Sound Waves

Ultrasound in the Offshore World

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Because light and radio-waves cannot penetrate more than a few metres of the sea the only medium for signalling measurements and communications is Sound. Nature has endowed marine animals like dolphins and whales to use ultrasound (those frequencies of Sound which exceed the 20 KHz limit for human hearing) for locating prey and even sing their songs! In this short article we shall see how ultrasound waves are generated, focussed, refracted, and reflected and how they are used to image the sea bed and generally used in the offshore world.

Sound waves are phenomenon of classical physics and thus easy to comprehend. Basically three conditions govern sound wave motion

- Water moves and changes its density.
- Change in density leads to pressure changes
- Pressure changes lead to motion of neighbouring water

Let us consider elemental volumes of water neighbouring each other and having a cross-sectional area of unity. This area which is perpendicular to the direction of wave motion, which itself is in the same direction as that of the vibrating elements.

Clearly the planes constitute what is known as a wave-front. Meaning all waves across the plane are in the same phase, that is to say they are vibrating around their equilibrium point in unison: rising together and falling together.

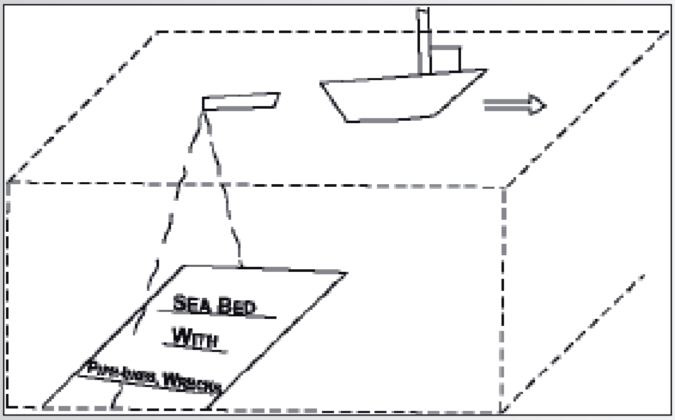
It should be seen that the elements are only vibrating across their equilibrium point, passing on their energy to the neighbouring element and so on. Thus it is only the energy which is propagating as a wave and the elements only being displaced around their mean positions.

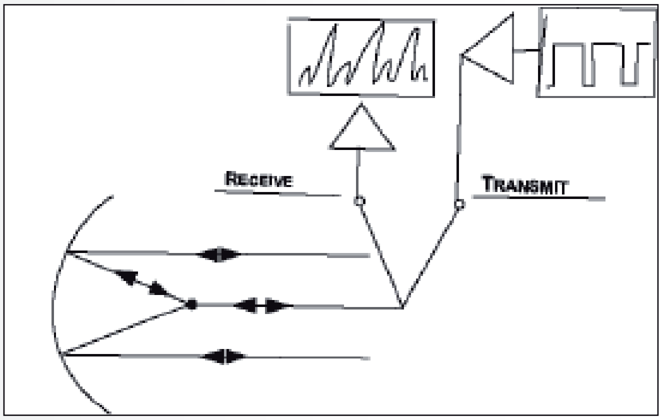
Let us now see the dependence of sound wave propagation on the elasticity and inertia of sea water.

We can feel that greater the elasticity and lower the elemental masses will lead to a speedier sound wave propagation. It is also at this point that we must also see that the ease at which sound waves travel in seawater depends inversely on the applied pressure and directly upon the displacement velocity of the elemental masses. This is the velocity at which the elemental masses move around their equilibrium positions and not the velocity at which wave energy moves from one mass element to its neighbour and so on. In fact the resistance of a medium to wave motion is the product of the density of the medium through which the wave passes and the wave velocity. This leads to an interesting result: wherever Sound has difficulty in being transmitted further i.e. after it encounters a media where the acoustic resistance is large, because of larger values of density and wave velocity, it gets easily reflected.

Consider a wave front that enters a medium with a contrasting acoustic resistance. If the velocity in the second medium is faster the wave front will both bend to a refracted wave and also get reflected at an angle of reflection, equal to, the angle of incidence.

Two things should be kept in mind





while we try and understand why this happens. One is that pressure or displacement velocity cannot change abruptly at a boundary, that is to say the sum of all pressures and displacement velocities should be the same on both ends of the boundary and secondly the left portion of the waveform will hit the boundary before the right end i.e.as we look into the paper. Now since the left end is moving faster than the right end the wave front will be bent or refracted. Further the wave front will also get reflected because the horizontal component of the incident pressure has also to be cancelled.

This can be appreciated in the following way: if the second media is say, a solid like the steel of a wrecked ship the higher velocity makes the left part of the wave front turn so fast that the wave gets reflected almost completely. The amount of reflection is thus dependent on the density of the target.

Now since the speed of sound in sea water is of the order of 1500 metres/second an ultrasonic (>20 KHz) signal of say 100 KHz will have a wavelength of the order of a centimetre.

Thus we can imagine a parabolic reflector of sound via which we can focus sound rays (since the dimensions are of the order of a centimetre we can view the wave-fronts as rays of Sound energy in the same manner as we deal with light rays in ordinary situations). We can focus the sound rays by placing a transceiver (transmitter-receiver) at the focal point of the parabolic reflector.

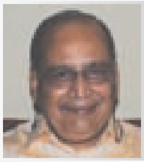
If we take a cylindrical fish (a group of transceivers towed by a survey ship) and have in that fish several parabolic reflectors look downwards at various inclinations then we can scan the sea bed and image that surface or any dense mass around it; matching the strengths of the reflections at various inclinations after tuning in to the transmitted frequency.

We must also understand that apart from reflected sound from the sea bed directly below the fish we will receive scattered sound from those points which are in an inclination from it. That is to say the focussed sound will make the target also oscillate resulting in Omni-directional spherical waves, whose strength at the receiver will be inversely proportional to the inclination of that portion of the target to the vertical. We can still tune in because the frequency will be the same. However the image processing computer on board will apply a gain to signals corresponding to the scattered sound waves to compensate for the weakening of signals received from the target not directly below the fish.

Let us also get a glimpse of how piezoelectric crystals are used as transceivers.

In these crystals the bonds are ionic and the structure is irregular. When a voltage is applied across two faces of this transducer, the ionic charges in each unit cell get displaced by electrostatic forces resulting in a mechanical deformation of the entire crystal. This is how the transmitter works i.e. after applying a voltage train of 100 KHz we get ultrasonic pulses of 100 KHz which we amplify focus and transmit. We then listen for a while and receive reflected ultrasound which is converted to an electric pulses in the manner illustrated below.

When the piezoelectric crystal is subjected to a pressure, the ions in each unit cell are displaced causing an electrical resultant of the pairs of positive and negative charges across the Ionic bonds in the unit crystal. This is accumulated over very many unit crystals to give a net effective voltage between certain faces of the crystal. This is how the piezoelectric crystal converts pressure to voltage such that it can be used as a receiver of sound. To summarize we focus ultrasound turn by turn over sections of the sea bed and image it and the objects lying on it by detecting the reflected and scattered radiations returned from this target; with darker portions allotted to denser portions of the sea-bed and objects like ship- wrecks and oil pipelines lying on it. ■



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