18ECO133T

Sensors and Transducers

UNIT V

Session 5: SLO – 2

Turbine Type Flowmeter

- Turbine type flowmeter is a simple way for measuring flow velocity.
- A rotating shaft with turbine type angular blades is placed inside the flow pipe. The fluid flowing through the pipeline will cause rotation of the turbine whose speed of rotation can be a measure of the flowrate. Referring fig.11, let blades make an angle α with the body. Then,

$$\frac{\omega_r R}{\bar{v}} = \tan\alpha$$

where,

$\bar{v}$ = Average velocity of the fluid = $\frac{Q}{A}$

Q = Volumetric flowrate

A = Effective flow area of the pipe

R = Radius of the blade

ω_r = Angular speed of the blade.

From the above expression, the volumetric flow rate can be related with the angular speed, as:

$$\omega_r = kQ \qquad (13)$$

where,

$$k = \frac{\tan\alpha}{RA}$$

Turbine Type Flowmeter

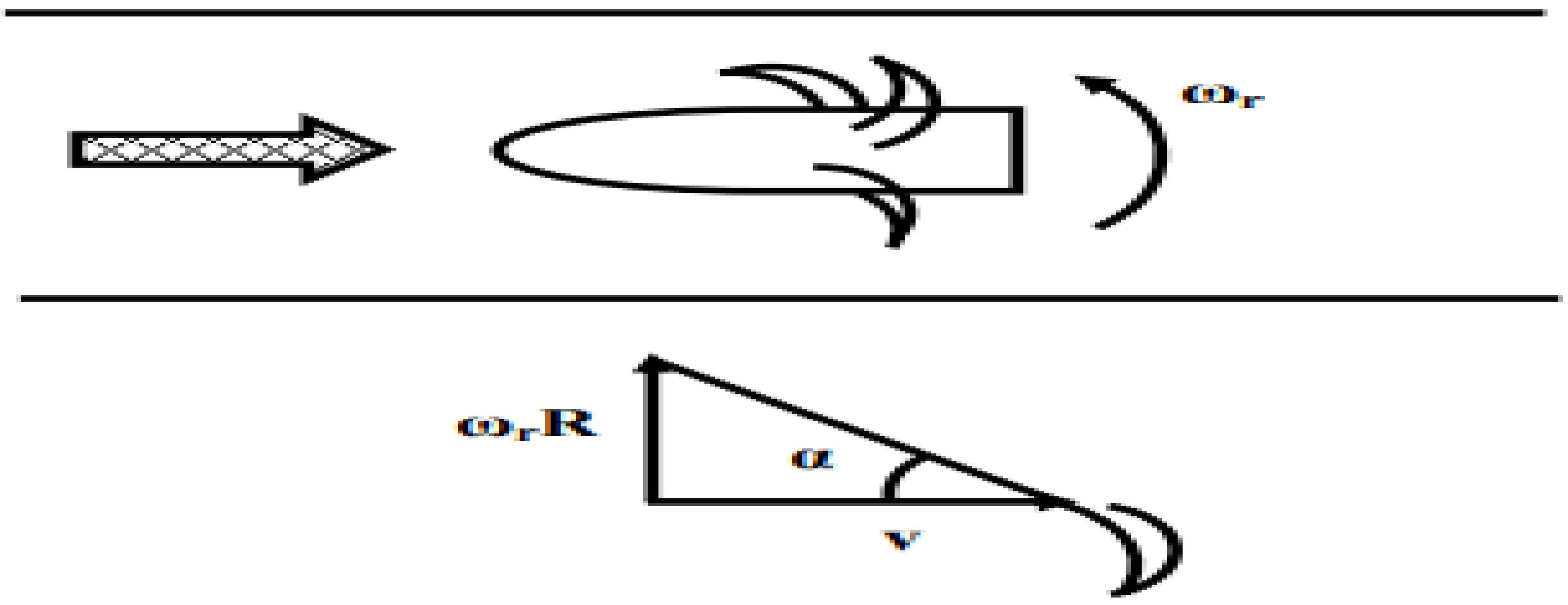
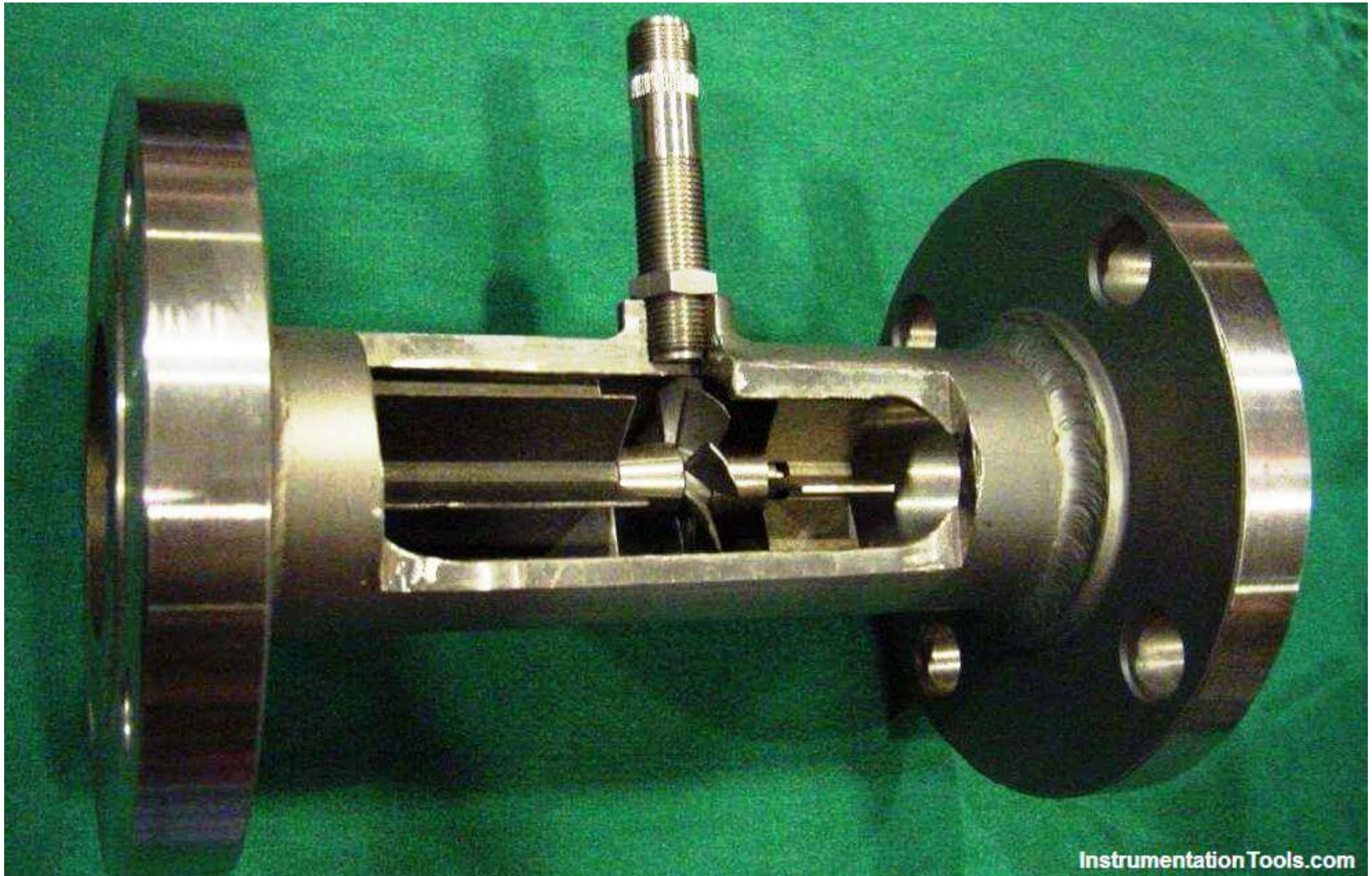


Fig. 11 Turbine type flowmeter

The speed of rotation of the turbine can be measured using several ways, such as, optical method, inductive pick up etc.

Turbine Type Flowmeter



Vortex type flowmeter

- Formation of vortex on a flowing stream by an obstruction like straw or stone is a common observation. But what is probably not commonly known is the fact that, the frequency of vortex formation is proportional to flow velocity.

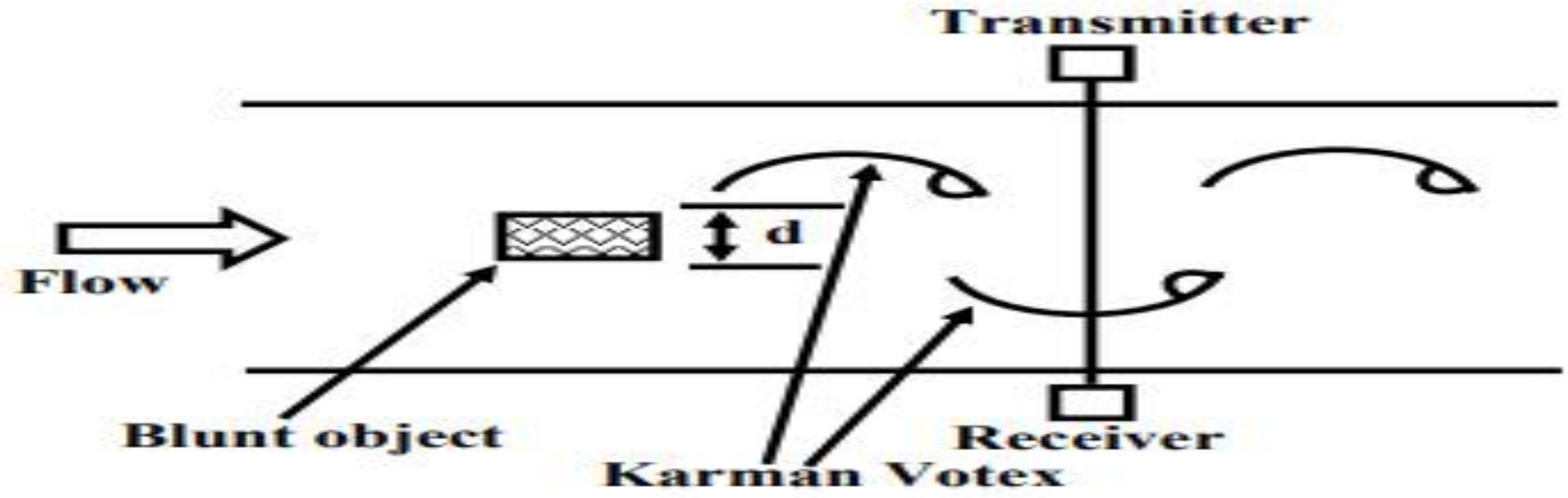


Fig. 12 Vortex type flowmeter

Vortex type flowmeter

Vortex type flowmeter

- Fig.12 shows the basic principle of vortex type flowmeter. It is based on the principle of vertex shading. When a blunt object is placed on the passage of a flowing stream, vortices are formed. A vortes of this sort is called Karman Vortex. If the flow is turbulent and the Reynold's number is $R_D > 10^4$, then the frequency of vortex formation is given by:

$$f = \frac{N_{st}}{d} v$$

Where, d= width of the blunt object.
v= velocity of the fluid
Nst = A constant, called Strouhal Number.

Vortex type flowmeter

- The fig. 12 shows a typical arrangement of measurement of frequency of vorticex formation using ultrasonic technique. Formation of a vortex will modulate the intensity of ultrasound received by the receiver, and the frequency of modulation can be measured easily.

Ultrasonic flow meter measure fluid velocity by passing high-frequency sound waves along the fluid flow path.

Fluid motion influences the propagation of these sound waves, which may then be measured to infer fluid velocity.

Two major sub-types of ultrasonic flow meters exist:

Doppler and transit-time.

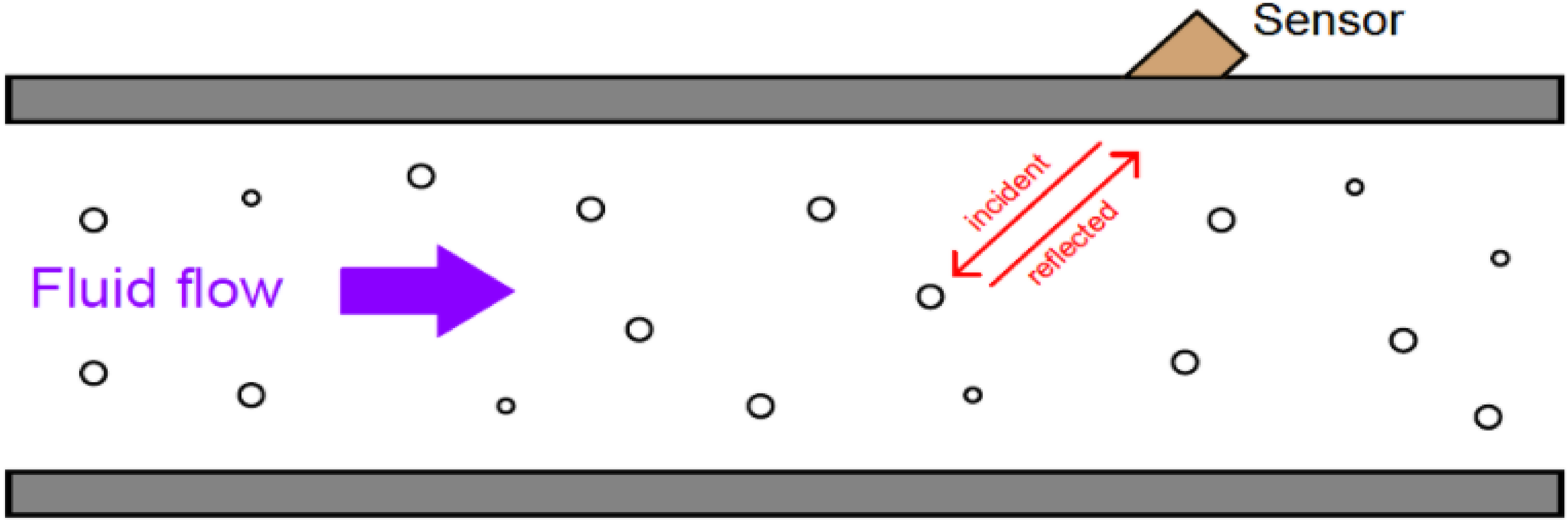
Both types of ultrasonic flowmeter work by transmitting a high-frequency sound wave into the fluid stream (the incident pulse) and analyzing the received pulse.

ULTRASONIC FLOW METER

- Doppler flowmeters exploit the Doppler effect, which is the shifting of frequency resulting from waves emitted by or reflected by a moving object.
- A common realization of the Doppler effect is the perceived shift in frequency of a horn’s report from a moving vehicle: as the vehicle approaches the listener, the pitch of the horn seems higher than normal; when the vehicle passes the listener and begins to move away, the horn’s pitch appears to suddenly “shift down” to a lower frequency.
- In reality, the horn’s frequency never changes, but the velocity of the approaching vehicle relative to the stationary listener acts to “compress” the sonic vibrations in the air. When the vehicle moves away, the sound waves are “stretched” from the perspective of the listener.

- The same effect takes place if a sound wave is aimed at a moving object, and the echo’s frequency is compared to the transmitted (incident) frequency. If the reflected wave returns from a bubble advancing toward the ultrasonic transducer, the reflected frequency will be greater than the incident frequency.
- If the flow reverses direction and the reflected wave returns from a bubble traveling away from the transducer, the reflected frequency will be less than the incident frequency.
- This matches the phenomenon of a vehicle’s horn pitch seemingly increasing as the vehicle approaches a listener and seemingly decreasing as the vehicle moves away from a listener.
- A Doppler flowmeter bounces sound waves off of bubbles or particulate material in the flow stream, measuring the frequency shift and inferring fluid velocity from the magnitude of that shift.

Ultrasonic Flow Meter – Doppler Flow meter



- The requirement for there to be objects in the flow stream large enough to reflect sound waves limits Doppler ultrasonic flow meters to liquid applications.
- Dirty liquids such as slurries and wastewater, or liquids carrying a substantial number of gas bubbles (e.g. carbonated beverages) are good candidate fluids for this technology.
- It is unrealistic to expect that any gas stream will be carrying liquid droplets or solid matter large enough to reflect strong echoes, and so Doppler flow meters cannot be used to measure gas flow.
- The mathematical relationship between fluid velocity (v) and the Doppler frequency shift (Δf) is as follows, for fluid velocities much less than the speed of sound through that fluid ($v \ll c$):

$$\Delta f = \frac{2 v f \cos\theta}{c}$$

$$\Delta f = \frac{2vf\cos\theta}{c}$$

Where,

Δf = Doppler frequency shift

v = Velocity of fluid (actually, of the particle reflecting the sound wave)

f = Frequency of incident sound wave

θ = Angle between transducer and pipe centerlines

c = Speed of sound in the process fluid

https://instrumentationtools.com/ultrasonic-flowmeters-animation/

- Note how the Doppler effect yields a direct measurement of fluid velocity from each echo received by the transducer.
- This stands in marked contrast to measurements of distance based on time-off light (time domain reflectometry – where the amount of time between the incident pulse and the returned echo is proportional to distance between the transducer and the reflecting surface)
- such as in the application of ultrasonic liquid level measurement. In a Doppler flowmeter, the time delay between the incident and reflected pulses is irrelevant. Only the frequency shift between the incident and reflected signals matters.
- This frequency shift is also directly proportional to the velocity of flow, making the Doppler ultrasonic flowmeter a linear measurement device.
- Re-arranging the Doppler frequency shift equation to solve for velocity (again, assuming $v << c$)

- A very important consideration for Doppler ultrasonic flow measurement is that the calibration of the flow meter varies with the speed of sound through the fluid (c).
- This is readily apparent by the presence of c in the above equation: as c increases, Δf must proportionately decrease for any fixed volumetric flow rate Q.
- Since the flowmeter is designed to directly interpret flow rate in terms of Δf, an increase in c causing a decrease in Δf will thus register as a decrease in Q.
- This means the speed of sound for a fluid must be precisely known in order for a Doppler ultrasonic flowmeter to accurately measure flow.

- The speed of sound through any fluid is a function of that medium’s density and bulk modulus (how easily it compresses):

$$c = \sqrt{\frac{B}{\rho}}$$

Where,
c = speed of sound in a material (meters per second)
B = Bulk modulus (pascals, or newtons per square meter)
ρ = Mass density of fluid (kilograms per cubic meter)

- Temperature affects liquid density, and composition (the chemical constituency of the liquid) affects bulk modulus. Thus, temperature and composition both are influencing factors for Doppler ultrasonic flowmeter calibration.
- Pressure is not a concern here, since pressure only affects the density of gases, and we already know Doppler flowmeters only function with liquids.
- Following on the theme of requiring bubbles or particles of sufficient size, another limitation of Doppler ultrasonic flowmeters is their inability to measure flow rates of liquids that are too clean and too homogeneous. In such applications, the sound-wave reflections will be too weak to reliably measure.
- Such is also the case when the solid particles have a speed of sound too close to the that of the liquid, since reflection happens only when a sound wave encounters a material with a markedly different speed of sound.
- Doppler-type ultrasonic flowmeters are useless in applications where we cannot obtain strong sound-wave reflections.