Department of Mechanical Engineering

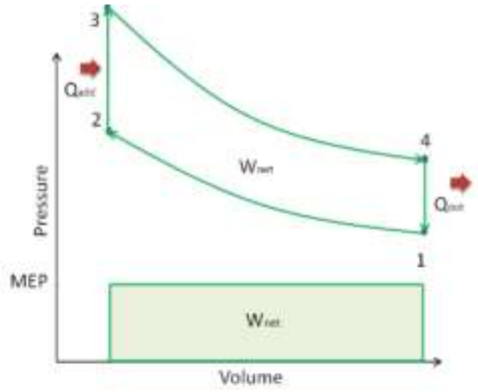
Exam Preparatory Class

Unit 1 – GAS AND STEAM POWER CYCLES

Part – A

1. Define air standard efficiency cycle?
It is defined as the ratio of work done by the cycle to the heat supplied to the cycle

2. Define Mean effective pressure. Show it on p-v diagram.
It is hypothetical pressure which is acting on the piston during the power stroke.
Mean effective pressure = workdone /stroke volume.



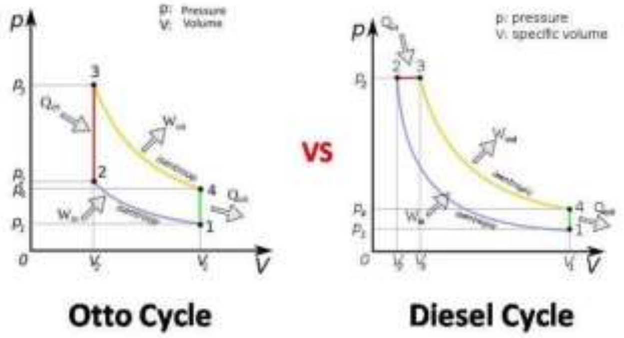
3. What are the assumptions made in air standard cycle?
- The work medium is a perfect gas throughout.
- The working medium does not undergo chemical change through the cycle.
- Kinetic and potential energies of the working fluid are neglected.
- The operation of the engine is frictionless

4. **Air standard efficiency equation of diesel and otto cycle.**

$$\eta_{Otto} = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$\eta_{diesel} = 1 - \frac{1}{\gamma (r)^{\gamma-1}} \left[\frac{\rho^{\gamma} - 1}{\rho - 1} \right]$$

5. **P-V diagram of diesel and otto cycle?**



6. What are the methods used to increase the efficiency of Rankine cycle.

Rankine cycle efficiency can be improved by using the following three methods.
1. Reheating 2. Regeneration 3. Combined reheating and regeneration

7. **What is the effect cut-off ratio on the efficiency of diesel cycle when the compression ratio is kept constant?**
When cut-off ratio of diesel cycle increases, the efficiency of cycle is decreased when compression ratio is kept constant and vice versa

8. **Why does diesel cycle have high efficiency compared to Otto cycle?**

The normal range of compression ratio for a diesel engine is 16 to 20 whereas for spark it is 6 to Due to higher compression ratios used in diesel engines, the efficiency of the diesel engine is more than that of a gasoline engine

9. **Four major difference between Otto and diesel cycle.**

S.No	Otto cycle	Diesel cycle
1	Efficiency is less due to low compression ratio	Efficiency is more due to low compression ratio
2	Fuel is admitted into the cylinder during suction stroke	Air alone is admitted in to the cylinder during suction stroke
3	Spark ignition system is used for ignition.	Compression ignition system is used for ignition.

10. **What is cutoff ratio?**

It is defined as the ratio of volume after the heat addition to volume before the heat addition.

Part B

1. In an Otto cycle air at 1bar and 290K is compressed isentropic ally until the pressure is 15bar The heat is added at constant volume until the pressure rises to 40bar. Calculate the air standard efficiency and mean effective pressure for the cycle. Take Cv=0.717 KJ/Kg K and R_{univ} = 8.314KJ/Kg K.

Given Data:

Pressure (P1) = 1bar = 100KN/m^2

Temperature(T1) = 290K

Pressure (P2) = 15bar = 1500KN/m^2

Pressure (P3) = 40bar = 4000KN/m^2

Cv = 0.717 KJ/KgK
R_{univ} = 8.314 KJ/Kg K

.

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To Find:

i) Air Standard Efficiency (η_{otto})

ii) Mean Effective Pressure (P_m)

Solution:

Here it is given R_{univ} = 8.314 KJ/KgK
We know that ,
$\gamma = Cp/Cv$ (Here Cp is unknown)
$R_{univ} = M \times R$

Since For air (O_2) molecular weight (M) = 28.97
$8.314 = 28.97 \times R$
$\therefore R = 0.2869$

(Since gas constant R = Cp-Cv)

$0.2869 = Cp - 0.717$
$\therefore$ Cp= 1.0039 KJ/Kg K

$$\gamma = \frac{Cp}{Cv} = \frac{1.0039}{0.717} = 1.4$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$\eta = 1 - \frac{1}{r^{1.4-1}}$$

Here 'r' is unknown.

We know that,

$$r = \left(\frac{V1}{V2}\right) = \left(\frac{P2}{P1}\right)^{\frac{1}{\gamma}}$$

$$= \left(\frac{1500}{100}\right)^{\frac{1}{1.4}}$$

$$r = 6.919$$

$$\eta_{otto} = 1 - \frac{1}{6.919^{0.4}}$$

$$\therefore \eta_{otto} = 3.87\%$$

Mean Effective Pressure (Pm)= $P_1\ r \frac{[(K-1)(r^{\gamma-1}-1)]}{[(\gamma-1)(r-1)]}$

$$Pm = \frac{(100)(6.919)[(2.67-1)(6.919^{1.4}-1)]}{[(1.4-1)(6.919-1)]}$$

$$Pm = 569.92\ KN/m^2$$

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2. Estimate the lose in air standard efficiency for the diesel engine for the compression ratio 14 and the cutoff changes from 6% to 13% of the stroke.

Given Data

Case (i)	Case (i)
Compression ratio (r) = 14	compression ratio (r) =14
ρ = 6% Vs	ρ = 13%Vs

To Find

Lose in air standard efficiency.

To Find

Lose in air standard efficiency.

Solution

Compression ratio (r) = $r = \frac{V1}{V2} = \frac{Vc+Vs}{Vc}$

$$14 = 1 + \frac{Vs}{Vc}$$

$$\frac{Vc}{Vs} = 13$$

Case (i):

Cutoff ratio (ρ) =V3/V2

$$\frac{V3}{V2} = \frac{Vc + 6\%Vs}{Vc}$$

$$= 1 + \frac{6\% Vs}{Vc}$$

$$\rho = \frac{V3}{V2} = 1 + (0.06)(13)$$

$$\rho = 1.78$$

We know that,

$$\eta_{diesel} = 1 - \frac{1}{\gamma \times r^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\rho-1}\right]$$

$$= 1 - \left(\frac{1}{(1.4)(14)^{1.4-1}}\right)\frac{[1.78^{1.4}-1]}{[1.78-1]}$$

$$= 1 - (0.2485)(1.5919)$$

$$= 0.6043 \times 100\%$$

$$\eta_{diesel} = 60.43\%$$

case (ii):

$$\text{cutoff ratio } (\rho) = \frac{V3}{V2} = \frac{Vc + 13\% Vs}{Vc}$$

$$= 1 + (0.13)(13)$$

$$\rho = 2.69$$

case (ii):

$$\text{cutoff ratio } (\rho) = \frac{V3}{V2} = \frac{Vc + 13\% Vs}{Vc}$$

$$= 1 + (0.13)(13)$$

$$\rho = 2.69$$

$$\eta_{diesel} = 1 - \frac{1}{\gamma \times r^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\rho-1}\right]$$

$$= 1 - \left(\frac{1}{(1.4)(14)^{1.4-1}}\right)\frac{[2.69^{1.4}-1]}{[2.69-1]}$$

$$= 1 - (0.24855)(1.7729)$$

$$= 0.5593 \times 100\%$$

$$= 55.93\%$$

Lose in air standard efficiency = $(\eta_{diesel\ CASE(i)}) - (\eta_{diesel\ CASE(i)})$

$$= 0.6043 - 0.5593$$

$$= 0.0449$$

$$= 4.49\%$$

3. The compression ratio of an air standard dual cycle is 12 and the maximum pressure on the cycle is limited to 70bar. The pressure and temperature of the cycle at the beginning of compression process are 1bar and 300K. Calculate the thermal efficiency and Mean Effective Pressure. Assume cylinder bore = 250mm, Stroke length = 300mm, Cp=1.005KJ/Kg K, Cv=0.718KJ/Kg K.

Given data:

Assume $Qs_1 = Qs_2$
Compression ratio (r) = 12
Maximum pressure $(P_3) = (P_4) = 7000\ KN/m^2$
Temperature $(T_1) = 300K$
Diameter (d) = 0.25m
Stroke length (l) = 0.3m

To find:

Dual cycle efficiency (η_{dual})
Mean Effective Pressure (P_m)

Solution:

By Process 1-2:

$$\frac{T2}{T1} = \left[\frac{V2}{V1}\right]^{\gamma-1}$$

$$= [r]^{\gamma-1}$$

$$T2 = 300[12]^{1.4-1}$$

$$T_2 = 810.58K$$

$$\frac{P2}{P1} = \left[\frac{V1}{V2}\right]^{\gamma}$$

$$P2 = [12]^{1.4} \times 100$$

$$P_2 = 3242.3KN/m^2$$

By process 2-3:

$$\frac{P2}{T2} = \frac{P3}{T3}$$

$$\frac{P3}{P2} = \frac{T3}{T2}$$

$$T3 = \left[\frac{7000}{3242.3}\right]810.58$$

$$T_3 = 1750K$$

Assuming $Qs_1 = Qs_2$

$$mCv[T3-T2] = mCp[T4-T3]$$

$$0.718\ [1750-810.58] = 1.005\ [T4-1750]$$

$$T_4 = 2421.15K$$

By process 4-5:

$$\frac{T4}{T5} = \left[\frac{V5}{V4}\right]^{\gamma-1}$$

$$= \left[\frac{r}{\rho}\right]^{1.4-1}$$

We know that, $\rho = \frac{V4}{V3} = \frac{T4}{T3} = \frac{2421.15}{1750} = 1.38$

$$\frac{T4}{T5} = \left[\frac{12}{1.38}\right]^{0.4}$$

$$T5 = \frac{2421.15}{\left(\frac{12}{1.38}\right)^{0.4}}$$

$$T5 = 1019.3K$$

Heat supplied $Q_s = 2 \times m\, C_v \times [T3 - T2]$

$$= 2 \times 1 \times 0.718 \times [1750 - 810.58]$$

$$Q_s = 1349 KJ/Kg$$

Heat rejected $Q_r = m\, C_v\, [T5 - T1]$

Q_r

$$= 516.45\ KJ/Kg$$

$$\eta_{dual} = \frac{Q_s - Q_r}{Q_s} = \frac{[illegible]}{1349} \times 100$$

$$\eta_{dual} = 61.72\%$$

Stroke volume $(V_s) = \frac{\pi}{4} \times d^2 \times l$

$$= \frac{\pi}{4} \times 0.25^2 \times 0.3$$

$$V_s = 0.0147 m^3$$

Mean Effective Pressure (P_m) $= W/V_s$

$$= 832.58/0.0147$$

$$P_m = 56535\ KN/m^2$$

4. A diesel engine operating an air standard diesel cycle has 20cm bore and 30cmstroke.the clearance volume is 420cm^3.if the fuel is injected at 5% of the stroke,find the air standard efficiency.

Given Data:-

Bore diameter (d) =20cm=0.2mk

Stroke, (l) =30cm=0.3m

Clearance volume, (v_2) =420cm^3=420/100^3= $4.2 \times 10^{-4} m^3$

To Find:-

Air standard efficiency, (d_{iesel}) Solution:-

Compression ratio, $r = v_1/v_2$

$= (v_c+v_s)/v_c$

We know that,

Stroke volume, v_s=area*length

$=\left(\frac{\pi}{4}\right) d^2 \times l$

$=\left(\frac{\pi}{4}\right) (0.2^2\ ) \times 0.3$

$V_s = 9.4 \times 10^{-3}\ m^3$

Therefore,

Compression ratio, $(r) = \frac{4.2\times10^{-4} + 9.42\times10^{-3}}{4.2\times10^{-4}}$

$r = 23.42$

Cut off ratio, $\rho = v_3 / v_2$

$= (v_c + 5\%\ v_s) / v_c$

$= 1 + \frac{(0.05\times9.42\times10^{-3})}{4.2\times10^{-4}}$

$\rho = 2.12$

We know the equation,

$$\eta_{diesel} = 1 - \left(\frac{1}{\gamma(r)^{\gamma-1}}\right) \times \left(\frac{\rho^{\gamma}-1}{\rho-1}\right)$$

$$= 1 - \frac{1}{1.4\times23.42^{1.4-1}}\left(\frac{(2.12^{1.4}-1)}{2.12-1}\right)$$

$= 1 - (0.20229)(1.6636)$

$= 0.6634 \times 100$

$\eta_{diesel} = 66.34\%$

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5. Drive and expression for the air standard efficiency of Otto cycle in terms of volume ratio.
6. Drive an expression for the air standard efficiency of Diesel cycle.
7. Drive an expression for the air standard efficiency of Dual cycle.
8. Explain the working of 4 stroke cycle Diesel engine. Draw the theoretical and actual PV diagram.
9. Drive the expression for air standard efficiency of Brayton cycle in terms of pressure ratio.

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Exam Preparatory Class

Unit 2 – Steam Nozzles & Injectors

Part – A

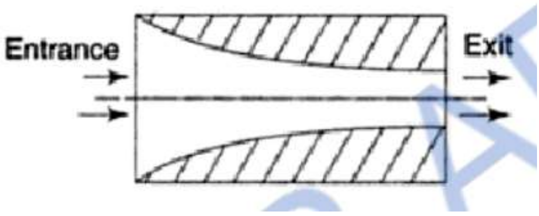
1.Define the steam nozzle

The steam nozzle is a passage of varying cross-section by means of which the thermal energy of steam is converted into kinetic energy

2.What are the various types of nozzles and their functions?

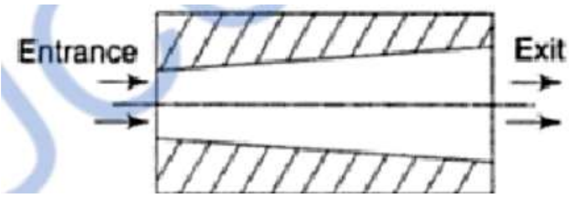
a) Convergent nozzle:

In the convergent nozzle, the cross-sectional area decreases from the inlet section to the outlet section. It is used in a case where the back pressure is equal to or greater than the critical pressure ratio.



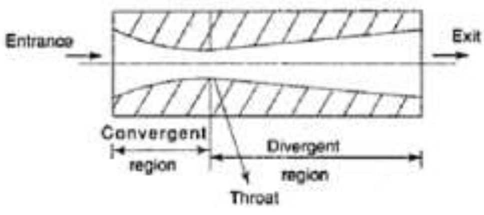
b) Divergent nozzle:

In the divergent nozzle, the cross-sectional area increases from the inlet section to the outlet section. It is used in a case where the back pressure is less than the critical pressure ratio.



c) Convergent-Divergent nozzle:

The cross-section of nozzle first decreases from the inlet section to the throat and then it increases from throat to outlet section. It is called a Convergent-divergent nozzle. This case is used in the case where the back pressure is less than the critical pressure. Also, in present day application, it is widely used in many types of steam turbines.



3. State the relation between the velocity of steam and heat during any part of a steam nozzle

$$\text{Velocity, } C = \sqrt{2000x\,(h1 - h2)}$$

Where

(h_1-h_2) = Heat contained in steam.

4. **Define nozzle efficiency**

Co-efficient of Nozzle or Nozzle efficiency is defined as the ratio of actual enthalpy drop to isentropic enthalpy drop.
Nozzle efficiency = (actual enthalpy drop) / (isentropic enthalpy drop)

5. **What are the effects of super saturation in a steam nozzle?**

The dryness fraction of the steam is increased.
- Entropy and specific volume of the steam are increased.
- The exit velocity of the steam is reduced.
- Mass of steam discharged is increased.

6. What is the critical pressure ratio of a steam nozzle?
Critical pressure ratio is one only value of the ratio (p_2/p_1) which produces maximum discharge from the nozzle. The ratio is called a critical pressure ratio.

7. **Write down the expression for the velocity at the exit from the steam nozzle**

$$\textit{Exit Velocity } C_2 = \sqrt{2000\,x\,(h_1 - h_2)}$$

or

$$C_2 = \sqrt{\frac{2n}{n-1}\,x\,p_1\,x\,v_1\,x\,[1-(p_2)]}$$

8. **What are the effects of friction on the flow through a steam nozzle?**

The expansion is no more isentropic and the enthalpy drop is reduced thereby resulting in the reduced exit velocity.
The final fraction of the steam is increased as a part of the kinetic energy gets converted into heat due to friction and absorbed by steam within the increase to enthalpy.
The specific volume of steam is increased as the steam becomes drier due to this

frictional reheating.

9. **What are the factors reducing the final velocity of steam in nozzle flow?**

The friction between nozzle surface and steam.
- The internal fluid friction in steam
- Shock losses.

10. **Define the degree of reaction.**

It is defined as the ratio of the actual isentropic heat drop to the total heat drop in the entire stage.

Part B

1.

Dry saturated steam at 6.5 bar with negligible velocity expands isentropically in a convergent nozzle to 1.4 bar and dryness fraction 0.956. Determine the velocity of steam leaving the nozzle. If 13% heat is lost in friction, find the % reduction in the final velocity.

Given data

$P_1 = 6.5$ bar.

$P_2 = 1.4$ bar

$x_2 = 0.956$

Heat loss = 13%

Solution

From steam table at 6.5 bar

$h_1 = h_g = 2758.8$ kJ/kg

At 1.4 bar

$h_f = 458.4$ kJ/kg $h_{fg} = 2231.9$ kJ/kg

$h_2 = h_{f2} + x_2 h_{fg}$

$= 458.4 + 0.956 (2231.9)$

$h_2 = 2592.1$ kJ/kg.

$V_2 = \sqrt{2000 \times (h_1 - h_2)}$

$= \sqrt{2000 \times (2758.8 - 2592.1)}$

$= 577.39$ m/sec

Heat drop 13% = 0.13

Nozzle η = 1 − 0.13

= 0.87

Velocity of steam by considering the nozzle η

$V_2 = \sqrt{2000 \times (h_1 - h_2)\eta}$

$= \sqrt{2000 \times (2758.8 - 2592.1) \times 0.87}$

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% Reduction in final velocity $= \frac{577.39 - 538.55}{577.39} \times 100$ (3)

$= 6.726\%$

2.

Problem no: 2

Steam is expanded in a set of nozzles from 10 bar and 200°C to 5 bar. What type of nozzle is it? Neglecting the initial velocity find min area of the nozzle required to allow a flow of 3 kg/s under the given conditions. Assume that expansion of steam to be isentropic.

Sol:

Given:

Pressure at the entry to the steam nozzles

$P_1 = 10$ bar

$T_1 = 200°C$

Steam at exit pressure

$P_2 = 5$ bar

We know that

$$\frac{P_2}{P_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$$

$$= \left(\frac{2}{1.3+1}\right)^{\frac{1.3}{0.3}}$$

$$= \left(\frac{2}{2.3}\right)^{4.333} = 0.5457$$

$P_2 = P_1 \times 0.5457$

$= 10 \times 0.5457$

$P_2 = 5.5$ bar

Since throat pressure (P_2) is greater than the exit pressure the nozzle used is Convergent divergent nozzle. The minimum area will be at throat, where the pressure is 5.5 bar.

Pressure at 10 bar $h_1 =$

s_1

$h_2 = s_1$

$S_1 = S_2$

$S_1 = Sf_2 + x_2 \, Sfg_2$

$h_2 = hf_2 + x_2 \, hfg_2$

$h_2 = hf_2 + x_2 (hg_2 - hf_2)$

4.

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Specific volume of 5.5 bar
$v = 0.345\ m^3/kg$.

Velocity of Throat $V_2 = 44.72\sqrt{h_1 - h_2}$
$= 44.72\sqrt{\ }$

Throat area $A_2 = \frac{mv}{C_2 v_2}$
$= \frac{3 \times 0.345}{}$

$A = 0.0021\ m^2$

3.

Problem no: 2

In a steam nozzle, the steam expands from 4 bar to 1 bar initial velocity is 60 m/s and the initial temperature 200°C. Determine the exit velocity if the nozzle efficiency is 92%.

pands
raction
f 13%
final

Solution

Steam pressure at entry to the nozzle $P_1 = 4$ bar 200°C.

Steam Pressure at exit from the nozzle $P_2 = 1$ bar

Intial velocity of steam $C_1 = 60$ m/sec

Nozzle efficiency $\eta_{nozzle} = 92\%$

Exit velocity : ?

using steam table

At $P_1 = 4$ bar 200°C
$h_1 = 2860.5$ kJ/kg. $S_1 = 7.171$ kJ/kg.

At $P_2 = 1$ bar
$hf_2 = 417.5$ kJ/kg $hfg_2 = 2257.9$ kJ/kg.
$Sf_2 = 1.3027$ kJ/kgK $Sfg_2 = 6.0571$ kJ/kg K.

Entropy remains constant.
$S_1 = S_2$
$S_1 = Sf_2 + x_2\, Sfg_2$

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$S_1 = S_{f2} + x_2 S_{fg2}$

$7.171 = S_{f2} + x_2 S_{fg2}$

$7.171 = 1.3027 + x_2 (6.0571)$

$x_2 = \frac{7.171 - 1.3027}{6.0571}$

$x_2 = 0.969$

$h_2 = H_{f2} + x_2 h_{fg2}$

$= 417.5 + 0.969 (2257.9)$

$\boxed{h_2 = 2605.4 \text{ kJ/kg}}$

$\therefore$ Enthalpy drop $= h_1 - h_2 = 2860.5 - 2605.4$

$\boxed{= 255.1 \text{ kJ/kg}}$

Actual enthalpy drop ~~$h_1 - h_2$~~

~~$= 2860.5 - 2605.4$~~

~~$= 25$~~

$= \eta_{nozzle} \times (h_1 - h_2)$

$= 0.92 \times (255.1)$

$\boxed{\text{Actual enthalpy drop} = 234.69 \text{ kJ/kg.}}$

Enthalpy drop Actual $= \frac{V_2^2 - V_1^2}{2}$

~~$V_2^2 =$~~ $\frac{V_2^2 - 60^2}{2} = 234.69$

$V_2^2 - 60^2 = 234.69 \times 2$

$V_2 = \sqrt{60^2 + 2 \times 234.69 \times 1000}$

$\boxed{V_2 = 687.7 \text{ m/sec}}$

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4.

Dry saturated steam at 6.5 bar with negligible velocity expands isentropically in a convergent nozzle to 1.4 bar and dryness fraction 0.956. Determine the velocity of steam leaving the nozzle. If 13% heat is lost in friction, find the percentage reduction in the final velocity.

Given data

$P_1 = 6.5$ bar.

$P_2 = 1.4$ bar

$x_2 = 0.956$

Heat loss $= 13\%$

From steam table at 6.5 bar.

$h_1 = h_g = 2758.8$ kJ/kg.

At 1.4 bar.

$h_{f_2} = 458.4$ kJ/kg.

$h_{fg_2} = 2231.9$ kJ/kg.

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$= 458.4 + 0.956 \times 2231.9$

$h_2 = 2592.1$ kJ/kg

$V_2 = \sqrt{2000(h_1 - h_2)}$

$= \sqrt{2000(2758.8 - 2592.1)} = 577.39$ m/sec.

Heat drop is 13% = 0.13

Nozzle efficiency $\eta = 1 - 0.13 = 0.87$

Velocity of steam by considering the nozzle efficiency

$V_2 = \sqrt{2000(h_1 - h_2)\eta}$

$= \sqrt{2000(2758.8 - 2592.1) \times 0.87}$

$V_2 = 538.55$ m/sec

% Reduction in final velocity $= \frac{577.39 - 538.55}{577.39} \times 100$

$= 6.726\%$

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5.

Dry saturated steam at 2.8 bar is expanded through a convergent nozzle to 1.7 bar. The exit area is $3 cm^2$. Calculate the exit velocity and mass flow rate for (i) Isentropic expansion and (ii) Super saturated flow.

Given data:

$P_1 = 2.8$ bar.

$P_2 = 1.7$ bar.

$A_2 = 3 cm^2 = 3 \times 10^{-4} m^2$

Solution

From steam table

At 2.8 bar

$h_1 = 2721.5$ kJ/kg

$S_1 = 7.014$ kJ/kg K.

$v_1 = 0.64600 m^3/kg$

At 1.7 bar.

$h_f = 483.2$ kJ/kg

$h_{fg} = 2215.6$ kJ/kg

$S_f = 1.475$ kJ/kg K.

$S_{fg} = 5.706$ kJ/kg K

$v_f = 0.001056 m^3/kg$

$v_g = 1.0309 m^3/kg$

For Isentropic flow

$S_1 = S_2 = 7.014$ kJ/kg K.

$S_2 = Sf_2 + x_2 \, Sfg_2$

$7.014 = 1.475 + x_2 \times 5.706$

$x_2 = 0.97$

$h_2 = hf_2 + x_2 \, hfg_2$

$= 483.2 + 0.97 \times 2215.6$

$h_2 = 2634.15$ kJ/kg

$v_2 = x_2 \, Vg_2$

$= 0.97 \times 1.0309$

Velocity of steam at exit

$$V_2 = \sqrt{2000(h_1 - h_2)}$$

$$= \sqrt{2000\,(2721.5 - 2631.15)}$$

$$\boxed{V_2 = 418\ m/s}$$

Mass flow rate of steam

$$m = \frac{A_2 V_2}{v_2} = \frac{3\times10^{4} \times 418}{1.00}$$

$$\boxed{m = 0.1257\ kg/sec}$$

For Super Saturated flow

$$V_2 = \sqrt{\frac{2n}{n-1}\, p_1 v_1 \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]}$$

$$= \sqrt{\frac{2\times1.3}{1.3-1} \times 2.8\times10^{5} \times 0.6460 \left[1 - \left(\frac{1.7}{2.8}\right)^{\frac{1.3-1}{1.3}}\right]}$$

$$V_2 = 413\ m/sec$$

Specific volume $v_2 = v_1 \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}}$

$$= 0.6460 \cdot \left(\frac{2.8}{1.7}\right)^{\frac{1}{1.3}}$$

$$V_2 = 413\ m/sec$$

Specific volume $v_2 = v_1 \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}}$

$$= 0.6460 \cdot \left(\frac{2.8}{1.7}\right)^{\frac{1}{1.3}}$$

$$= 0.94827\ m^3/kg.$$

Mass flow rate

$$m = \frac{A_2 V_2}{v_2} = \frac{3\times10^{-4} \times 413}{0.94827}$$

$$\boxed{m = 0.1306\ kg/sec}$$

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6.

Dry air at a pressure of 12 bar and 573 K is expanded isentropically through a nozzle at a pressure of 2 bar. Determine the maximum mass flow rate through the nozzle of 0.00015 m² area.

Given data:

$P_1 = 12$ bar $= 1200$ kpa $\quad \frac{12 \times 10^5}{1000} =$ kpa

$T_1 = 573$ K

$P_2 = 2$ bar $= 200$ kpa.

$A = 0.00015 m^2$

To find: max mass flow rate

Formula

(i) Mass flow rate through nozzle

$$m = \frac{A C_2}{V_2}$$

(ii) For isentropic process

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$V_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} \times V_1$$

(iii) From ideal gas equation

$$P_1 V_1 = RT_1$$

$$V_1 = \frac{RT_1}{P_1}$$

(iv) $C_2 = \sqrt{2000(h_1 - h_2)}$

$$C_2 = \sqrt{2000 \times C_p (T_1 - T_2)} \qquad T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} T_1$$

Solution

From ideal gas equation

$$P_1 V_1 = RT_1$$

$$V_1 = \frac{RT_1}{P_1}$$

$$V_1 = \frac{0.287 \times 573}{1200} = 0.137 \text{ m}^3/\text{kg}.$$

For isentropic process

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$V_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} \times V_1$$

$$= \left(\frac{12}{2}\right)^{\frac{1}{1.4}} \times 0.137$$

$$V_2 = 0.493 \ m^3/kg.$$

Relation between pressure and Temperature for isentropic process

$$T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \times T_1$$

$$T_2 = \left(\frac{2}{12}\right)^{\frac{1.4-1}{1.4}} \times 573$$

$$\boxed{T_2 = 343.42 \ K}$$

$$C_2 = \sqrt{2000 \times C_p (T_1 - T_2)}$$

$$= \sqrt{2000 \times 1.005 (573 - 343.42)}$$

$$C_2 = 679.305 \ m/sec.$$

Mass flowrate through nozzle

$$m = \frac{A C_2}{V_2}$$

$$m = \frac{0.00015 \times 679.305}{0.493}$$

$$\boxed{m = 0.207 \ kg/s}$$

7.

Steam at 20 bar and 250°c enters a group of Convergent-divergent nozzles. The back up pressure of nozzle is 0.07 bar. Neglect the losses in convergent part. Assume a loss 10% of enthalpy drop available in the divergent part. Find the number of nozzles required to discharge 13.6 kg/s. The throat area of each nozzle is 3.97 cm². Also Determine area of exit of each nozzle.
Assume Critical pr ratio 0.546

Given data

$P_1 = 20$ bar $P_r = 0.546$

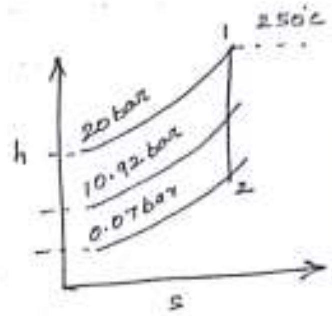
$T_1 = 250°c$

$P_2 = 0.07$ bar

$m = 13.6$ kg/sec

$\eta = 90\%$

Throat area = 3.97 cm^2.



To find

(i) no of nozzles

(ii) Throat area at the exit.

Formula

(i) Exit area of nozzle $A_2 = \frac{(m) \times v_2}{V_2}$ $V_2 = \sqrt{2000(h_1 - h_2)\eta}$

(ii) Mass flow rate of steam/nozzle = $m = \frac{A_t \times V_t}{v_t}$

(iii) No of nozzle required = $\frac{\text{Total mass flow rate}}{m}$

(iv) $V_t = \sqrt{2000(h_1 - h_t)}$

Solution

Properties of steam (from mollier diagram) at 20 bar and 250°C

$h_1 = 2900$ kJ/kg

The process is isentropic. from $h_1 = 2900$ kJ/kg draw a vertical line in the Mollier diagram upto 0.07 bar pressure line.

$h_2 = 2030$ kJ/kg

$v_2 = 15.9313 \text{ m}^3/\text{kg}$

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$\frac{P_t}{P_1} = 0.546$

∴ Throat Pressure $P_t = P_1 \times 0.546$

$= 20 \times 0.546$

$= 10.92$ bar

The expansion is isentropic from $h_1 = 2900$ kJ/kg. draw vertical line in the Mollier diagram upto 10.92 bar pressure line. Now note the following values at that point

$v_t = 0.177213$ m³/kg

$h_t = 2780$ kJ/kg

$V_t = \sqrt{2000\,(h_1 - h_t)} = \sqrt{2000\,(2900 - 2780)}$

$V_t = 489.9$ m/sec

Velocity of steam at exit

$V_2 = \sqrt{2000\,(h_t - h_2)\times\eta} = \sqrt{2000(2780 - 2030)\times 0.9}$

$= 1161.895$ m/s.

i) Mass flow rate of steam / nozzle

$m = \frac{A_t \times V_t}{v_t} = \frac{3.97\times10^{-4} \times 489.9}{0.177213}$

$m = 1.0975$ kg/s

(ii) No of nozzle required $= \frac{\text{Total mass flowrate}}{m}$

$= \frac{13.6}{1.0975} = 12.39 \simeq 12$

iii) Exit area of nozzle $A_2 = \frac{m \times v_2}{V_2}$

$= \frac{1.0975 \times 15.9313}{1161.895}$

$= 150.48 \times 10^{-4}$ m²

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ME8531 – Thermal Engineering

Exam Preparatory Class

Unit 3 – Steam and Gas Turbine

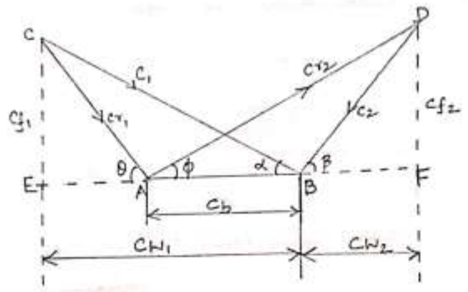
Part - A

1. **What are the principles of impulse and reaction turbines?**
   In impulse turbines, the high-velocity jet of steam, which is obtained, from the nozzle impinges on blades fixed on a rotor. The blades change the direction of the steam flow without changing its pressure. It causes the change in momentum and the force developed drives the turbine rotor. In reaction turbines, there is no sudden pressure drop. There is a gradual pressure drop and it takes continuously place over the fixed and moving blades. A number of wheels are fixed to the rotating shaft. Fixed guideways are provided in between such pair of rotating wheels.
2. **What does the compounding of steam turbines mean?**
   Compounding is a method of absorbing the jet velocity in stages when the steam flows over moving blades
3. **Explain the need of compounding in steam turbine.**
   In a simple impulse turbine, the expansion of steam from the boiler pressure to condenser pressure takes place in a single stage turbine. The velocity of steam at the exit of the turbine is very high. Hence, there is a considerable loss of kinetic energy (i.e. about 10 to 12%). In addition, the speed of the rotor is very high (i.e up to 30000rpm). There are several methods of reducing this speed to lower value. Compounding is a method of absorbing the jet velocity in stages when the steam flows over moving blades.
4. **What is blading efficiency?**
   Blade efficiency is defined as the ratio between work done on the blade and energy supplied to the blade.
   ηb = Work done on the blade / Energy supplied to the blade = $2U (V_{w1} + V_{w2}) / V_1^2$
5. **Define the degree of reaction.**
   It is defined as the ratio of isentropic heat drop in moving blades to isentropic heat drop in the entire stage of the reaction turbine.

$$R = \frac{\text{Enthalpy drop in moving blades}}{\text{Enthalpy drop in the entire stage}} = \frac{h_2 - h_3}{h_1 - h_3}$$

Part – B

Combined Velocity diagram.



Work done on blades of Impulse Turbine

Tangential force on the wheel = mass of steam × Acceleration

= mass of steam/s × change of Velocity

Driving force $F_x = m \times (C_{W_1} + C_{W_2})$

∴ Work done on blade/s = Force × Distance traveled

$= m \times (C_{W_1} + C_{W_2}) \times C_b$

∴ Power developed/wheel $P = m \times (C_{W_1} + C_{W_2}) \times C_b$

Available energy of the steam entering the blade

$$= \frac{m C_1^2}{2}$$

Blade efficiency $\eta_b = \dfrac{\text{Work done on the blade}}{\text{Energy supplied to the blade}}$

$$= \frac{m (C_{W_1} + C_{W_2}) C_b}{\frac{m C_1^2}{2}} = \frac{2 C_b (C_{W_1} + C_{W_2})}{C_1^2}$$

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Stage efficiency $\eta_{stage} = \dfrac{\text{Work done on the blade}}{\text{Total energy supplied / stage}}$

$$= \frac{c_b (C_{W_1} + C_{W_2})}{h_1 - h_2}$$

η_{stage} = Blade efficiency × Nozzle efficiency

Axial force on wheel = Mass of steam × Acceleration in axial direction

= Mass of steam/s × change in axial velocities

Axial Thrust $F_y = m(C_{f_1} - C_{f_2})$

Effect of friction on velocity diagram:

Friction factor $k = \dfrac{C_{r_2}}{C_{r_1}}$

$AC \neq AD$

$C_{r_2} \neq C_{r_1}$

Heat due to blade friction = Loss of kinetic energy during flow over blades

$$= \frac{m(C_{r_1}^2 - C_{r_2}^2)}{2}$$

Velocity Diagram for reaction Turbine

Tangential force $F_x = m(C_{W_1} + C_{W_2}) C_b$

Work done per kg of steam $W = m C_b (C_{W_1} + C_{W_2})$

Power Produced by the turbine $P = m(C_{W_1} + C_{W_2}) C_b$

Axial Thrust on the wheel $F_y = m(C_{f_1} - C_{f_2})$

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1.

The following data refer to a single stage impulse turbine. Isentropic nozzle entropy drop = 200 kJ/kg. Nozzle efficiency = 90%. Nozzle angle = 25°. Ratio of blade speed to whirl component of steam speed = 0.5. Blade coefficient = 0.9. The velocity of steam entering the nozzle 30 m/sec. Find (i) The blade angle at the inlet and outlet if the steam enters the blade without shock and leaves the blade in the axial direction (ii) Blade efficiency (iii) power developed and (iv) Axial thrust if the steam flow rate is 10 kg/s.

Given data

h_e = 200 kJ/kg

η_N = 90%

nozzle angle: α

V_b = blade speed, $\frac{V_b}{V_W} = 0.5$

V_W = Whirl speed

blade co-eff $\frac{V_{r2}}{V_{r1}} = 0.9$

V_1 = Velocity of steam entering the nozzle, V_1 = 30 m/sec.

$V_2 = V_{f2}$

$V_{W2} = 0$

$\beta = 90°$

Actual enthalpy drop = $h_i - h_e$

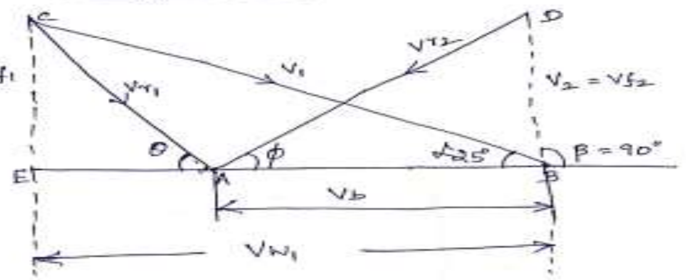
Formulas

(i) power developed $P = m(V_{w1} + V_{w2}) \times V_b$

(ii) Blade efficiency $\eta_b = \frac{m(V_{w1}+V_{w2}) \times V_b}{m \times \frac{1}{2}V^2}$

(iii) Axial Thrust $F_y = m(V_{f1} - V_{f2})$

Velocity triangle



Actual enthalpy drop $h_i - h_e = (h_i - h_e) \times \eta_N$
$= 200 \times 0.9$
$= 180$ kJ/kg.
$= 180 \times 10^3$ J/kg

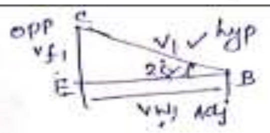
Exit velocity nozzle $V_e = \sqrt{2(h_i - h_e) + V_1^2}$

$= \sqrt{2 \times 180 \times 10^3 + 30^2}$

$V_e = 600.75 \text{ m/s}$

$V_e = V_1 = 600.75 \text{ m/sec}$

From Δ BCE



$\cos\theta = \frac{Adj}{hyp}$

$\cos\theta = \frac{V_{W1}}{V_1}$

$V_{W1} = \cos\theta \cdot V_1$

$V_{W1} = V_1 \cos 25°$

$= 600.75 \cos 25° = 544.46$

$V_{f1} = V_1 \sin 25°$

$= 600.75 \sin 25° = 253.89$

$\sin\theta = \frac{opp}{hyp}$

$\sin\theta = \frac{V_{f1}}{V_1}$

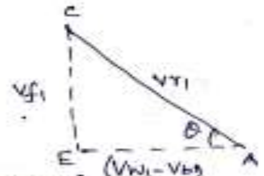
$V_{f1} = \sin\theta \cdot V_1$

$\frac{V_b}{V_{W1}} = 0.5$

$V_b = 0.5\, V_{W1}$

$= 272.23 \text{ m/sec.}$

From Δ ACE



$V_{r1} = \sqrt{V_{f1}^2 + (V_{W1} - V_b)^2}$

$= \sqrt{(253.89)^2 + (544.46 - 272.23)^2}$

$V_{r1} = 372.25 \text{ m/sec.}$

$\tan\theta = \frac{V_{f1}}{V_{W1} - V_b} = \frac{253.89}{544.46 - 272.23}$

$\theta = 43°$

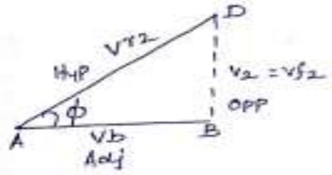
But

$V_{r2} = 0.9\, V_{r1}$

$= 0.9 \times 372.25 = 335.03 \text{ m/sec}$

$V_{r2} = 335.03 \text{ m/sec}$

From Δ ADB $\cos\phi$



$\cos\phi = \frac{Adj}{Hyp}$

$= \frac{AB}{AD} = \frac{V_b}{V_{r2}}$

$= \frac{272.23}{372.25}$

$\phi = 35° 39'$

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$V_2 = \sqrt{Vr^2 - Vb^2}$

$= \sqrt{335.03^2 - 272.03^2}$

$V_{f2} = V_2 = 195.28$ m/sec

Power developed $P = m\,(V_{w1} + V_{w2}) \times V_b$

m assume 1

$= 1\,(544.46 + 0) \times 272.23$

$P = 148.21$ kW.

Blade $\eta = \dfrac{m\,(V_{w1} + V_{w2})\,V_b}{m \times \frac{1}{2} V_1^2}$

$= \dfrac{(544.46 + 0)\,272.23}{\frac{1}{2} \times (600.75)^2}$

$= \dfrac{148218.3}{180.45 \times 10^3} = 82\,\%$

Axial Thrust $F_y = m\,(V_{f1} - V_{f2})$

$= 1\,(253.89 - 195.28)$

2.

The velocity of steam leaving the nozzle of an impulse turbine is 1000 m/s and the nozzle angle is 20°. The blade velocity is 350 m/sec and the blade velocity co-efficient is 0.85. Assuming no losses due to shock at inlet calculate for a mass flow of 1.5 kg/sec and symmetrical blading (a) blade inlet angle (b) driving force on the wheel (c) axial thrust on the wheel (d) Power developed by the turbine

Given data.

$C_1 = 1000$ m/sec

$\alpha = 20°$

$C_b = 350$ m/sec

$K = 0.85$

$m = 1.5$ kg/sec

For symmetrical blading $\theta = \phi$

Solution

From $\triangle$ EBC $\quad C_{w1} = C_1 \cos 20° = 1000 \cos 20° = 939.69$ m/sec

$C_{f1} = C_1 \sin 20° = 1000 \sin 20° = 342.02$ m/sec

$\tan\theta = \dfrac{C_{f1}}{C_{w1} - C_b} = \dfrac{342.02}{939.68 - 350}$

$\theta = 30° 7'$

From $\triangle$ EAC $\quad C_{r1} = \sqrt{C_{f1}^2 + (C_{w1} - C_b)^2}$

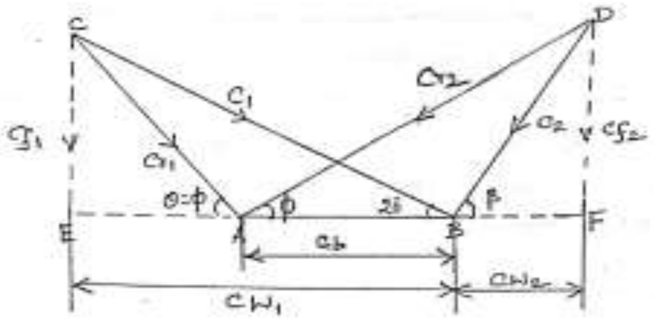
$= \sqrt{(342.02)^2 + (939.69 - 350)^2}$

$= 681.7\ m/sec$

But $K = \frac{Cr_2}{Cr_1} = 0.85$

$\therefore Cr_2 = 0.85 Cr_1$

$= 0.85 \times 681.7 = 579.45\ m/sec$



For symmetrical blading

$\theta = \phi = 30°7'$

From Δ DAF $\quad C_{f2} = Cr_2 \sin\phi = 579.44 \sin 30°7'$

$= 290.79\ m/sec.$

lly

$C_b + C_{w2} = Cr_2 \cos\phi$

$350 + C_{w2} = 579.45 \cos 30°7'$

$\therefore C_{w2} = 151.76\ m/sec.$

$\therefore$ From Δ BDF $\quad C_2 = \sqrt{C_{f2}^2 + C_{w2}^2} = \sqrt{(290.79)^2 + (151.76)^2}$

$= 328\ m/sec$

Driving force $\quad F_x = m(C_{w1} + C_{w2})$

$= 1.5\ (939.69 + 151.76)$

$= 1637.18\ N$

Axial Thrust $\quad F_y = m(C_{f1} - C_{f2})$

$= 1.5\ (342.02 - 290.79)$

$= 76.85\ N$

Power developed $\quad P = m\,C_b\,(C_{w1} + C_{w2})$

$= m\,C_b \times (C_{w1} + C_{w2}) = F_x \times C_b$

$= 1637.18 \times 350 = 573.01\ kW$

$P = 573.01\ kW$

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3.

Problem no: 3.

Saturated steam at 8 bar is supplied to a single stage steam turbine through a convergent divergent steam nozzle. The nozzle angle is 20° and the mean blade speed is 450m/sec. The steam pressure leaving the nozzle is 1 bar. Find the (a) best angle if the blades are equiangular, (b) maximum power developed by the turbine and (c) stage efficiency if the number of nozzles used are 5 and area at the throat of each nozzle is 0.4 cm². Assume nozzle efficiency of 95% and the blade friction coefficient of 0.85.

Given data.

$P_1 = 8$ bar

$\alpha = 20°$

$C_b = 450$ m/sec

$P_e = 1$ bar

$\theta = \phi$

$n = 5$

Area at throat $A = 0.4\ cm^2 = 4\times10^{-5} m^2$

$\eta = 95\%$

$\frac{C_{r2}}{C_{r1}} = 0.85$

Sol

From saturated steam table, corresponding to $P_1 = 8$ bar, the values of enthalpy and entropy are read.

$h_1 = 2767.4$ kJ/kg $\quad S_1 = 6.66$ kJ/kg K

$\because h_1 = h_g,\ S_1 = S_g$

Corresponding to 1 bar, the values of parameters

$h_{fe} = 417.5$ kJ/kg $\quad h_{fge} = 2257.9$ kJ/kg

$S_{fe} = 1.303$ kJ/kg K $\quad S_{fge} = 6.057$ kJ/kg K

Since the expansion between inlet and exit of the nozzle is isentropic

$S_i = S_e = 6.66$ kJ/kg K

$S_e = S_{fe} + x_e S_{fge}$

$6.66 = 1.303 + x_e \times 6.057$

$x_e = 0.88$

$H_e = h_{fe} + x_e h_{fge}$

$= 417.5 + 0.88 \times 2257.9$

$h_e = 2404.45$ kJ/kg

Exit velocity of steam from the nozzle

$C_e = \sqrt{2000(h_i - h_e)\times\eta}$

$= \sqrt{2000\times(2767.4 - 2404.45)\times0.95}$

$C_e = 830.43$ m/sec

Exit velocity of nozzle is same as the inlet velocity of steam entering the turbine.

$C_1 = C_e = 830.43$ m/sec.

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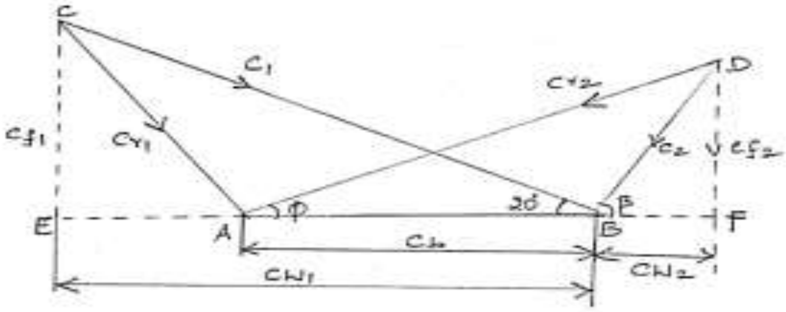

From Δ EBC $\quad C_{W1} = C_1 \cos\alpha = 830.43 \cos 20^\circ$

$= 780.35 \text{ m/sec}$

$C_{f1} = C_1 \sin\alpha = 830.43 \sin 20^\circ$

$= 284.02 \text{ m/sec}$

From Δ EAC $\quad \tan\theta = \dfrac{C_{f1}}{C_{W1} - C_b} = \dfrac{284.02}{780.35 - 450}$

$\theta = 40^\circ 4'$

$C_{r1} = \sqrt{C_{f1}^2 + (C_{W1} - C_b)^2}$

$= \sqrt{(284.02)^2 + (780.35 - 450)^2}$

$= 435.66 \text{ m/sec}$

But $\dfrac{C_{r2}}{C_{r1}} = 0.85$

$\therefore C_{r2} = 0.85 \times 435.66 = 370.31 \text{ m/sec}$

From Δ AFD

$C_{f2} = C_{r2} \sin\phi$

$= 370.31 \sin 40^\circ 11' = 241.56 \text{ m/sec}$

$C_b + C_{W2} = C_{r2} \cos\phi$

$= 370.31 \cos 40^\circ 11'$

$= 282.88 \text{ m/sec}.$

$\therefore C_{W2} = 282.88 - 450 = -167.12 \text{ m/sec}.$

Both velocity and specific volume at the throat can be found to calculate mass flow rate of steam.

$$\frac{P_t}{P_i} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$$

For saturated steam

$n = 1.135$

$$\frac{P_t}{P_i} = \left(\frac{2}{1.135+1}\right)^{\frac{1.135}{1.135-1}}$$

$P_t = 0.577 \times 8 = 4.62 \text{ bar}.$

Corresponding to $P_t = 4.62$ bar from steam table

$h_{f1} = 627.38 \text{ kJ/kg} \qquad h_{fg1} = 2116.7 \text{ kJ/kg}$

$S_{f1} = 1.8306 \text{ kJ/kg K} \qquad S_{fg1} = 5.015 \text{ kJ/kg K}$

$V_{f1} = 0.00109 \text{ m}^3\text{/kg} \qquad V_{g1} = 0.4036 \text{ m}^3\text{/kg}$

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Since the expansion between inlet and throat of the nozzle is isentropic.

$$s_1 = s_t = 6.66 \text{ kJ/kg K}$$

$$s_t = s_{ft} + x_t s_{fgt}$$

$$6.66 = 1.8... + x_t \times 5.015$$

$$x_t = 0.96$$

$$h_t = h_{ft} + x_t h_{fgt}$$

$$= 627.24 + 0.96 \times 2116.7$$

$$h_t = 2659.41 \text{ kJ/kg}$$

Velocity of steam at throat of the nozzle

$$c_t = \sqrt{2000(h_1 - h_t) \times \eta_N}$$

$$= \sqrt{2000(2767.4 - 2659.41) \times 0.95}$$

$$= 452.97 \text{ m/sec.}$$

Specific volume of steam at throat of the nozzle

$$v_t = x_t v_{gt}$$

$$= 0.96 \times 0.40304$$

$$= 0.388 \text{ m}^3/\text{kg}$$

∴ Mass flow rate of steam through the nozzle

$$m = \frac{A_t c_t}{v_t} = \frac{4 \times 10^{-5} \times 452.97}{0.388}$$

$$= 0.047 \text{ kg/sec.}$$

Total mass of steam $m = 0.047 \times$ Number of nozzles

$$= 0.047 \times 5$$

$$= 0.235 \text{ kg/sec.}$$

Maximum power developed in the turbine $\Big\}$ $P = m(c_{w1} + c_{w2}) \times c_b$

$$P = 0.235(780.35 - 167.12) \times 450$$

$$= 64.85 \text{ kW}$$

Blade efficiency $\eta_b = \dfrac{2(c_{w1} + c_{w2})c_b}{c_1^2}$

$$= \frac{2 \times (780.35 + 167.12) \times 450}{(870.43)^2}$$

$$= 0.8003 = 80.03\%$$

Stage efficiency $\eta_{stage} = \eta_b \times \eta_N$

$$= 80.03 \times 0.95$$

$$= 76.03\%$$

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4.

300 kg/min of steam (2 bar, 0.08 dry) flows through a given stage of reaction turbine. The exit angles of fixed blades as well as moving blades are 20° and 3.68 kW of power is developed. If the rotor speed is 360 rpm and tip leakage is 5 percent, calculate the mean drum diameter and the blade height. The axial flow velocity is 0.8 times the blade velocity. (May 12)

Given data:

$m = 300\ kg/min = 5\ kg/sec$

$P = 2\ bar$

$x = 0.08$

$\alpha = \phi = 20^\circ$

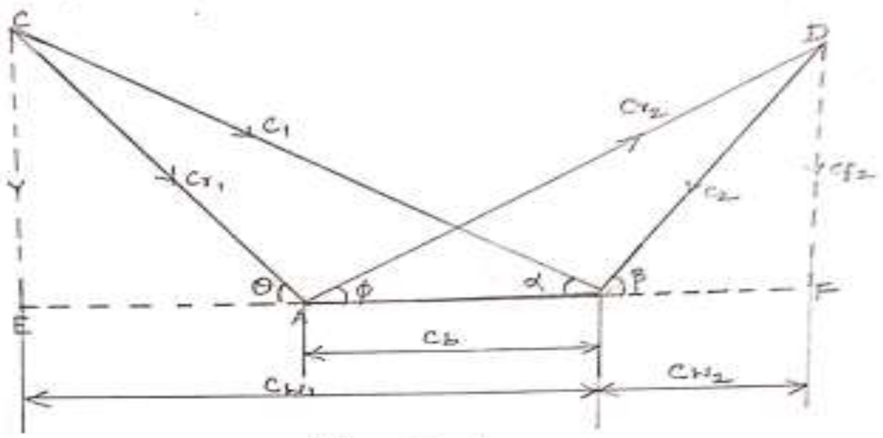
$P = 3.68\ kW = 3680\ W$

$N = 360\ rpm$

Tip leakage $= 5\%$

$\frac{C_{f1}}{C_b} = \frac{C_{f2}}{C_b} = 0.8$

From the velocity diagram by considering ΔEBC



Velocity diagram

Ily from ΔDAF

$$\tan\phi = \frac{C_{f2}}{AF} = \frac{C_{f2}}{C_b + C_{w2}}$$

$$C_b + C_{w2} = \frac{C_{f2}}{\tan\phi} = \frac{C_{f2}}{\tan 20} = 2.75\,C_{f2}$$

$$C_b + C_{w2} = 2.75\,C_{f1} \qquad \therefore C_{f2} = C_{f1} \quad [C_{f1} = 0.34\,C_1]$$

$$0.43C_1 + C_{w2} = 2.75 \times 0.34C_1$$

$$0.43C_1 + C_{w2} = 0.935C_1$$

$$C_{w2} = 0.505C_1$$

Power developed $P = m(C_{w1} + C_{w2})C_b$

$$3680 = 5(0.94C_1 + 0.505C_1)\,0.43C_1$$

$$C_1 = 34.42\ m/sec$$

$$C_b = 0.43C_1 = 0.43 \times 34.42 = 14.8\ m/sec$$

$$C_{f1} = C_{f2} = 0.8\,C_b$$

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$= 0.8 \times 14.8 = 11.84 \, m/sec$

$$C_b = \frac{\pi D_m N}{60}$$

$$14.8 = \frac{\pi \times D_m \times 360}{60}$$

Mean drum diameter $D_m = 0.79m$.

Actual mass of steam used by considering tip leakage

$M = 5 - (5 \times 0.05) = 4.75 \, m/sec$.

From steam table at $P_1 = 2$ bar

$V_g = V_s = 0.8854 \, m^3/kg$

Mass of steam flow /sec

$$M = \frac{\pi D_m h C_{f2}}{x V_s}$$

$$4.75 = \frac{\pi \times 0.79 \times h \times 11.84}{0.8 \times 0.8854}$$

Height of the blade $h = 0.1145 m = 114.5 mm$.

5.

Problem no: 6.

The following particulars refer to a two-row velocity compounded impulse wheel which forms the first stage of a combination turbine.

Stage velocity at nozzle outlet = 630 m/sec

Blade velocity = 125 m/sec

Nozzle angle = 16°

outlet angle, first row of moving blades = 18°

outlet angle, fixed guide blades = 22°

outlet angle, second row of moving blades = 36°

Steam flow rate = 2.6 kg/sec.

The ratio of the relative velocity at outlet to that at inlet is 0.85 for all blades. Determine (a) velocity of whirl (b) tangential thrust on the blades. (c) axial thrust on the blades, (d) power developed (e) blading efficiency.

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Given data:

$C_1 = 630$ m/sec

$C_b = 125$ m/sec

$\alpha_1 = 16°$

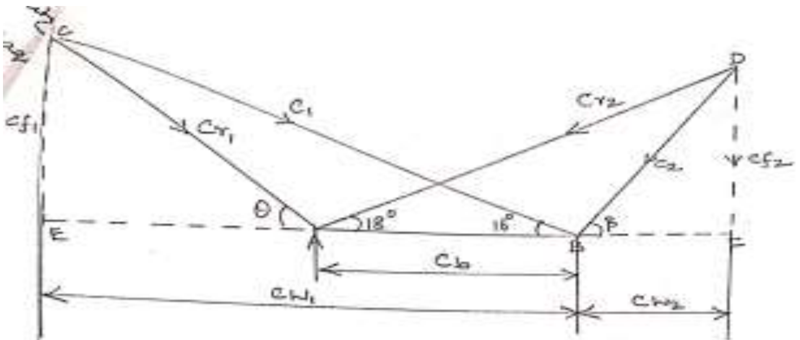
$\phi_1 = 18°$

$\alpha_2 = 22°$

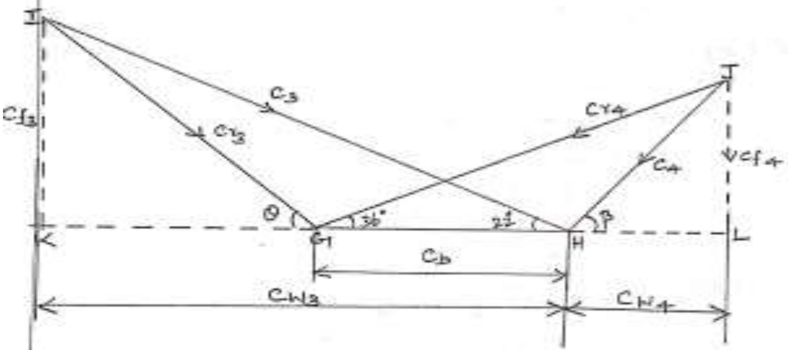
$\phi_2 = 36°$

$m = 2.6$ kg/sec

$\frac{C_{r2}}{C_{r1}} = \frac{C_3}{C_2} = \frac{C_{r4}}{C_{r3}} = 0.85$



Velocity diagram for the first stage.



Velocity diagram for the Second stage

From Δ EBC

$C_{w1} = C_1 \cos 16°$

$= 630 \cos 16° = 605.6$ m/sec

$C_{f1} = C_1 \sin 16°$

$= 630 \sin 16° = 173.65$ m/sec

From Δ ACE

$C_{r1} = \sqrt{C_{f1}^2 + (C_{w1} - C_b)^2}$

$= \sqrt{173.65^2 + (605.6 - 125)^2}$

$= 511.01$ m/sec.

But $\frac{C_{r2}}{C_{r1}} = 0.85$

$\therefore C_{r2} = 0.85 \times 511.01 = 434.36$ m/sec

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From ΔDAF

$$C_b + C_{W_2} = C_{r_2} \cos 18^\circ$$

$$125 + C_{W_2} = 434.36 \cos 18^\circ$$

$$C_{W_2} = 288.1 \text{ m/sec}$$

$$C_{f_2} = C_{r_2} \sin 18^\circ$$

$$= 434.36 \sin 18^\circ$$

$$= 134.23 \text{ m/sec}$$

From ΔDBF $\quad C_2 = \sqrt{C_{f_2}^2 + C_{W}^2}$

$$= \sqrt{134.23^2 + 288.1^2}$$

$$= 317.84 \text{ m/sec}$$

But $\frac{C_3}{C_2} = 0.85$

$$C_3 = 0.85 \times 317.84 = 270.16 \text{ m/sec}$$

From ΔHIK

$$C_{W_3} = C_3 \cos 22^\circ$$

$$= 270.16 \cos 22^\circ$$

$$= 250.49 \text{ m/sec}$$

$$C_{f_3} = C_3 \sin 22^\circ = 270.16 \sin 22^\circ$$

$$= 101.2 \text{ m/sec}$$

$$\therefore C_{r_3} = \sqrt{C_{f_3}^2 + (C_{W_3} - C_b)^2}$$

$$= \sqrt{(101.2)^2 + (250.49 - 125)^2}$$

$$= 161.21 \text{ m/sec}$$

$$\frac{C_{r_4}}{C_{r_3}} = 0.85$$

$$\therefore C_{r_4} = 0.85 \times 161.21 = 137.03 \text{ m/sec}$$

From ΔGJL

$$C_b + C_{W_4} = C_{r_4} \cos 36^\circ$$

$$125 + C_{W_4} = 137.03 \cos 36^\circ$$

$$\therefore C_{W_4} = 137.03 \cos 36^\circ - 125$$

$$= -14.14 \text{ m/sec}$$

$$C_{f_4} = C_{r_4} \sin 36^\circ$$

$$= 137.03 \sin 36^\circ$$

$$= 80.54 \text{ m/sec}$$

Total whirl velocity $\quad C_W = \left[C_{W_1} + C_{W_2}\right]_{\text{stage 1}} + \left[C_{W_3} + C_{W_4}\right]_{\text{stage 2}}$

$$= 605.6 + 288.1 + 250.49 - 14.14$$

$$= 1130.05 \text{ m/sec}$$

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Tangential thrust $F_x = m\left[(C_{w1}+C_{w2})_{stage1} + (C_{w3}+C_{w4})_{stage2}\right]$

$= 2.6 \times 1130.05$

$= 2938.13\ N$ or $2.94\ kN$

Axial Thrust $F_y = m\left[(C_{f1}-C_{f2})_{stage1} + (C_{f3}-C_{f4})_{stage2}\right]$

$= 2.6\left[(173.65-124.23)+(101.2-89.54)\right]$

$= 156.21\ N$

Power developed $P = m\left[(C_{w1}+C_{w2})_{stage1} + (C_{w3}+C_{w4})_{stage2}\right]$

$= 2938.13 \times 125$

$= 367266.25\ W$

$= 367.27\ kW$

Total energy supplied

$= (\text{Energy supplied})_{stage1} + (\text{Energy supplied})_{stage2}$

$= m\left[\frac{1}{2}C_1^2 + \frac{1}{2}C_3^2\right]$

$= 2.6\left[\frac{1}{2}630^2 + \frac{1}{2}270.16^2\right]$

$= 610.85\ kW$

∴ Blading efficiency

$\eta_b = \frac{\text{Power developed}}{\text{Energy supplied}}$

$= \frac{367.27}{610.85}$

$= 0.6012 = 60.12\%$

ME 8493 THERMAL ENGINEERING - I - 2 MARKS – UNIT 4,5

UNIT IV INTERNAL COMBUSTION ENGINE PERFORMANCE AND SYSTEMS

1. **What are the advantages of MPFI diagram? (May -17)**

   (1) More uniform A/F mixture will be supplied to each cylinder, hence the difference in power developed in each cylinder is minimum.

   (2) No need to crank the engine twice or thrice in case of cold starting as happens in the carburetor system.

   (3) Immediate response, in case of sudden acceleration / deceleration.

   (4) Since the engine is controlled by ECM* (Engine Control Module), more accurate amount of A/F mixture will be supplied.

2. **Write the important requirements of fuel injection system (Nov 2015)**
   - The beginning as well as the end of injection should takes place sharply.
   - The injection of fuel should occur at the correct movement, correct rate and correct quantity as required by the varying engine load.
   - The fuel should be injected in a finely atomized condition and should be uniformly distributed inside the combustion chamber.

3. **State the purpose of thermostat in an engine cooling system (Nov 2015)**

   A thermostat is used in the water cooling system to regulate the circulation of water in system to maintain the normal working temperature of the engine parts during the different operating conditions.

4. **What is the effect of supercharging on the power output of the IC engine? (May 2013)**

   Supercharging increases the power output of the engine due to the increased induction of air.This makes more oxygen available for combustion.

5. **What is the antifreeze solutions used in the cooling systems (Nov -16)**
   - Water and ethylene glycol
   - Water and propylene glycol

6. **What is meant by motoring test? (Nov -16)**

   Motoring test determine the friction power at conditions very near to the actual operating temperatures at the test speed and load.

7. **Use of morse test? (May -19)**

   The purpose of Morse test is to obtain the approximate indicated power of a Multi cylinder engine. It consist of running the engine against the dynamo-meter at a particular speed, cutting out the firing of each cylinder in turn and noting the fall in BP each time while maintaining the speed constant.

8. **Functions of lubrication test? (May -19)**

   Lubricant testing and oil condition monitoring provides quality and condition assessment of lubricants and oils used in engines and other expensive machinery and systems. Lubricant quality control testing includes lubricant analysis programs for large, high-value engines and drive-trains, turbines, ships, trains, generators, offshore platforms, and other highly valuable machinery. lubricant quality testing helps clients minimize costly down-time and repairs by alerting the customer to early, developing problems before they become big, expensive, and costly failures.

9. Define the term brake power. (May 2014)

The power developed at the output shaft (crank shaft) is called the brake power.

B.P=2πNT

N=speed in rpm

T=Torque in KN.m

10. Differentiate between the supercharging and turbo charging.

Supercharger and turbocharger both are used for increasing the volumetric efficiency of engine through increasing in density of intake air and this lead to increase power of engine that is power booster for engine. This is possible with the help of compressor. But,

In supercharger engine:

1. Compressor get drive from engine and this increase load on engine.
2. Wastage of engine power.
3. Same time supercharge engine are more prone to knocking this damage engine internal parts

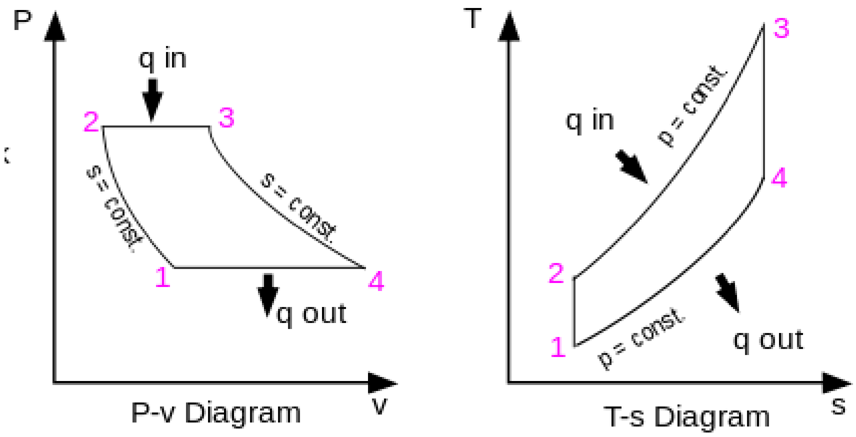
Where as

In turbocharger engine :

1. Compressor get drive from turbine and this turbine gets drive from exhaust gases so no extra load on engine.
2. No wastage of engine power
3. Same time turbocharger engine are less prone to knocking because inter cooler used with turbocharger which maintain intake air temperature.

UNIT V GAS TURBINES

1. Draw brayton cycle in T-S and P-V planes. (May -15, 17, Nov -17)



2. What are the applications of gas turbine power plants? (A/M 18)

(a) Peak load plants: gas turbine power plants are used to supply peak loads in steam or hydro plants
(b) Standby plants: They are used as Standby plants for hydro – electric plants
(c) They are used in industries for driving compressors & electric generators
(d) They are used in Jet planes, aircrafts & ships.

3. What are the advantages of closed cycle gas turbine over open cycle gas turbine? (N/D 18)

Merits:

(i) Efficiency is same throughout the cycle
(ii)The turbine blades do not wear away since the combustion is external
(iii)Starting of the plant is easy
(iv) Low quality fuel can be used since the combustion is external.

Demerits:

(i) A separate pre cooler arrangement is necessary
(ii)The size & weight are more
(iii)Initial cost & maintenance cost are more
(iv)Combustion efficiency is less.

4. What is reheating and regeneration of gas turbine? (N/D 14, 16)

If the dryness fraction of steam leaving the turbine is less than 0.88, then, corrosion and erosion of turbine blades occur. To avoid this situation, reheat is used. In the simple open cycle system the heat of the turbine exhaust gases goes as waste. To make use of this heat a regenerator is provided. In the regenerator the heat of the hot exhaust gases from the turbine is used to preheat the air entering the combustion chamber.

5. **Why power generation by gas turbine is more attractive than other turbines? (N/D 15)**

Gas turbine power plant is attractive because of their ability to quickly ramp up power production

6. **What are the effects of introducing regeneration in the basic gas turbine cycle?**

- The fuel economy is improved the quantity of the fuel required per unit mass of air is less.
- The work output from the turbine, work required to the compressor will not change.
- Pressure drop will occur during regeneration.
- It increases the thermal efficiency when the low pressure ratio reduces.

7. **List down the various processes of the Brayton cycle. (A/M 17)**

- Isentropic compression
- Constant pressure heat addition
- Isentropic expansion
- Constant pressure heat rejection

8. **What fuel does a gas turbine use? (May -19)**

Gas turbines operate on natural gas, synthetic gas, landfill gas, and fuel oils. Plants typically operate on gaseous fuel with a stored liquid fuel for backup to obtain the less expensive, interruptible rate for natural gas

9. **Effect of reheat on the brayton efficiency cycle? And why? (May -19)**

Efficiency was improved with a Reheat Stage on the brayton cycle. To bring the average temperature at which we add heat to the cycle closer to the peak temperature, we can add a reheat stage to the cycle.

10. **What are the factors influencing ideal brayton cycle efficiency? (May -19)**

Key factors affecting the Brayton cycle efficiency includes the turbine inlet temperature, compressor and turbine adiabatic efficiencies, recuperator effectiveness and cycle fractional pressure loss.

ME 8493 THERMAL ENGINEERING – I - PART B & C– UNIT 4,5

UNIT IV INTERNAL COMBUSTION ENGINE PERFORMANCE AND SYSTEMS

1. A four cylinder four stroke oil engine 1o cm in dia and 15 cm in stroke develops a torque of 185 Nm at 2000 rpm. The oil consumption is 14.5 lit/hr. the specific gravity of oil is 0.82 and calorific value of oil is 42000 KJ/Kg. If the Imep taken from indicated diagram is 6.7 bar find I. Mechanical efficiency II. Break thermal efficiency III. Break mean effective pressure IV. Specific fuel consumption in litres on break power basis. **(Concept: May - 16, 17, 18, Nov – 14)** (**Nov – 15**)

2. A six cylinder four stroke engine of 340mm bore and 390 mm stroke was tested and the following information: Engine speed = 360 rpm; Brake power=180 kW;mf= 0.77 kg/min, calorific value= 45000kJ/kg; I.M.E.P = 3.8 bar.Flow of cooling water=6.4 kg/min with a temperature rise of 9C. Draw the heat balance for the engine. **(Nov - 15)**

3. Explain the 3 types of Ignition system. **(May - 18, Nov – 17, 18)**

4. Explain the lubrication system I.C Engine. **(May - 19, Nov – 16)**

5. Explain the function of a fuel injector with a simple sketch. **(May - 16, Nov – 14, 16, 17)**

6. Briefly discuss about MPFI. **(May - 18)**

7. Explain the functions of CRDI with neat sketch. **(May - 19)**

8. Explain the cooling system in I.C Engine.

UNIT V GAS TURBINES

1. Drive the expression for air standard efficiency of Brayton cycle in terms of pressure ratio. **(May - 19)**

2. Briefly discuss about the improvisation of Gas Turbine. **(May - 19)**

3. In a gas turbine plant working on the Brayton cycle the air at the inlet is at 27 ^{o}C, 0.1 MPa. The pressure ratio is 6.25 and the maximum temperature is 800^{0}C. the turbine and compressor efficiencies are each 80%.Find, (a) Compressor work per kg of air, (b) Turbine work per kg of air, (c) Heat supplied per kg of air, (d) Cycle efficiency, and (e) Turbine exhaust temperature. **(Concept: May - 15, 19, Nov – 14, 18) (Nov - 16)**

4. Air enters the compressor of a gas turbine plant operating on Brayton cycle at 1 bar, 270C. The pressure ratio in the cycle is 6. If WT = 2.5 WC. Calculate maximum temperature and cycle efficiency.(Apr - 15)

5. In a gas turbine plant working on the brayton cycle the air at the inlet is at 25 o C, 1 bar. The maximum pressure and temperature are limited to 3 bar and 6500C. Determine heat supplied and heat rejected per kg of air, Cycle efficiency and work output. (Nov - 14)

6. Explain the working principle of open and closed cycle Gas turbine.

7. A gas turbine draws in air from atmosphere at 1 bar and 10°C and compresses it to 5 bar with an isentropic efficiency of 80%. The air is heated to 1200 K at constant pressure and then expanded through two stages in series back to 1 bar. The high pressure turbine is connected to the compressor and produces just enough power to drive it. The low pressure stage is connected to an external load and produces 80 kW of power. The isentropic efficiency is 85% for both stages. Calculate the mass flow of air, the inter-stage pressure of the turbines and the thermal efficiency of the cycle. = 1.333.γ = 1.4 and for the turbines γFor the compressor The gas constant R is 0.287 kJ/kg K for both. Neglect the increase in mass due to the addition of fuel for burning.

8. What are the materials used in Gas turbines? Discuss in detail.

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Exam Preparatory Class

Unit 5 – Internal Combustion Engine and Auxiliary System

Part – A

1. **Define the term brake power**
   Brake power is the useful power available at the crankshaft. It is always lesser than the indicated power. The brake power of an IC is usually measured by means of brake mechanism.
2. **Mention different types of fuel injection systems in C.I. engines.**
   Air injection system Airless or solid injection Common rail system Individual pump system.
3. **The bore and stroke of a water-cooled, vertical, single-cylinder, four-stroke Diesel engine are 80 mm and 110 mm respectively and the torque is 23.5 Nm. Calculate the mean effective pressure of the engine.**
   Given Data: No. of cylinder, k =1 Speed, n= N/2 Bore, d = 80 mm Stroke, l = 110mm Torque, T = 23.5 Nm

   Solution

   Power of work done, $P = 2(NT/60$.

   $$P = 2(xNx23.5/60 \quad = 2.4597N$$

   $$P = \frac{Pm.l.a.n.k}{60}$$

   $$P = \frac{Pm.l.a(N\,l\,2).k}{60}$$

   $$2.459N = \frac{Pm \times 0.11 \times (/(4) \times (0.08)^2 \times (N/2) \times 1}{60}$$

   $$P_m = 534.098 \text{ kPa}$$

4. **Differentiate between SFC and TFC in engine performance**
   SFC means Specific Fuel Consumption, which is defined as the fuel consumed by the engine in kg for producing 1 kW-hr of power.
   TFC means Total Fuel Consumption, which is defined as the fuel consumed by the engine in kg for 1 hr operation.

5. **What are the characteristics or function of an efficient cooling system?**
   It reduces the friction between moving parts. 2. It reduces the wear and tear of the moving parts. 3. It minimizes the power loss due to friction. 4. It provides the cooling effect: During circulation, it carries heat from hot moving parts and delivers it to the surrounding through crankcase

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Part – B

1.

A two stroke two cylinder engine runs with speed of 3000 rpm and fuel consumption of 5 litres/hr. The fuel has specific gravity of 0.7 and air-fuel ratio is 19. The piston speed is 500 m/min and indicated mean effective pressure is 6 bar. The ambient conditions are 1.013 bar, 15°C. The volumetric efficiency is 0.7 and mechanical efficiency is 0.8. Determine brake power output considering R for gas = 0.287 kJ/kgK. (Take piston speed, m/min = 2 LN where L is stroke (m) and N is rpm)

GIVEN:

N=3000rpm, $m_f = 5\ \frac{lit}{hr}$, $\omega = 0.7$, $\frac{m_a}{m_f} = 19$, Piston Speed=500 m/min, $P_{IMEP} = 6$ bar, $P_1 = 1.013$bar,

$T_1 = 15°C$, $\eta_v = 0.7$, $\eta_{mech} = 0.8$, R = 0.287 kJ/kgK,

SOLUTION:

LENGTH OF STROKE:

$$\text{Piston Speed} = 2LN \Rightarrow 500 = 2 \times L \times 3000 \Rightarrow \mathbf{L = 0.0833m}$$

MASS FLOWRATE OF AIR:

$$\dot{m}_f = 5\ \frac{lit}{hr} \Rightarrow \dot{m}_f = 5 \times 0.7 \Rightarrow \dot{m}_f = 3.5\ \frac{kg}{hr} = 0.00972 kg/s$$

$$\frac{\dot{m}_a}{\dot{m}_f} = 19 \Rightarrow \dot{m}_a = 19 \times 0.00972 \Rightarrow \dot{m}_a = 0.0183\ kg/s$$

VOLUME FLOWRATE OF AIR:

$$P_aV_a = m_aRT_a \Rightarrow V_a = \frac{m_aRT_a}{P_a} \Rightarrow V_a = \frac{0.0183 \times 0.287 \times 288}{1.013 \times 10^2} \Rightarrow V_a = 0.0151\frac{m^3}{s}$$

STROKE VOLUME:

$$\eta_v = \frac{V_a}{V_S \times n \times k} \Rightarrow V_S = \frac{0.0151}{0.7 \times \frac{3000}{60} \times 2} \Rightarrow V_s = 2.153 \times 10^{-4}\ m^3$$

DIAMETER OR BORE OF THE CYLINDER:

$$V_s = \frac{\pi \times d^2}{4} \times L \Rightarrow 2.153 \times 10^{-4} = \frac{\pi \times D^2}{4} \times 0.0833 \Rightarrow D = 0.0574m$$

INDICATED POWER:

$$IP = P_{IMEP}LAnk \Rightarrow IP = 6 \times 10^2 \times 0.0833 \times \frac{\pi \times 0.0574^2}{4} \times \frac{3000}{60} \times 2 \Rightarrow \mathbf{IP = 12.92kW}$$

MECHANICAL EFFICIENCY:

$$\eta_{Mech} = \frac{\text{Brake Power}}{\text{Indicated Power}} \Rightarrow 0.8 = \frac{\text{Brake Power}}{18.47} \Rightarrow \textbf{Brake Power = 10.33kW}$$

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2.

During trial of four stroke single cylinder engine the load on dynamometer is found 20 kg at radius of 50 cm. The speed of rotation is 3000 rpm. The bore and stroke are 20 cm and 30 respectively. Fuel is supplied at the rate of 0.15 kg/min. The calorific value of fuel may be taken as 43 MJ/kg. After some time the fuel supply is cut and the engine is rotated with motor which required 5 kW to maintain the same speed of rotation of engine. Determine the brake power, indicated power, mechanical efficiency, brake thermal efficiency, indicated thermal efficiency, brake mean effective pressure, indicated mean effective pressure.

GIVEN:

$W = 20$kg, R=50cm, N=3000rpm, D=20cm, L=30cm, $m_f = 0.15\ \frac{kg}{min}$, CV=43MJ/kg, FP=5kW

SOLUTION:

TORQUE:

$W = \frac{T}{R\ X\ 9.81} \Rightarrow T = W \times R\ X\ 9.81 \Rightarrow T = 20 \times 0.5\ X\ 9.81 \Rightarrow \mathbf{T = 98.1Nm}$

BRAKE POWER:

$BP = \frac{2\pi NT}{60} \Rightarrow BP = \frac{2\times\pi\times3000\times98.1}{60} \Rightarrow BP = 30819.02\ W \Rightarrow \mathbf{BP = 30.82\ kW}$

INDICATED POWER:

Indicated Power = Brake Power + Friction Power $\Rightarrow$ IP=30.82+5 $\Rightarrow \mathbf{IP = 35.82\ kW}$

MECHANICAL EFFICIENCY:

$\eta_{Mech} = \frac{\text{Brake Power}}{\text{Indicated Power}} \Rightarrow \eta_{Mech} = \frac{30.82}{35.82} \Rightarrow \boldsymbol{\eta_{Mech} = 86.04\%}$

BRAKE SPECIFIC FUEL CONSUMPTION

$BSFC = \frac{m_f}{BP} \Rightarrow BSFC = \frac{0.15\times60}{30.82} \Rightarrow \mathbf{BSFC = 0.292\ \frac{kg}{kW\,hr}}$

BRAKE THERMAL EFFICIENCY:

$\eta_{BT} = \frac{BP}{\dot{m}_f\times CV} \Rightarrow \eta_{BT} = \frac{30.82\times60}{0.15\times43000} \Rightarrow \boldsymbol{\eta_{BT} = 0.2867\ or\ 28.67\%}$

INDICATED THERMAL EFFICIENCY:

$\eta_{IT} = \frac{IP}{\dot{m}_f\times CV} \Rightarrow \eta_{IT} = \frac{35.82\times60}{0.15\times43000} \Rightarrow \boldsymbol{\eta_{BT} = 0.3332\ or\ 33.32\%}$

INDICATED MEAN EFFECTIVE PRESSURE

$IP = P_{IMEP}LAnk \Rightarrow 35.82 = P_{IMEP} \times 0.3 \times \frac{\pi\times0.2^2}{4} \times \frac{3000}{2\times60} \times 1 \Rightarrow \mathbf{P_{IMEP} = 152.02\ \frac{kN}{m^2}}$

BRAKE MEAN EFFECTIVE PRESSURE

$BP = P_{BMEP}LAnk \Rightarrow 30.82 = P_{BMEP} \times 0.3 \times \frac{\pi\times0.2^2}{4} \times \frac{3000}{2\times60} \times 1 \Rightarrow \mathbf{P_{BMEP} = 130.8\ \frac{kN}{m^2}}$

3.

During the trial of a single acting oil engine, cylinder diameter is 20 cm, stroke 28 cm, working on two stroke cycle and firing every cycle, the following observations were made:

Duration of trial	= 1 hour	Total fuel used	= 4.22 kg
Calorific value	= 44670 kJ/kg	Proportion of hydrogen in fuel	= 15%
Total number of revolutions	= 21000	Mean effective pressure	= 2.74 bar
Net brake load applied to a drum	= 600 N	Drum Diameter	= 100 cm
Total mass of cooling water circulated	= 495 kg	Cooling water enters	= 13°C
Cooling water leaves	= 38^0C	Air used	=135kg
Temperature of air in test room	= 20^0C	Temperature of exhaust gases	= 370^0C
Cp_{gases}	= 1.005 kJ/kgK	$Cp_{\text{steam at atm}}$	= 2.093 kJ/kg K

Calculate thermal efficiency and draw up the heat balance.

SOLUTION:

INDICATED POWER:

$$IP = P_{IMEP}LAnk \Rightarrow IP = 2.74 \times 10^2 \times 0.28 \times \frac{\pi \times 0.2^2}{4} \times \frac{21000}{3600} \times 1 \Rightarrow \mathbf{IP = 14.06\ kW}$$

BRAKE POWER:

$$BP = \frac{2\pi NT}{60} \Rightarrow BP = \frac{2\times\pi\times21000\times0.3}{3600} \Rightarrow \mathbf{BP = 10.99\ kW}$$

$$T = W \times R \Rightarrow T = W \times \frac{d+D}{2} \Rightarrow T = 600 \times \frac{0+1}{2} \Rightarrow \mathbf{T = 0.3\ kNm}$$

MECHANICAL EFFICIENCY:

$$\eta_{Mech} = \frac{\text{Brake Power}}{\text{Indicated Power}} \Rightarrow \eta_{Mech} = \frac{10.99}{14.06} \Rightarrow \mathbf{\eta_{Mech} = 78.17\%}$$

INDICATED THERMAL EFFICIENCY:

$$\eta_{IT} = \frac{IP}{\dot{m}_f \times CV} \Rightarrow \eta_{IT} = \frac{14.06\times3600}{4.22\times44670} \Rightarrow \mathbf{\eta_{BT} = 0.2685\ or\ 26.85\%}$$

HEAT INPUT:

$$Q_S = \dot{m}_f \times CV \Rightarrow Q_S = 4.22 \times 44670 \Rightarrow \mathbf{Q_S = 188507.4\ \frac{kJ}{hr}}$$

HEAT LOSS DUE TO THE COOLING WATER

$$Q_w = m_w \times C_W \times (T_{w2} - T_{w1}) \Rightarrow Q_w = 495 \times 4.187 \times (38 - 13) \Rightarrow \mathbf{Q_w = 51814.13\ \frac{kJ}{hr}}$$

HEAT CARRIED AWAY BY EXHAUST GAS:

MASS OF THE EXHAUST GAS:

$$m_g = m_a + m_f \Rightarrow m_g = 135 + 4.22 \Rightarrow \mathbf{m_g = 139.22\ \frac{kg}{hr}}$$

Heat carried away by exhaust gas = Heat carried away by steam in exhaust gas + Heat carried away by dry gas in exhaust gas

$$\text{Mass of steam in exhaust gas} = 9 \times [0.15 \times 4.22] \Rightarrow \mathbf{m_{sg} = 5.697\ \frac{kg}{hr}}$$

$$\text{Mass of Dry Gas in exhaust gas} = m_g - m_{sg} \Rightarrow m_{dg} = 139.22 - 5.697 \Rightarrow \mathbf{m_{dg} = 133.523\ \frac{kg}{hr}}$$

HEAT CARRIED AWAY BY STEAM IN EXHAUST GAS:

$Q_{sg} = m_{sg} \times \{\text{Sensible heat of water} + \text{Latent heat of water} + \text{Sensible heat of steam}\}$

$Q_{sg} = 5.697 \times \{[4.187 \times (100 - 20)] + 2257 + [2.093 \times (370 - 100)]\} \Rightarrow \mathbf{Q_{sg} = 17985.83 \frac{kJ}{hr}}$

HEAT CARRIED AWAY BY DRY GAS IN EXHAUST GAS:

$Q_{dg} = m_{dg} \times C_{dg} \times (T_{g2} - T_a) \Rightarrow Q_{dg} = 133.523 \times 1.005 \times (370 - 20) \Rightarrow \mathbf{Q_{dg} = 46966.72 \frac{kJ}{hr}}$

$Q_g = Q_{sg} + Q_{dg} \Rightarrow Q_g = 17985.83 + 46966.72 \Rightarrow \mathbf{Q_g = 64952.55 \frac{kJ}{hr}}$

HEAT LOSS DUE TO BRAKE POWER:

$P = \frac{2\pi NT}{60} \Rightarrow BP = 10.99 \frac{kJ}{s} \times 3600 \Rightarrow \mathbf{BP = 39564 \frac{kJ}{hr}}$

UNACCOUNTED LOSS:

$Q_{ua} = Q_S - Q_w + Q_g + Q_{BP} \Rightarrow Q_{ua} = 188507.4 - 51814.13 + 64952.55 + 39564$

$\Rightarrow \mathbf{Q_{ua} = 32176.72 \frac{kJ}{hr}}$

PERCENTAGE OF HEAT LOSS:

$\%Q_w = \frac{Q_w}{Q_S} \Rightarrow \%Q_w = \frac{51814.13}{188507.4} \Rightarrow \mathbf{\%Q_w = 27.48}$

$\%Q_g = \frac{Q_g}{Q_S} \Rightarrow \%Q_g = \frac{64952.55}{188507.4} \Rightarrow \mathbf{\%Q_g = 34.46}$

$\%Q_{BP} = \frac{Q_{BP}}{Q_S} \Rightarrow \%Q_{BP} = \frac{39564}{188507.4} \Rightarrow \mathbf{\%Q_{BP} = 20.99}$

$\%Q_{un} = \frac{Q_{un}}{Q_S} \Rightarrow \%Q_{un} = \frac{32176.72}{188507.4} \Rightarrow \mathbf{\%Q_{un} = 17.07}$

4.

Complete carburetor: (i) main metering system (ii) idling system (iii) economizer system (iv) acceleration pump system (v) choke

A simple carburetor is capable to supply a correct air-fuel mixture to the engine only at a particular load and speed. In order to meet the engine demand at various operating conditions, the following additional systems are added to the simple carburetor.

- Idling system
- Auxiliary port system
- Power enrichment by economizer system
- Accelerating pump system
- Chock

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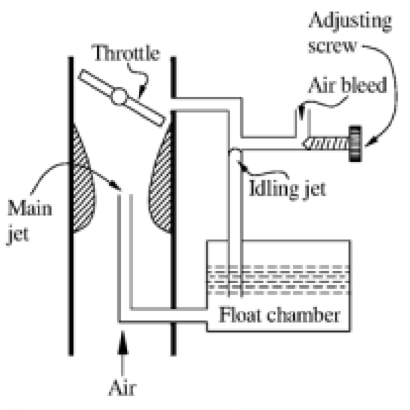
Idling System:

During starting or idling, engine runs without load and the throttle valve remains in closed position. Engine produces power only to covercome friction between the parts and a rich mixture is to be fed to the engine to sustain combustion.

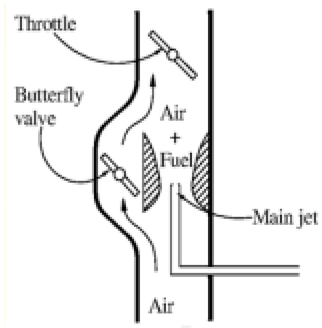


Choke:

During cold starting period, at low cranking speed and before the engine gets warmed up, a rich mixture has to be supplied. The most common method of obtaining this rich mixture is to use a choke valve between the entry to the carburetor and the venture throat.

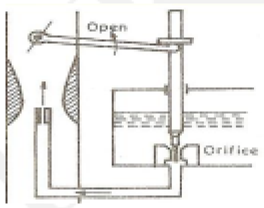
Auxiliary Port System:

During normal power or crusing operation, where the engine runs for most of the period, the fuel economy has to be maintained. Thus, it is necessary to have lower fuel consumption for maximum economy. One such arrangement used is the auxiliary port carburetor as shown, where opening of butterfly valve allows additional air to be admitted and at the same time depression at the venture throat gets reduced, therby decreasing the fuel flow rate



Powerenrichment System:

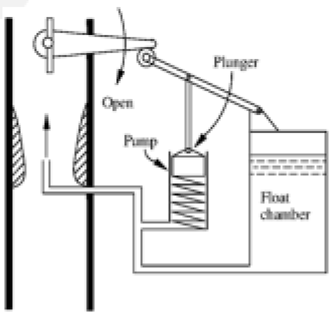
In order to obtain maximum power, the carburetor must supply a rich mixture. This additional fuel required is supplied by a power enrichment system that contains a meter rod economizer that provides a larger orifice opening to the main jet as the throttle is opened beyond a certain point.



Accelerating Pump System:

During sudden acceleration of an engine(e.g., overtaking a vehicle), an extra amount of fuel is momentarily required to supply a rich mixture. This is obtained by an accelerating pump system. It consists of a spring-loaded plunger and the necessary linkage mechanism.

The rapid opening of the throttle moves the plunger into the cylinder, and an additional amount of fuel is forced into the venturi



5.

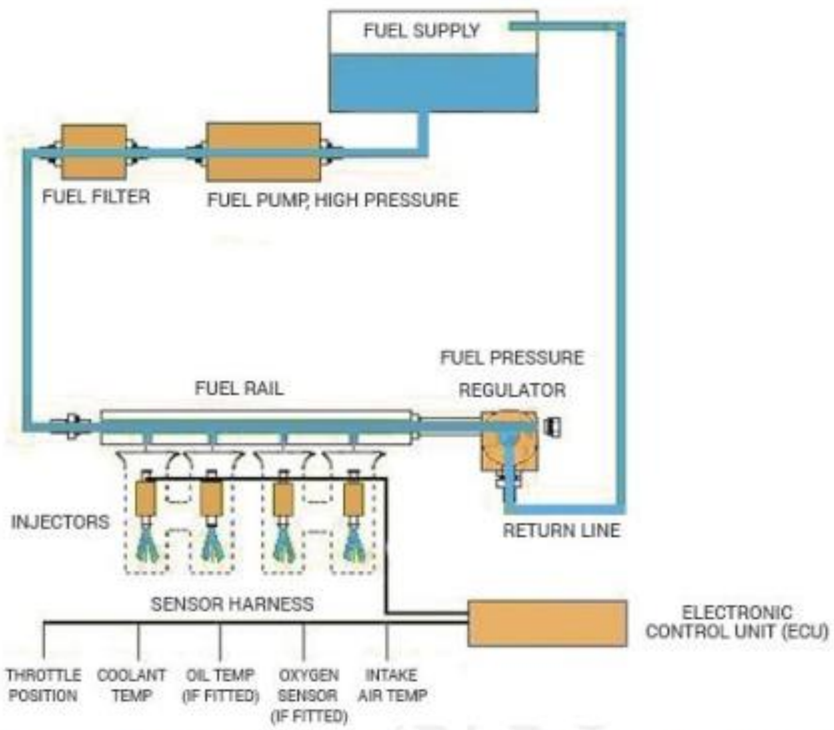
Working of Multi point fuel injector:

Principle MPFI:

- Multi point fuel injection system is an electronic system in petrol engine which aims to have efficient combustion with reduction in emmisions.
- Electronic system senses the parameters of engine like speed,load,temperature, rpm to calculte the amount of fuel which is to be injected and the pressure at which the air fuel mixture is to be injected.
- The timing of injection is also taken in account by sensing the crank angle.

Working of MPFI engine:

- When you step on the gas pedal, the throttle valve opens up more, letting in more air. The engine control unit (ECU, the computer that controls all of the electronic components on your engine) "sees" the throttle valve open (with the help of Mass airflow sensor) and increases the fuel rate in anticipation of more air entering the engine.
- It is important to increase the fuel rate as soon as the throttle valve opens; otherwise, when the gas pedal is first pressed, there may be a hesitation as some air reaches the cylinders without enough fuel in it.



- Sensors monitor the mass of air entering the engine, as well as the amount of oxygen in the exhaust. The ECU uses this information to fine-tune the fuel delivery so that the air-to-fuel ratio is just right.

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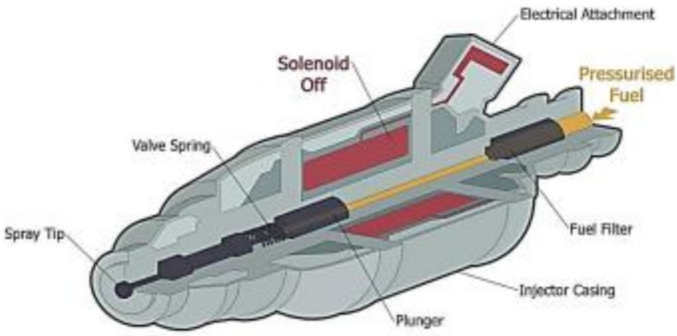
KEY PARTS OF MPFI

Fuel Injector



- A fuel injector is nothing but an electronically controlled valve. It is supplied with pressurized fuel by the fuel pump in your car, and it is capable of opening and closing many times per second

Engine Sensors

- In order to provide the correct amount of fuel for every operating condition, **the engine control unit** (ECU) has to monitor a huge number of input sensors. Here are just a few-
- **Mass airflow sensor** - Tells the ECU the mass of air entering the engine.

- **Oxygen sensor(s)** - Monitors the amount of oxygen in the exhaust so the ECU can determine how rich or lean the fuel mixture is and make adjustments accordingly
- **Throttle position sensor** - Monitors the throttle valve position (which determines how much air goes into the engine) so the ECU can respond quickly to changes, increasing or decreasing the fuel rate as necessary.
- **Coolant temperature sensor** - Allows the ECU to determine when the engine has reached its proper operating temperature Voltage sensor - Monitors the system voltage in the car so the ECU can raise the idle speed if voltage is dropping (which would indicate a high electrical load).
- **Engine speed sensor** - Monitors engine speed, which is one of the factors used to calculate the pulse width

Advantage of Electronic Fuel injection over carburettor:-

- Better atomization of fuel
- Lower emission of pollutant
- Better flow due to elimination of venture
- Rapid response time with respect to the changes
- Improved fuel efficiency