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A VELOCITY MICROPHONE FOR SOUND INTENSITY MEASUREMENT

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The acoustic intensity is defined as the average rate of flow of energy through a unit area normal to the direction of wave propagation

$$\vec{I} = \frac{1}{T} \int_0^T p(t)\vec{v}(t)dt \qquad (1)$$

In contrast to a pressure wave p(t), which is a scalar quantity, the velocity component, $\vec{v}(t)$, is a vector quantity, so both magnitude and direction must be measured. The intensity magnitude may be measured in any specific direction:

$$I_x = \frac{1}{T} \int_0^T p(t)v_x(t)dt \qquad (2)$$

The intensity may be calculated knowing the pressure and the particle-velocity. The following requirements are needed for an intensity microphone system:

- The transducers must cover the frequency range of interest.
- The response of the pressure microphone must be omnidirectional.
- The velocity transducer must have a cardioide response (cosine).
- The pressure and velocity transducers must have similar phase characteristics.

Currently pressure microphones are normally used for both the pressure and velocity measurement. The velocity is usually derived from the pressure difference of two adjacent points.

The problem with this method is that the pressure differences may be small, particularly at lower frequencies. It is also difficult to cover a wide frequency range without changing the microphone spacing, and the matching of the microphones is very critical.

NORWEGIAN ELECTRONICS a.s. are developing a new velocity transducer for direct measurement of the particle velocity. The microphone will be used for real time intensity measurements in combination with a dual channel real time analyser.

If an ultrasonic wave is transmitted from a transducer to a receiver, the wave will travel with the normal speed of sound plus or minus the velocity of the airmovement. If the distance between the transmitter and receiver is small compared to the wave-length of the acoustic field, the particle velocity will act as a gas flow and the transmission time will be modulated by the particle-velocity. As the air itself acts as the microphone diaphram, the influence of the transducer on the field will be small.

The transmitting and receiving transducers are identical and consist of a piezoelectric crystal. In order to increase the efficiency of the transducer, a $\lambda/4$ coupler is mounted in front of the piezoelectric element.

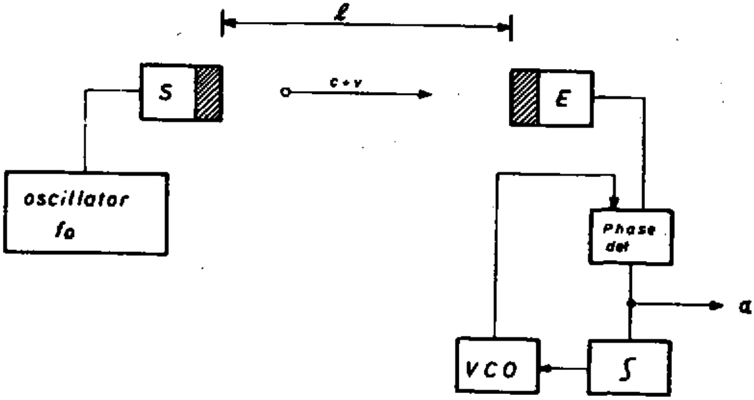

Fig. 1. Principle of particle velocity microphone.

Figure 1 shows a practical arrangement for the microphone. A continuous wave of 500 kHz is used, and any modulation of the transmission time will lead to a phase modulation of the received signal. The phase changes are proportional to the particle velocity.

In the prototype, a distance of 20 mm is used between the crystals which is equal to approx. 30 wave-lengths of the ultrasound.

A plane wave sound field of 50 dB corresponds to a particle velocity of 15 μm/s, which gives a phase modulation of 0.0005° in the received signal. This corresponds to a time modulation of $3 \cdot 10^{-12}$ s.

In the case of the prototype microphone, the noise floor was approximately 50 dB in the 1/3 octave bands.

To obtain the intensity value, the velocity signal is multiplied by the pressure component and therefore the noise will be greatly reduced in the averaging circuits. As a result, the microphone may be used for intensity levels down to about 30 dB.

Looking at the microphone in more detail, we find that the transmission time will also be influenced by the pressure wave. This is because the pressure will compress the air adiabatically and thus increase the temperature of the gas leading to a higher sound velocity. For a plane progressive wave this contributes 20% to the velocity signal.

As we are measuring the pressure by a pressure microphone, the pressure effect may be eliminated by substracting this signal and thus restoring the ideal cosine response of the transducer.

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Another method is to transmit the ultrasound simultaneously in both directions and measure the difference in the transmission times. This will eliminate the pressure effect and will also improve the frequency response.

If we look more closely at the response of the microphone for a plane progressive wave, we find that the sound velocity will be a function of the time and the position

$$c(x,t) = c + v_o \cos\Phi \cos(\omega t - k\cos\Phi x + \theta_v) + bp_o \cos(\omega t - k\cos\Phi x + \theta_p) \qquad (3)$$

where p_o and v_o are the pressure and velocity amplitudes. b is a factor indicating the pressure sensitivity.

For a microphone with unidirectional ultrasound, the response will be approximately

$$s = v_o \quad (\cos + \frac{\varkappa-1}{2}) \frac{\sin((1-\cos\Phi)\pi\ell/\lambda))}{(1-\cos\Phi)\pi\ell/\lambda)} - \frac{\varkappa-1}{2} \qquad (4)$$

A polar plot of this is shown on figure 2 for various frequencies. The response is good for sound entering from the front but has serious frequency limitation for wave lengths smaller than three times the distance between the crystals when the sound enters in other directions.

In the case of bidirectional ultrasound, the response of the microphone will be:

$$s = v_o \cos \frac{1}{2}(\frac{\sin(1-\cos\Phi)\pi\ell/\lambda}{(1-\cos\Phi)\pi\ell/\lambda} + \frac{\sin(1+\cos\Phi)\pi\ell/\lambda}{(1+\cos\Phi)\pi\ell/\lambda}$$

$$+ \frac{\varkappa-1}{2}\frac{1}{2} \frac{\sin(1-\cos\Phi)\pi\ell/\lambda}{(1-\cos\Phi)\pi\ell/\lambda} - \frac{\sin(1+\cos\Phi)\pi\ell/\lambda}{(1+\cos\Phi)\pi\ell/\lambda}) \qquad (5)$$

This shows that although the amplitude response is not ideal for higher frequencies, the directional sensitivity is quite good. The amplitude response may be compensated electronically. The result is shown on figure 3 and it will be seen that the response is fairly good up to wavelengths equal the distance between the ultrasound transducers.

We may summarize the characteristics of the microphone in the followingway:

- Broad frequency response. In principle from 0 Hz to a frequency limitated by the distance between the crystals. In practice 20 Hz - 10 kHz has been achieved.
- Cosine directivity. Very close approximation to the ideal cosine response.
- Small size. Crystalt of 3 mm diameter have little influence on the acoustic field.
- Robust. No critical matching as in a pressure difference technique. Insensitive to amplitude variations in the ultrasound wave.

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These benefits more than compensate for the drawbacks of the system, i.e. relatively low sensitivity and more complex electronics.

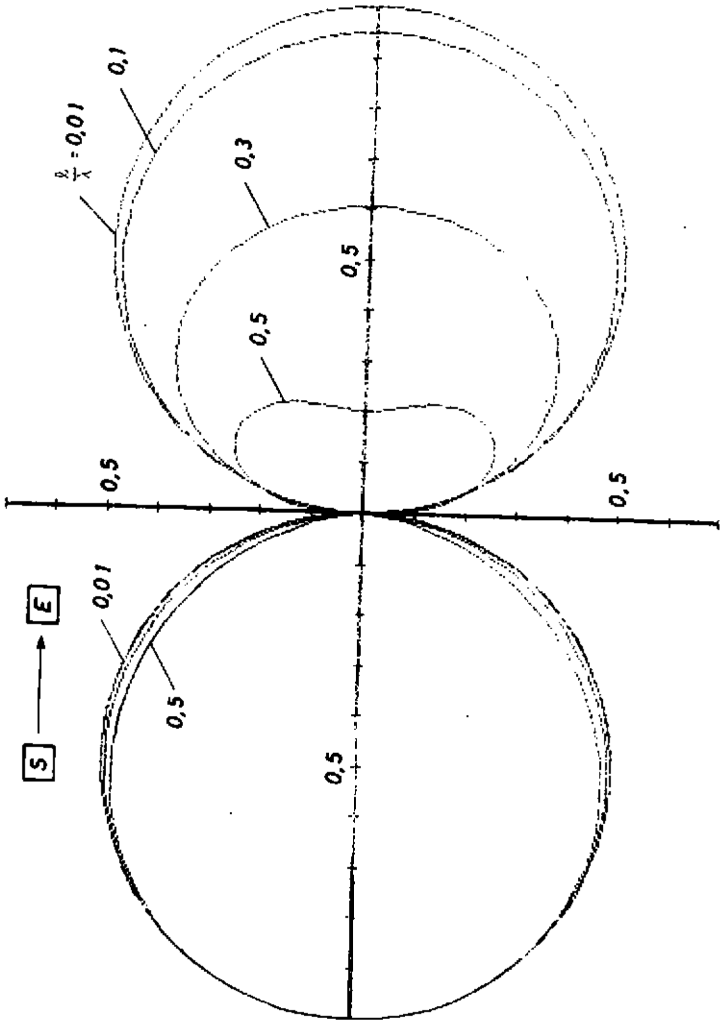

Figure 2.

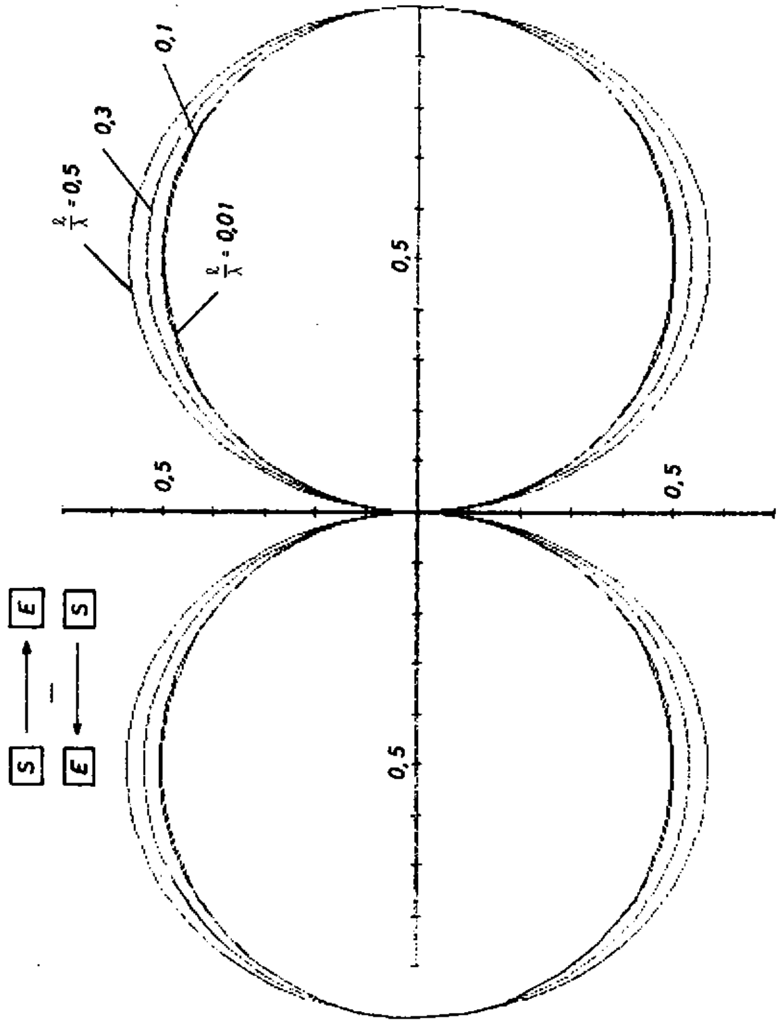

Figure 3