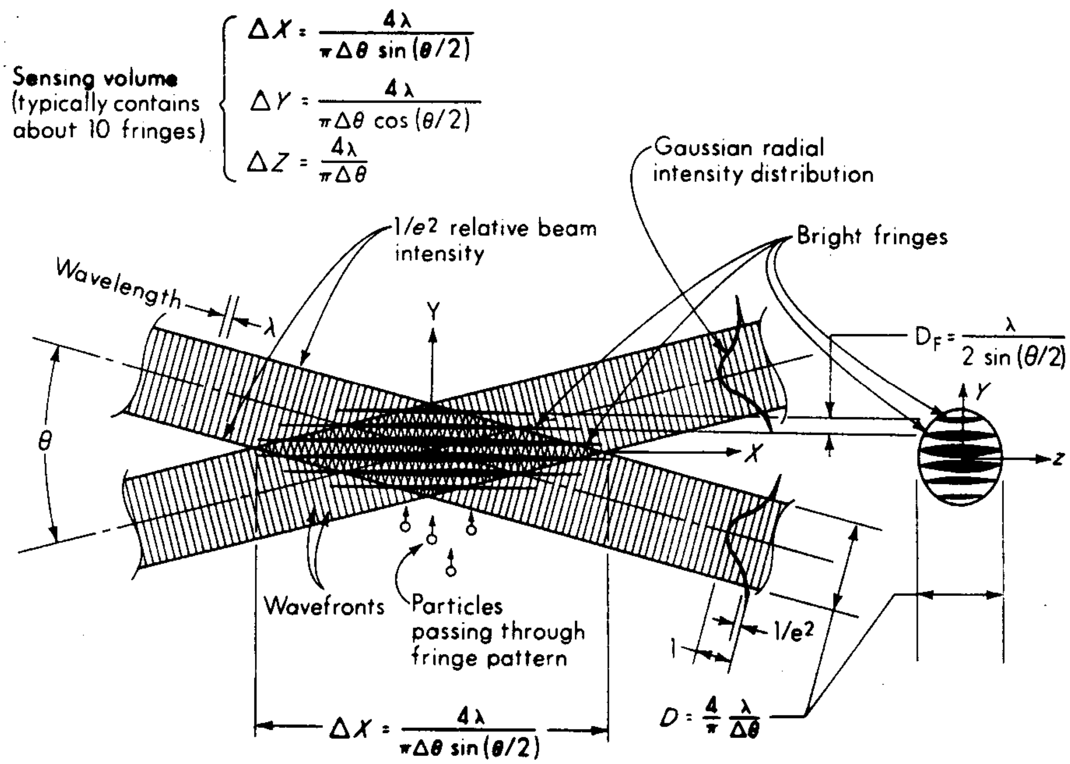
Final Examination Sensing and Actuation AT74.03 January 12, 2012

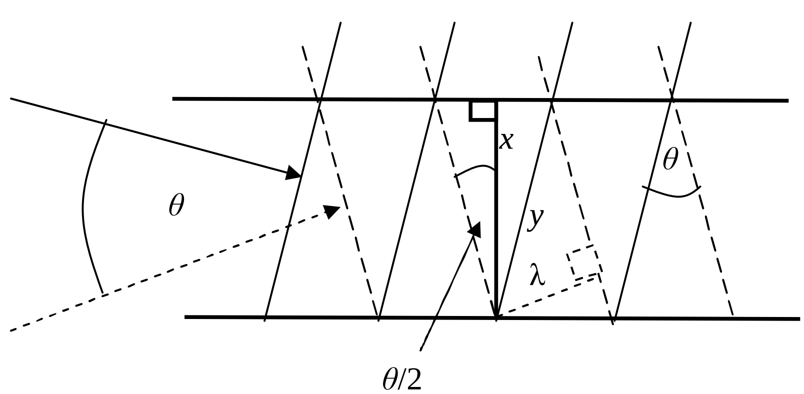
Time: 9:00-10:30 h. Open Book
Marks: 100

Attempt all questions.

Q.1 Prove that the distance between 2 lines in the fringe pattern of Laser Doppler Velocimeter when the two laser beams have an angle, θ, from each other is $\frac{\lambda}{2\sin(\theta/2)}$. (20)



Solution



From the figure,

$$y = \frac{\lambda}{\sin(\theta)} \quad (1)$$

$$x = y cos\left(\frac{\theta}{2}\right) \quad (2)$$

Substitute (1) into (2),

$$x = \frac{\lambda\cos(\theta/2)}{\sin(\theta)} \quad (3)$$

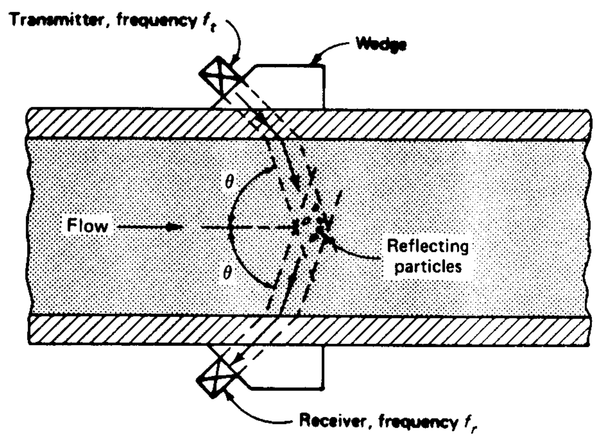
Since

$$\sin(\theta) = sin\left(\frac{\theta}{2} + \frac{\theta}{2}\right) = 2sin\left(\frac{\theta}{2}\right) cos\left(\frac{\theta}{2}\right) \quad (4)$$

Substitute (4) into (3),

$$x = \frac{\lambda\cos(\theta/2)}{2sin\left(\frac{\theta}{2}\right)cos\left(\frac{\theta}{2}\right)} = \frac{\lambda}{2sin\left(\frac{\theta}{2}\right)} \quad \underline{(5)}$$

Q.2 Prove that the frequency difference between transmitter and receiver of Doppler Ultrasonic Flowmeter is approximately $\Delta f = f_t - f_r = \frac{2f_t\cos(\theta)}{c}V$, when c is much higher than V. (20)



<u>Solution</u>

The frequency observed at the stationary receiver with a moving source, V_s (positive when moving away from receiver), is determined from,

$$f = \frac{c}{\lambda} \quad (1)$$

$$\lambda = \frac{c+V_s}{f_t} \quad (2)$$

Substitute (2) in (1),

$$f = \frac{c}{\frac{c+V_s}{f_t}} = \frac{c}{c+V_s} f_t \tag{3}$$

The frequency observed at the moving receiver, V_r (positive when moving toward source), with stationary source is determined from,

$$f = \frac{c}{\lambda} \tag{4}$$

$$c = c + V_r \tag{5}$$

Substitute (5) in (4),

$$f = \frac{c+V_r}{\frac{c}{f_t}} = \frac{c+V_r}{c} f_t \tag{6}$$

From (6), the frequency observed at the moving particle with stationary source becomes

$$f_{particle} = \frac{c-V\cos(\theta)}{c} f_t \tag{7}$$

From (3), the frequency observed at the stationary receiver with moving source becomes

$$f_r = \frac{c}{c+V\cos(\theta)} f_{particle} = \frac{c-V\cos(\theta)}{c+V\cos(\theta)} f_t \tag{8}$$

The frequency difference, thus, becomes

$$\Delta f = f_t - f_r = f_t - \frac{c-V\cos(\theta)}{c+V\cos(\theta)} f_t = \frac{2f_t V\cos(\theta)}{c+V\cos(\theta)} \tag{9}$$

Since *c* is much higher than *V*, thus

$$\Delta f \approx \frac{2f_t \cos(\theta)}{c} V \tag{10}$$

Q.3 The radius of curvature of a bimetallic thermometer was measured at 2 meters when the temperature was 30 ˚C, the radius of curvature was measured at 3 meters when the temperature was 40 ˚C. Determine the temperature when the radius of curvature is measured at – 1 meter.

(20)

Solution

Since the radius of curvature is an inverse of change of temperature from reference temperature,

$$r_a = \frac{K}{t-t_r} \tag{1}$$

At 30 ˚C,

$$2 = \frac{K}{30-t_r} \tag{2}$$

At 40 ˚C,

$$3 = \frac{K}{40-t_r} \tag{3}$$

(2)/(3),

$$\frac{2}{3} = \frac{40-t_r}{30-t_r} \tag{4}$$

$$60 - 2t_r = 120 - 3t_r \quad (5)$$

Thus,

$$t_r = 60 \quad (6)$$

Substitute (6) into (2),

$$2 = \frac{K}{30-60} \quad (7)$$

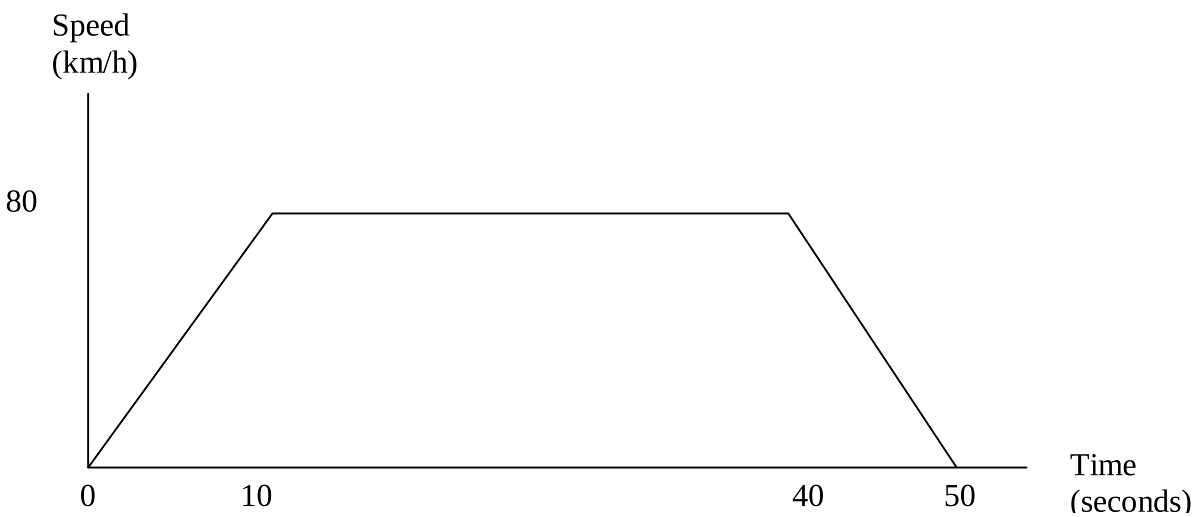
$$K = -60 \quad (8)$$

When the radius of curvature is -1 meter,

$$-1 = \frac{-60}{t-60} \quad (9)$$

$$t = 120 \ ^{\circ}\mathrm{C} \quad \underline{(10)}$$

Q.4 If a DC motor is used to drive an electrical car with the total weight of 1,200 kg. Assume the total resistance from aerodynamic, friction, and so on of this car is 200 N. Determine the required power from the motor as function of time when the speed of the car is shown by the below graph. (20)



<u>Solution</u>

During 0-10 seconds,

The acceleration,

$$a_1 = \frac{80000}{3600 \times 10} = 2.22 \text{ m/s}^2 \quad (1)$$

The required force from DC motor,

$$f_1 = 1200 \times 2.22 + 200 = 2864 \text{ N} \quad (2)$$

The function of speed,

$$v_1 = 2.22t \text{ m/s} \quad (3)$$

The required power,

$$P_1 = f_1 \times v_1 = 6358.08t \text{ W} \tag{4}$$

During 10-40 seconds,

The acceleration,

$$a_2 = 0 \text{ m/s}^2 \tag{5}$$

The required force from DC motor,

$$f_2 = 1200 \times 0 + 200 = 200 \text{ N} \tag{6}$$

The function of speed,

$$v_2 = 22.22 \text{ m/s} \tag{7}$$

The required power,

$$P_2 = f_2 \times v_2 = 4444 \text{ W} \tag{8}$$

During 40-50 seconds,

The acceleration,

$$a_3 = -\frac{80000}{3600 \times 10} = -2.22 \text{ m/s}^2 \tag{9}$$

The required force from DC motor,

$$f_3 = -1200 \times 2.22 + 200 = -2464 \text{ N} \tag{10}$$

Since the required force is negative, the motor will be off.

The required power,

$$P_3 = 0 \text{ W} \tag{11}$$

Q.5 Explain your interested research topic, and describe how you would apply the knowledge learnt from Sensing and Actuation course to your research. (20)