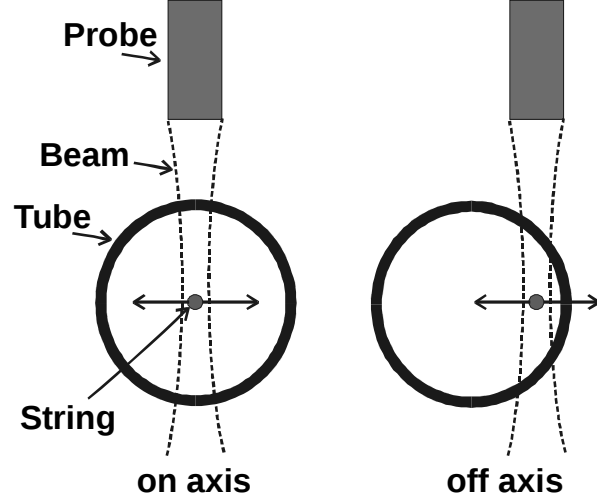


Fig. 5. View looking along axis of tube showing relative positions of probe, tube and string for measuring beam sensitivity variation with the beam axis passing through the tube axis (left) and laterally displaced (right).

potentiometers coupled to the micro-manipulators were sampled and stored using a data logger coupled to a PC. Plots of the Doppler signal power averaged for 1s versus string position relative to the beam axis were generated with and without the tube in the beam, for different tubes and with the Doppler beam passing through the tube axis and at number of positions displaced horizontally from the tube axis as illustrated in figure 5.

Both the insertion loss (reduction in Doppler signal power resulting from the presence of the tube) and the variation of this loss across the tube are of interest. The latter is important since it is a measure of the degree to which the ultrasound beam has been distorted. In order to assess this more easily, the ratio of the powers at each string position with and without the tube were calculated and plotted to show the fractional change in signal power versus string position. Measurements have been made on the tubes shown in the first column of table 1.

III. RESULTS AND DISCUSSION

Sample graphical results [6] for 8mm ID/1.6mm wall C-Flex are shown in Figs. 6 and 7. Doppler power versus string position for four beam axis positions across the tube is shown in Fig. 6. The ratio of power measured with the tube in place to that measured without for the cases shown in Fig. 6(a) and (d) is plotted in Fig. 7. These plots have been normalised to a maximum of unity. The insertion losses, with the beam passing through the tube axis and with the beam displaced by 0.67 of the lumen radius, are shown in table 1 together with the range of insertion loss across the beam in brackets.

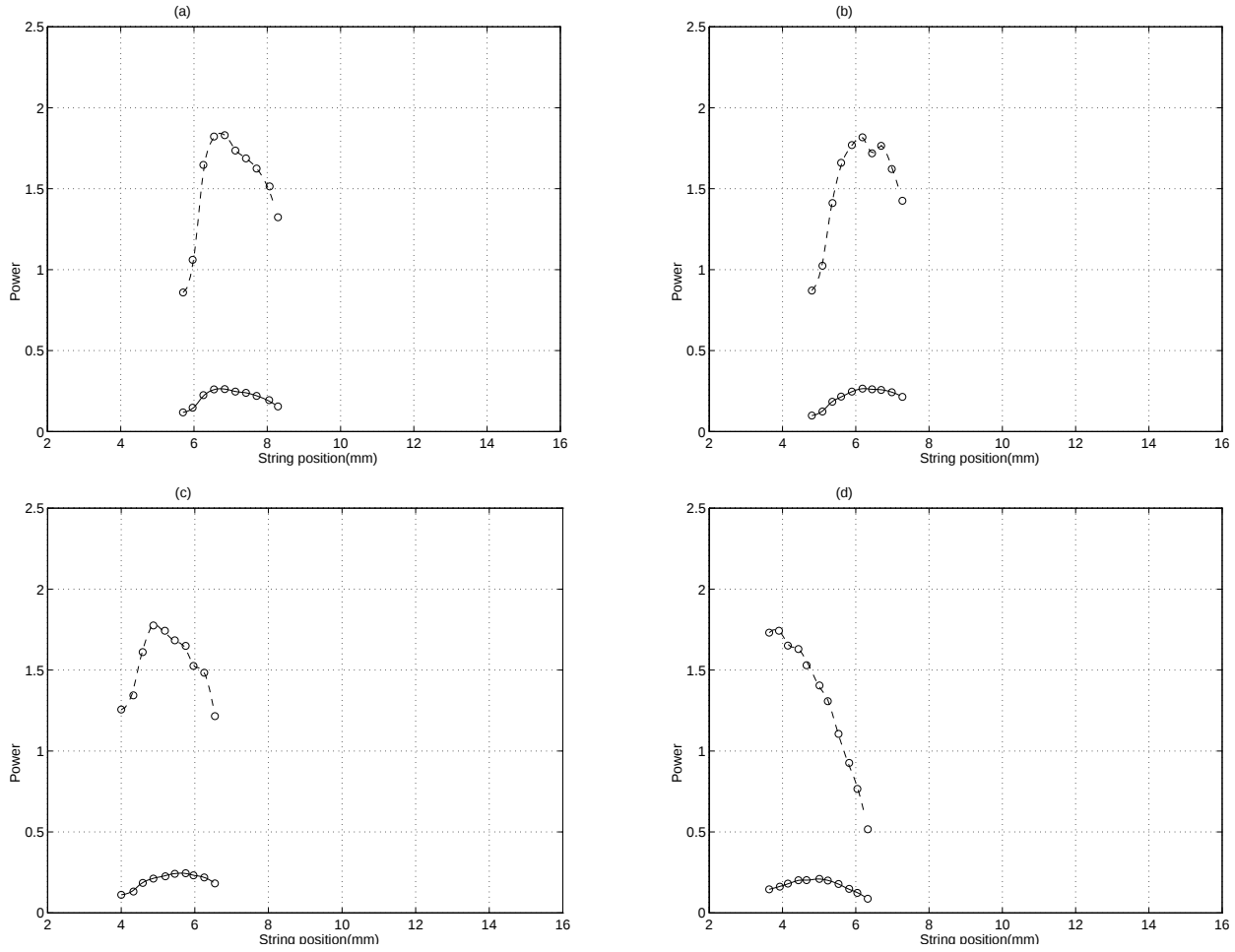


Fig. 6. Doppler power (arbitrary scale) versus string position. Upper plot without tube, lower plot with tube. Tube – 8mm ID, 1.6mm wall, C-Flex. Beam axis displacement from tube axis (a) 0mm, (b) 0.9mm, (c) 1.8mm, (d) 2.7mm.

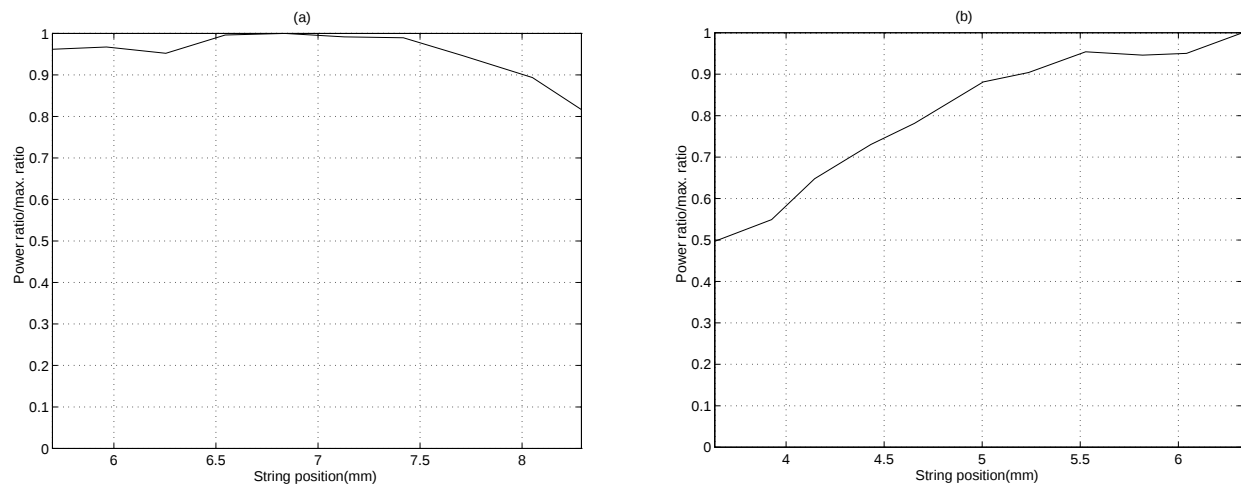


Fig. 7. Power ratio plots normalised to a maximum of unity. Tube - 8mm ID, 1.6mm wall, C-Flex. Beam axis displacement from tube axis (a) 0mm, (b) 2.7mm.

TABLE 1
TUBE DIMENSIONS AND INSERTION LOSS

	I.D.(mm)	Wall(mm)	Insertion loss (dB)	
			Beam centred	Beam off-axis
Rubber	7.94	1.58	9.1(0.2)	12.4(3.3)
Thin-wall C-Flex	8.0	0.8	4.2(0.1)	5.5(1.4)
Thick-wall C-Flex	7.94	1.58	8.4(0.9)	10.5(3.0)
TFE-Teflon	7.98	1.01	14.3(0.4)	17.0(2.7)
Heatshrink	12.0	0.27	4.1(2.2)	7.0(13.0)
Perspex	10.0	1.0	10.5(2.4)	-

The measurements were taken at the string position giving the greatest Doppler power without the tube. The distortion of the beam by the tube may mean that this is not the position of greatest Doppler power with the tube in place. Estimated error in insertion loss 1dB. The figures in brackets give the range of insertion loss across the beam. The off-axis measurements are for a beam axis displaced by 0.67 of the tube radius.

Even though there is a significant insertion loss with the tube in place (Fig. 6 and Table 1), since the beam is relatively narrow (Fig.6) compared with the tube, the variation of loss across the tube is small when the beam is centred (Fig. 7a and Table 1). As the beam is moved towards the side of the tube the loss - primarily as a result of absorption in this relatively soft material [6]- becomes more pronounced in the part of the beam closer to the side of the tube (Fig. 7b and Table 1).

The first three tubes in Table 1 are of relatively soft materials, reasonably well impedance-matched to water [6]. The insertion losses for the two examples of C-Flex are approximately in the same ratio as the wall thickness as would be expected if the loss is dominated by absorption. TFE-Teflon is less well matched and is more highly absorbing and has a higher insertion loss at a lower wall thickness [6]. Heatshrink has been included as an example of a material that has been used for flow phantoms since it combines a thin wall with structural stability. However, even with this relatively large diameter tube the range of insertion loss across the off-axis beam is high, probably as a result of more complex beam interference effects resulting in turn from mode conversion and low critical angle. The insertion loss in the case of Perspex for the off-axis beam was too high for measurements to be made.

Of the tubes measured the thin-walled C-Flex was clearly the most suitable for a Doppler flow phantom, having a low insertion loss and, probably more importantly, a low range of insertion loss across the tube.

IV. CONCLUSION

The degree to which the tube in a Doppler flow phantom can attenuate and distort the beam of an ultrasonic flow detector is important when selecting tubes for such a device. A simple CW Doppler flow detector may be used to determine the insertion loss of the tube at a range of positions of the beam relative to the tube axis and assist in the choice of tube.

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