Ultrasonic Flowmeters

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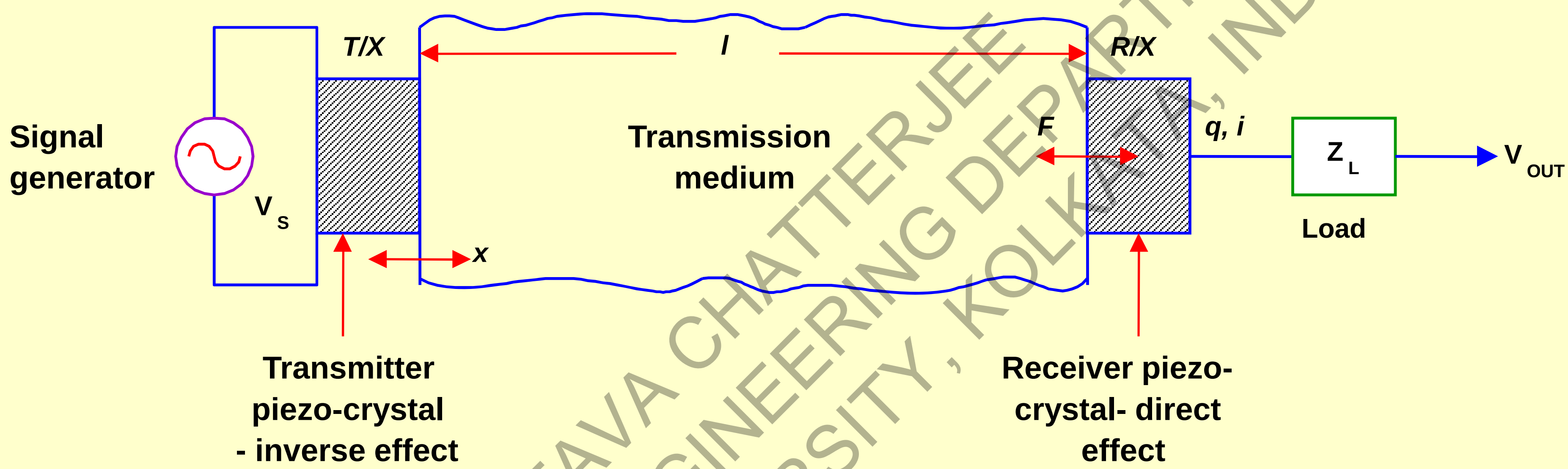
Ultrasonic Measurement Systems

Features:

- ✓ **Ultrasound refers to sound waves at frequencies higher than the range of the human ear.**
- ✓ **Higher frequency waves have shorter wave-lengths, hence it is easier to direct and focus a beam of ultrasound.**
- ✓ **Ultrasonic waves can pass easily through the metal walls of pipes and vessels.**
- ✓ **Ultrasound can be launched into and propagated through biological tissue making it useful for medical applications.**
- ✓ **The silence of ultrasound makes it suitable for military applications.**

Basic Ultrasonic Transmission Link



- ✓ **If a sinusoidal voltage is applied to the transmitting crystal, then the crystal undergoes a corresponding sinusoidal deformation *x*.**
- ✓ **In the receiver, the fluctuating pressure causes a sinusoidal force *F* over the area of the crystal, thus producing a corresponding time-varying charge *q* and current *i*. This produces a voltage V_{OUT} across a load Z_L.**

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Features:

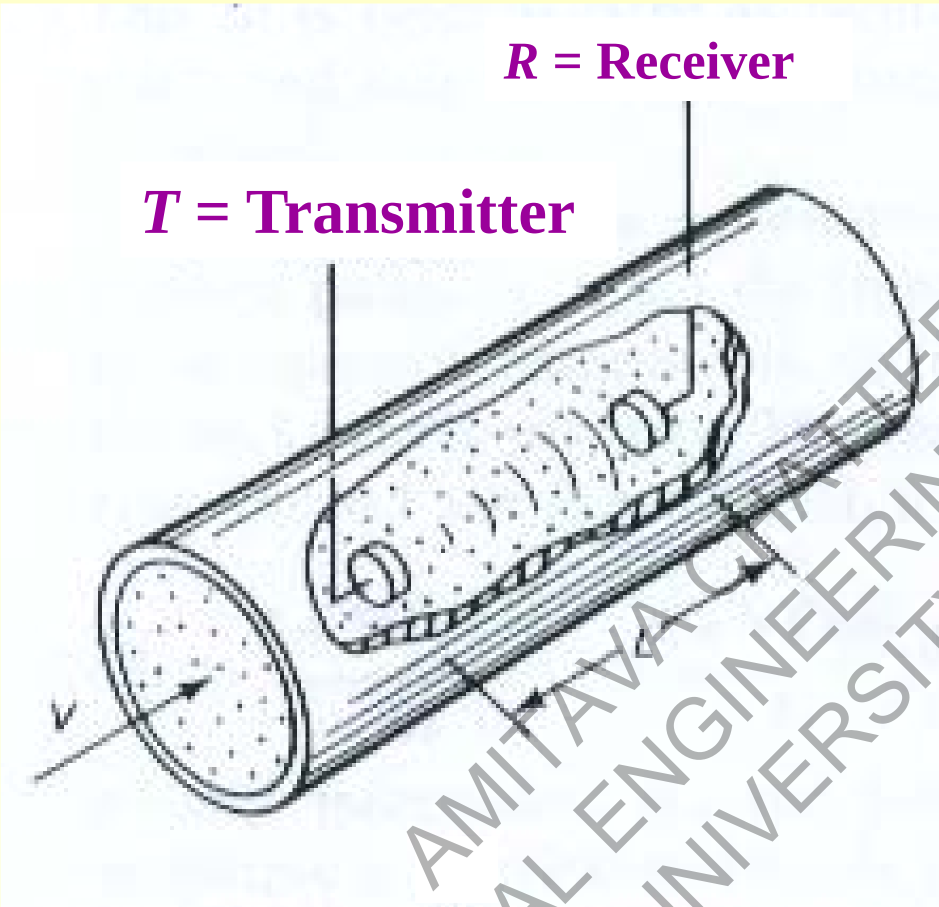
- **Small-magnitude pressure disturbances are propagated through a fluid at a definite velocity (the speed of sound) relative to the fluid.**

- **The pressure disturbances usually are short bursts of sine waves whose frequency is above 20,000 Hz.**

- **If the fluid also has a velocity, then the absolute velocity of propagation of the pressure-disturbance is the algebraic sum of the two.**

- **A common approach is to utilize piezoelectric crystal transducers as transmitters and receivers of acoustic energy.**

Transit-Time Ultrasonic Flowmeters



With zero flow velocity:

$$t_o = \frac{L}{c}$$

With flow velocity V:

$$t = \frac{L}{c+V} \approx \frac{L}{c}\left(1 - \frac{V}{c}\right)$$

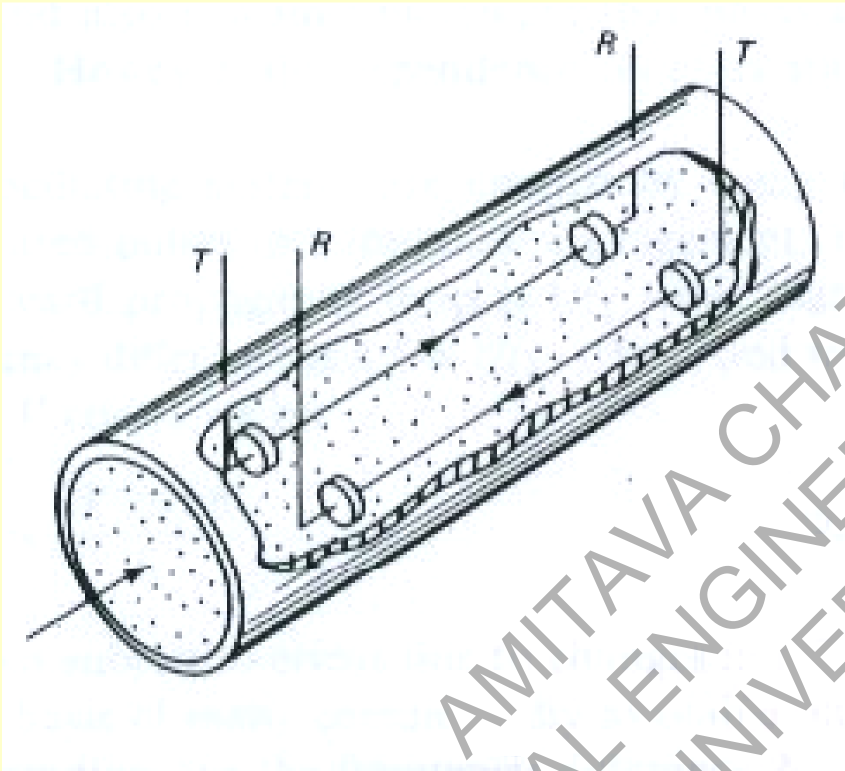
$$(\because V << c)$$

$$\Delta t \approx \frac{LV}{c^2}$$

Problem: c varies with temperature.

Also, Δt is quite small since V is a small fraction of c. For example, if V = 10 ft/s, L = 1 ft, and c = 5,000 ft/s, then Δt = 0.4 μs, a very short increment of time that can be measured accurately.

Transit-Time Ultrasonic Flowmeters (contd…)



Transit time with the flow:

$$t_1 = \frac{L}{c+V}$$

Transit time against the flow:

$$t_2 = \frac{L}{c-V}$$

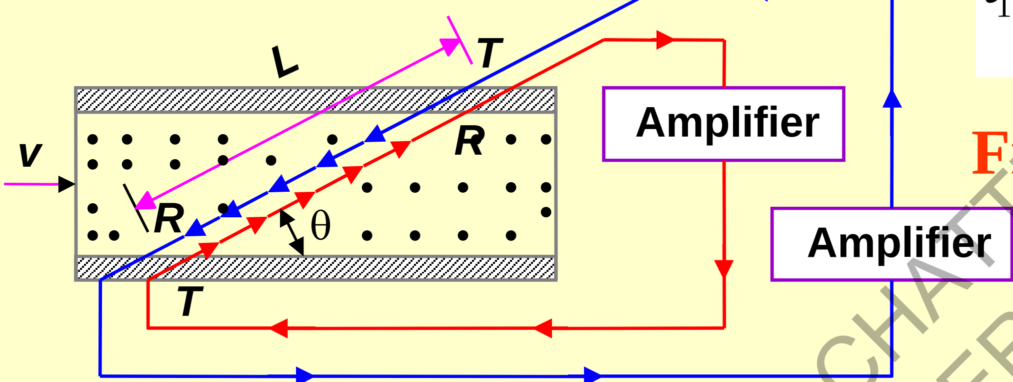
$$\nabla t = t_2 - t_1 \approx \frac{2VL}{c^2}$$

Improvement: **Δt is twice as large as before.**

Also, Δt is a time increment that physically exists and may be measured directly.

Problem: **the dependence on c^2 is still a drawback.**

Transit-Time Ultrasonic Flowmeters (contd…)



$$t_1 = \frac{L}{(c + V\cos\theta)} \text{ and } t_2 = \frac{L}{(c - V\cos\theta)},$$

Frequency difference:

$$\Delta f = \frac{1}{t_1} - \frac{1}{t_2},$$

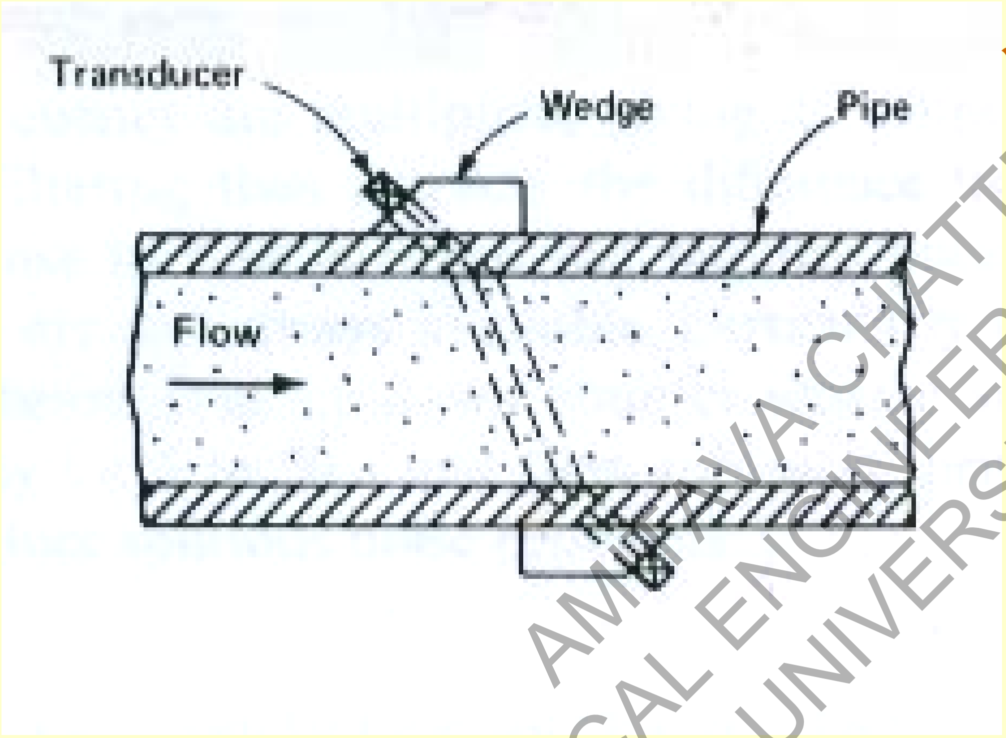
$$\Delta f = \frac{c + V\cos\theta}{L} - \frac{c - V\cos\theta}{L}; \Delta f = \frac{2V\cos\theta}{L}$$

The pulse repetition freq. in the forward propagating loop is ($1/t_1$) and in the backward loop is ($1/t_2$).

Improvement: Δf is independent of c and thus not subject to errors due to changes in c.

Two methods of reading out the frequency difference are common: the 'sing-around' and the up-down counter.

Transit-Time Ultrasonic Flowmeters (contd…)



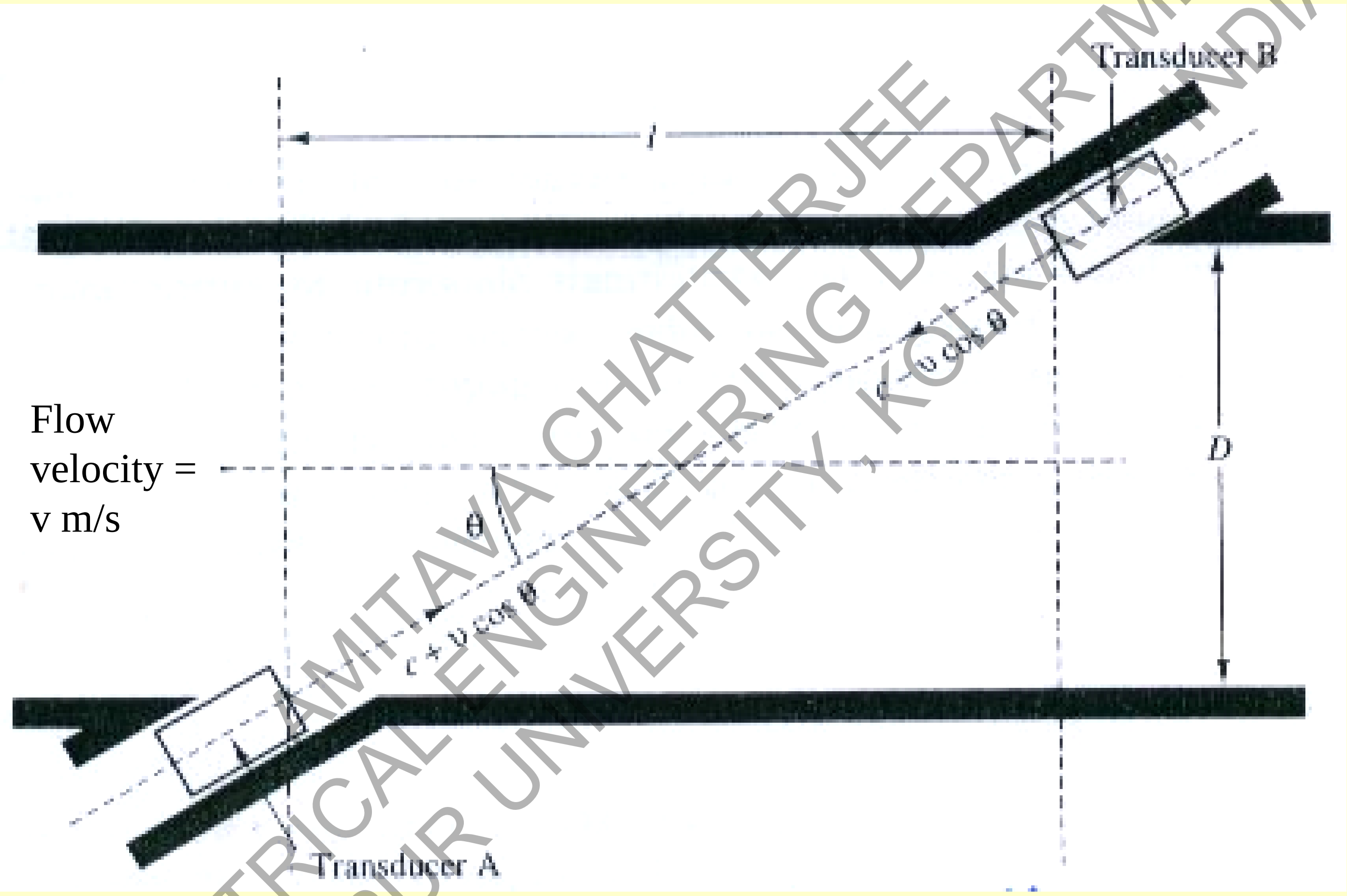
Clamp-on type ultrasonic flowmeter.

- ✓ **The transducers are outside the pipe, which eliminate the fouling problems and give an extremely convenient installation.**

Problems:

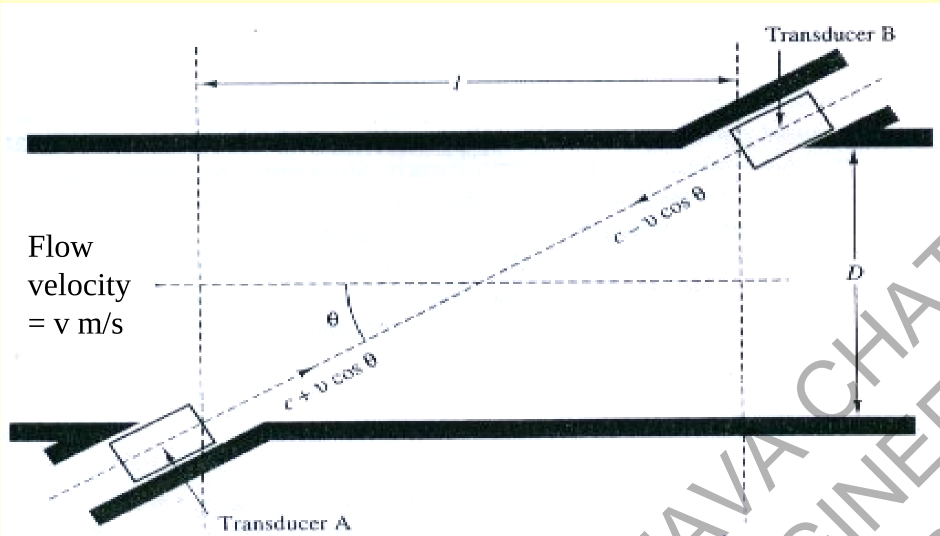
- ✓ **The problem due to acoustic short circuiting.**
- ✓ **Change in beam path due to clamp slippage, temperature expansion etc.**

Transit-Time Ultrasonic Flowmeters (contd…)



Wetted sensor type ultrasonic flowmeter.

Transit-Time Ultrasonic Flowmeters (contd…)



$$T_{BA} = \frac{L}{c - v\cos\theta} \qquad L = \frac{D}{\sin\theta}$$

$$T_{AB} = \frac{L}{c + v\cos\theta}$$

$$\Delta T = T_{BA} - T_{AB} = \frac{D}{\sin\theta}\left[\frac{1}{c - v\cos\theta} - \frac{1}{c + v\cos\theta}\right]$$

$$= \frac{2Dv\cot\theta}{c^2\left(1 - \frac{v^2}{c^2}\cos^2\theta\right)}$$

Wetted sensor type ultrasonic flowmeter.

$$\Delta T = \frac{2D\cot\theta}{c^2}v \qquad \left(\because \frac{v^2}{c^2}cos^2\theta << 1\right)$$

Thank You