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Influences of fixed and moving interfaces in the measurement of velocity profiles

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ABSTRACT

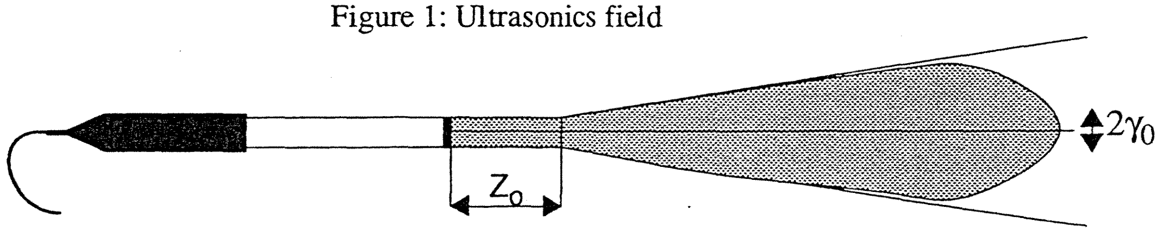
The knowledge of the size and positions of the measuring volumes of a multigate Doppler velocimeter are often difficult. These difficulties arise from many factors. The precise knowledge of the ultrasonic field is seldom known. Moving or fixed interfaces affect the shape of the ultrasonic field.

In order to profit from the main advantage of pulsed ultrasonic Doppler velocimeters, which is a depth resolution, it is of utmost importance to have a good understanding of acoustical phenomena which generate the echoes.

1. Acoustical field

In Doppler echography, the object is not to make use of a plane longitudinal wave, but rather an ultrasonic beam that is as thin as possible throughout the measurement depth. The geometry of the acoustic field generated by the ultrasonic wave determines the lateral resolution. The characteristics of the acoustic field depend on the size and shape of the piezoelectric element for a single element transducer, and on the combination of the individual emissions in the case of a multi-element transducer. Using Huygen's principle, one may theoretically predict the geometry of the acoustic field. In this approach, the transducer is modeled as a combination of several adjacent point sources, each generating a spherical wave. For a circular transducer operating in a piston-like manner, the acoustic field possesses two characteristic regions, the near field and the far field.

Figure 1: Ultrasonics field



The geometry of the acoustic field in the near field is basically contained in a cylinder having the same diameter as the transducer and a length equal to:

$$z_0 = \frac{r^2}{\lambda}$$

where r is the radius of the transducer and λ the wave length. The zone lying beyond z_0 is called the far field. In the far field, the intensity of the acoustic field varies approximately as the inverse of the square of the distance from the transducer. In the far field, the acoustic field may possess intensity lobes as one moves away from the axis of the transducer. The angle of divergence of the main lobe γ is given by:

$$\gamma_0 = \sin^{-1}\left(\frac{0.61\lambda}{r}\right)$$

The acoustic energy contained in the secondary lobes is always much smaller than that contained in the main lobe. For a circular transducer, the acoustic energy contained in the secondary lobe is 18 dB less than in the main lobe.

2. Influences of interfaces

The above simplified approach shows that it is possible to have an approximate knowledge of the acoustic field generated by circular ultrasonic transducers when no interfaces are present. Or this situation rarely appears. The interfaces reflect and modify the acoustic field. The intensity of the acoustic field received in a point, which depends on the material, the shape and the number of these interfaces, is very difficult to evaluate. This lack of knowledge does not allow a precise determination of the size of the measuring volume.

These interfaces may generate, in certain situations, artifacts and induce modifications in the velocity profiles as presented in the figures 2 and 3.

The ultrasonic beam BC reflected by the far interface of the figure 2 transforms this interface in a transmitter. The same particles contained in the liquid will backscatter a second time energy in the direction to the transducer. The depth associated to the path ABC is located outside the flowing liquid. Imaginary velocity components are added to the real velocity profile. The measurement of velocities near the far interface is affected by this phenomenon. The size of the ultrasonic beam determines mainly the level of this artifact.

The figure 3 displays another situation often founded. The reflected ultrasonic waves inside a wall enlarge the ultrasonic beam inside the liquid and modify its shape. These reflections disturb the determination of the size and the shape of the measuring volume. The thickness, the acoustical impedance and the attenuation coefficient of the interface determines the level of this phenomenon.

The interfaces often give strong reflections. Despite of the many reflections which are necessary to reach the transducer, the energy reflected by these interfaces is often stronger than the energy coming from the particles flowing with the liquid. Most of the algorithms used to compute the Doppler frequency shift do not allow stationary components. The elimination of these stationary components by high-pass filtering implies an increase in the dynamic of the analyzed echoes and a reduction in the sensitivity in the measurement of low velocities.

Figure 2

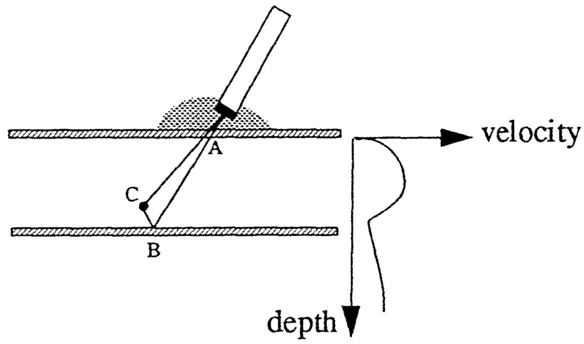
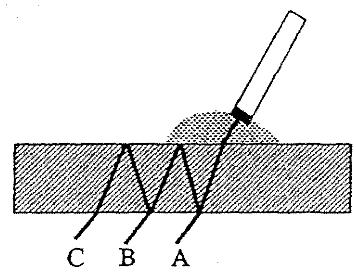


Figure 3

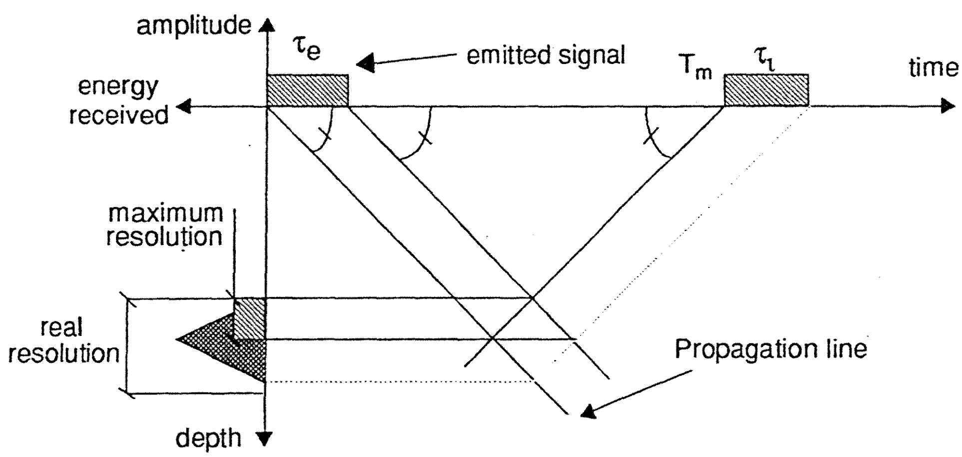


When some interfaces are in movement the correct estimation of all the velocity field is very difficult. The echoes generated by such interfaces may affect the velocity profile in many places due to the combination of many reflections. The Doppler frequency shift induced by these movable interfaces can not be removed if their values have the same values as the flowing particles.

3. Spatial resolution

For an unlimited bandwidth receiver and if no interfaces are present, the duration of the impulse determines the depth resolution by determining the longitudinal size of the sample volume. The other dimensions are determined by the beam pattern of the transducer.

Figure 4: Longitudinal resolution



Consider an impulse of duration τ_e as illustrated in the figure 4. The impulse propagates in time along a straight slanted line, with the slope being the speed of sound. Consider a measurement time T_m on the time axis. By drawing a straight line which is perpendicular to the propagation line and which passes through T_m, the depth resolution may be determined by the projection of the intersection of these two lines on the depth axis. The corresponding resolution is the maximum attainable resolution for this type of emission.

The demodulated Doppler signals must be filtered in order to eliminate unwanted frequencies generated by the demodulation process. This filter acts as an integrator and reduces the depth resolution, as shown in the figure by the broken line. There is an optimum value for the product of the bandwidth and the impulse duration which will give the maximum SNR, provided the frequency and temporal characteristics of the noise are known. This value also depends on the characteristics of the filter and the signal to be filtered.

4. Conclusion

In order to be able to correctly use the results of an ultrasonic pulsed Doppler velocimeter it is of utmost importance to have a good understanding of the generation process of the echoes. This understanding is much easier when the velocimeter can:

- adapt the emitting frequency to the analyzed medium,
- adapt the acoustical level emitted,
- adapt the amplification level of the echo in relation to the depth,
- visualize the modulus of the echo versus depth,
- visualize the Doppler energy versus depth,
- have a powerful Doppler frequency shift estimator, which gives the first moment order of the power spectrum density,
- adapt the number of ultrasonic bursts emitted used to compute the Doppler frequency shift.

5. References

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