INTRODUCTION

A self propelled vehicle used for the transportation of goods and passengers on the ground is called automobile.

Vehicle design is the very important section in the automobile engineering. It contains the following.

1. calculation of rolling resistance, air, gradient resistances for the assumed vehicle.
2. Calculation of excessive driving force.
3. calculation of driving force.
4. From the above various values BHP and IHP are calculated.
5. From the indicated power the engine volume, pressure are calculated.
6. From the above values the engine speed and vehicle speeds are calculated.
7. For the various values of engine speed the torque, BMEP, Mechanical efficiency are calculated.

8. Piston velocity and acceleration are calculated.

9. The engine cylinder is determined for calculating volume, bore and stroke are calculated.

10. Inertia force, Gas force and resultant force are calculated for engines.

11. From this the engine turning moment for single cylinder and combined TM are calculated.

12. Now the correct values of the acceleration gradiability and gear ratios are calculated.

13. Finally the performance of the designed vehicle is calculated and various graphs are drawn for different parameters.

Above design fully calculated by using the assumed values of the vehicle, the assumed values are taken from the practical works.

VEHICLE DESIGN

COMPARISON OF VEHICLES:

To compare any vehicle the following parameters are necessary.

1. Weight of the vehicle.
2. Engine displacement capacity
3. Engine horse power.

WEIGHT OF THE VEHICLE:

1. Dry Weight:

This is the weight of the vehicle without oil, grease, water and fuel when it is transported by ship are huge truck from one place to another.

2. Kerb Weight:

Kerb weight is the sum of the dry weight and weight of fuel, oil, water and grease. It is also termed as unladden weight (ULW).

3. Normal ladden weight:

NLW is the sum of the kerb weight and payload. Payload is the sum of weight of passengers and Luggage. For heavy vehicles NLW is termed as Gross vehicle Weight (GVW)

DISPLACEMENT CAPACITY OF ENGINE:

The classification of vehicle based on the engine displacement is as follows.

SL. NO.	Class of vehicle	Engine displacement in cc	Acceleration m/s^2	Max. permissible speed KMPH
1.	Small cars	800 - 1000 (M-800)	0.73 - 0.9	110 - 115
2.	small Medium cars	1000 - 1200 (FIAT)	0.9 - 1.05	115 - 130
3.	Medium cars	12000 - 1500 (AMBASSADOR)	1.05 - 1.2	130
4.	Medium large cars	1500 - 2000 (CANTASSA)	1.05 - 1.20	130 - 160
5.	Large cars	2500 - 3000 (BENZ)	1.05 - 1.50	160 - 190
6.	Luxury cars	3000 - 4000 (FORD)	1 - 1.50	190 - 200

ENGINE POWER (BHP):

Horse power required for propulsion of vehicle:

The motion of the vehicle moving in forward direction is resisted by aerodynamic forces known wind or air resistance, road resistance. Inaddition gradient resistance when the vehicle is moving up in a slope because the weight of vehicle is carried over a vertical distance. Therefor HP depends on the total resistance and the forward speed of vehicle.

RESISTANCES:

1) Air Resistance (Ra):

Whenever a body is moving it has certain amount of resistance due to air. the resistance offered by the air to the movement of the vehicle is called as air resistance. It depends on the following.

1. Density of Medium (air)
2. size and shape of vehicle body (A)
3. Aerodynamic drag co-efficient (c)
4. Velocity of the vehicle (v)
5. Acceleration dueto gravity (g)

$$\therefore \quad Ra = \frac{C \rho A V^2}{2g} \;\ldots\ldots\; \text{kgf.}$$

$$\Rightarrow \quad Ra = K_a A V^2 \;\ldots\ldots\; \text{kgf.}$$

where,

$K_a = \frac{c\rho}{2g}$ = Aerodynamic constant = 0·0032

A = projected Frontal area (m^2)

V = vehicle speed (KMPH)

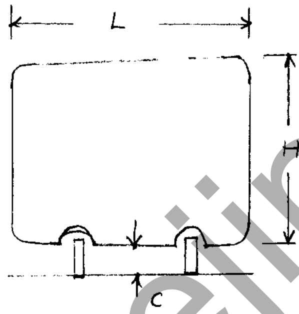
C = drag coefficient = 0·45

ρ = density of air.

Value of Ka:

1. Perfectly stream lined body = 0.0013
2. Early passenger cars = 0.00526 to 0.0015
3. For Modern passenger cars = 0.0032
4. Racing cars = 0.00245
5. Trucks = 0.0047
6. Double Decker buses = 0.006

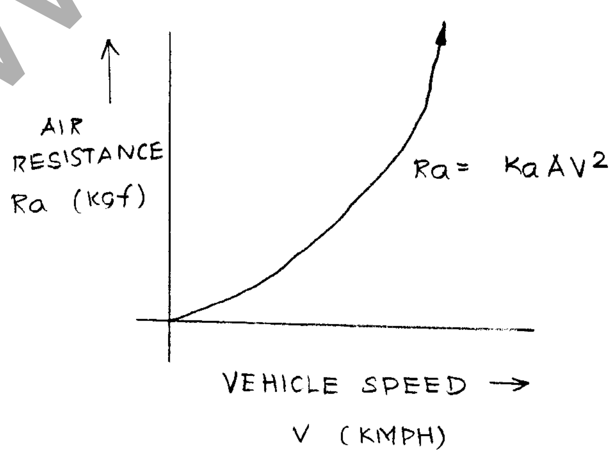
Frontal Area:



H = height
L - Width
C - Ground clearance

Frontal Area = A = (H-C) x L

For passenger cars, A = 1.7 to 1.8 m^2



Rolling Resistance (R_r):

The resistance offered by the road surfaces to move the vehicle is called as Road Resistance or Rolling Resistance. It depends on the following.

1. Nature of road surface.
2. Type of tyre (Pneumatic or solid rubber)
3. Weight of the vehicle.
4. vehicle speed.

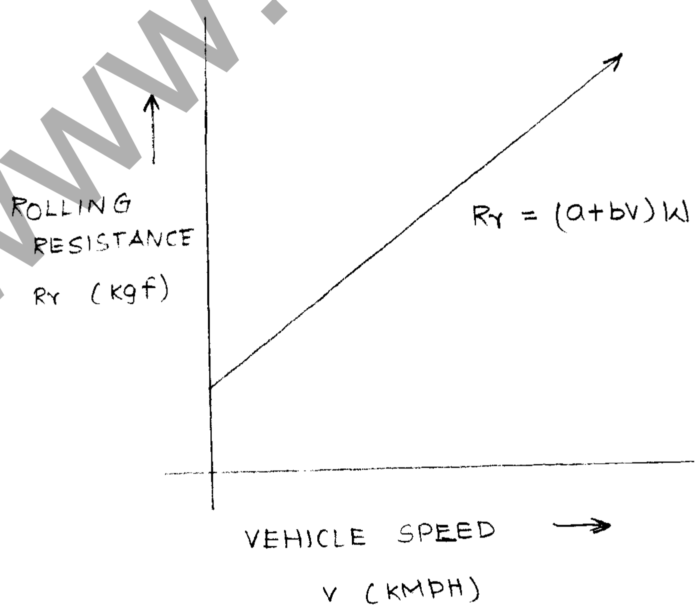
$$R_r = (a+bV)\,W \quad \ldots\ldots\ \text{kgf}$$

where, $a = 7.6$ constant.

$b = 0.05625$ constant.

V = Vehicle speed in KMPH.

W = NLW or GLW in Tonnes.

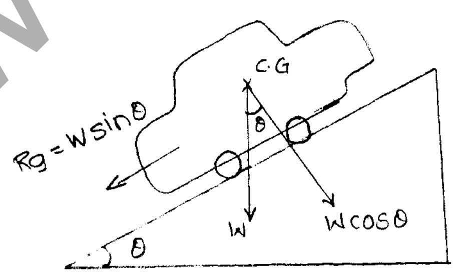


Value of Rr (Kgf / Tonnes) :

1. Rail road - 4.55
2. Grod Asphalt - 6.82
3. Wood paring - 13.64
4. Granite sets - 15.91
5. Well rolled Gravel - 25.91
6. Hard dry clay - 45.45
7. Sand road - 163.65
8. Loose sand - 254.55

Gradient Resistance (Rg) :

The resistance offered by a grade to move up of the vehicle is called as gradient resistance. It depends on grade slope.



$$R_g = W \sin\theta \;\ldots\ldots\; kgf$$

where, θ - Angle of slope

W - GVW or NLW

Total Resistance:

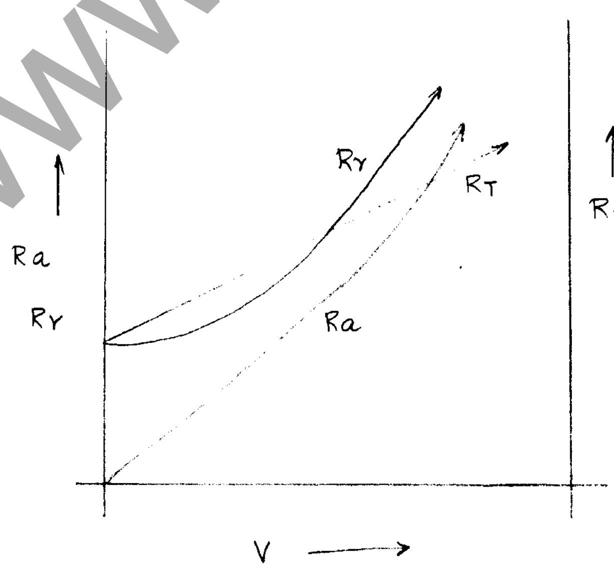
Total resistance is the sum of all the resistance, air resistance, gradient resistance, Rolling resistance.

Total Resistance, $R = R_a + R_r + R_g \cdots$ kgf (gradient road)

$R = R_a + R_r \cdots\cdots$ kgf (Level road)

ASSUME FOLLOWING DATA:

1. kerb weight (ULW) - 810 kg.
2. Max. Pay load - 320 kg.
3. Normal ladden wt - 1130 kg.
4. Maximum speed - 120 KMPH.
5. Frontal Area - 1.8 m^2.



Vehicle speed V (KMPH)	Ra $K_a A V^2$ kgf	Rr $(a+bV)W$ kgf	RT Ra+ Rr kgf
0	0	8.588	8.588
10	0.576	9.2236	9.8
20	2.304	9.8522	12.16
30	5.184	10.94	15.67
40	9.216	11.13	20.13
50	14.4	11.76	26.16
60	20.736	12.4018	33.14
70	28.224	13.037	41.26
80	36.864	13.67	50.5
90	46.656	14.35	60.9
100	57.6	14.95	72.5
110	69.696	15.58	85.3
120	82.944	16.2	99.17

CALCULATION:

V= 50 KMPH.

(i) $R_a = K_a A V^2 = 0.0032 \times 1.8 \times 50^2 = 14.4$ kgf.

(ii) $R_r = (a+bV)W = (7.6 + 0.05625 \cdot 50)1.13 = 11.76$ kgf.

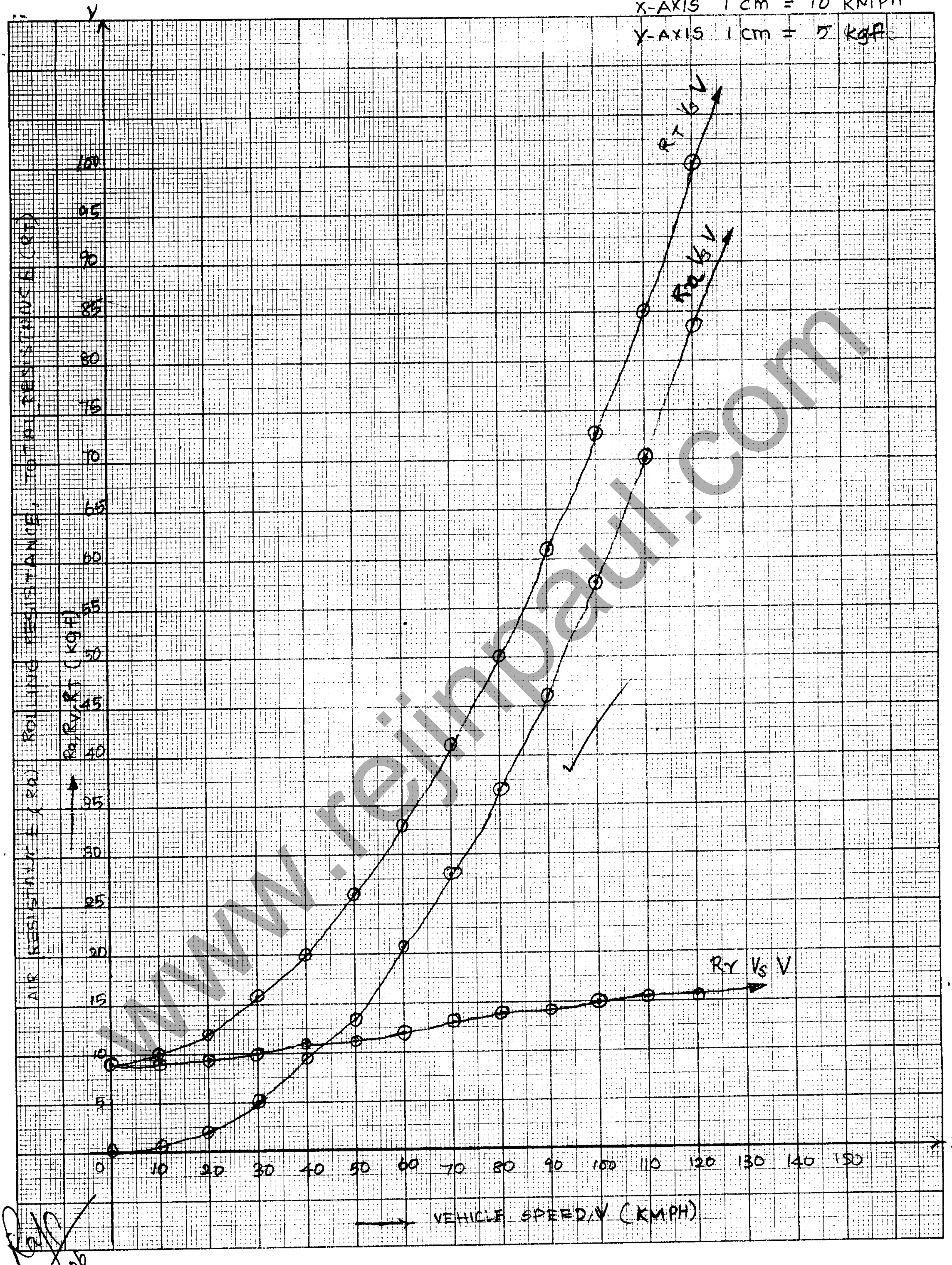
(iii) $R_t = R_a + R_r = 14.4 + 11.76 = 26.16$ kgf.

RESISTANCES Vs VEHICLE SPEEDS

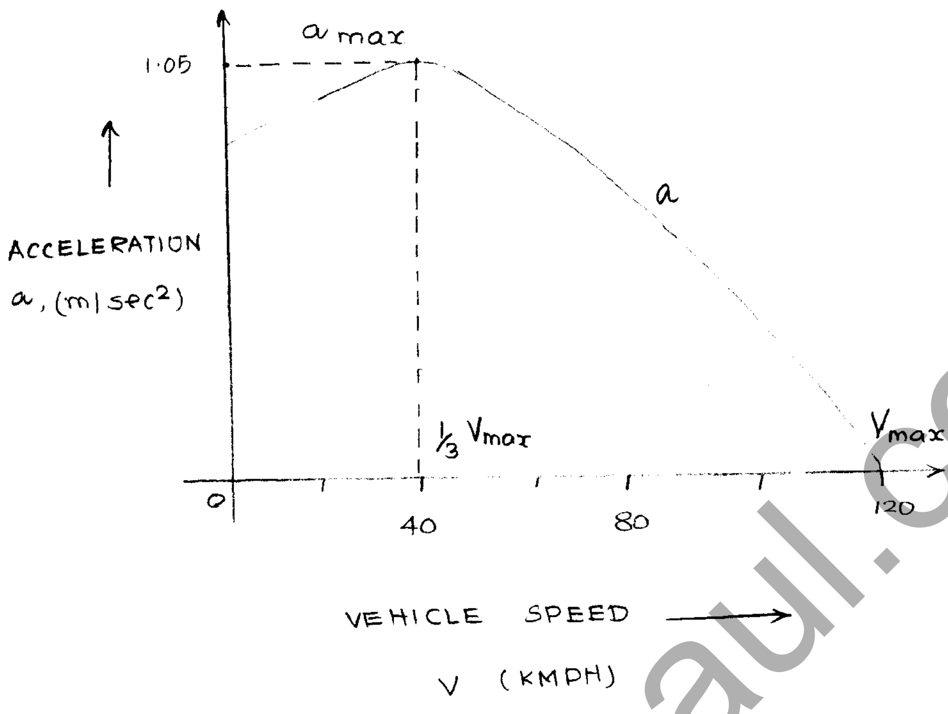
SCALE:

X-AXIS 1 cm = 10 KMPH

Y-AXIS 1 cm = 5 kgf



VEHICLE ACCELERATION :



$$a_{max} = 0.9 \text{ to } 1.05 \ m/s^2$$

$$V_{max} = 120 \text{ KMPH}.$$

$$a = 0 \text{ at } V_{max}$$

Assume max. acceleration from vehicle data it is 0.9 to 1.05 m/s². for the vehicle which is having maximum vehicle speed 120 KMPH. The max. acceleration always occurs at ⅓ of maximum vehicle speed. The acceleration of the vehicle at max. speed is zero. Now, using this concept draw a smooth curve as shown in figure.

Now find the acceleration for different vehicle speed from the above curve.

The excess driving Force,

$$EDF = \frac{W}{g} \times \frac{a}{Ka} \text{ .... kgf}$$

where, W = NLW

a = Acceleration

Ka = Acceleration constant (0.9)

g = Acceleration due to gravity

Value of Ka	Four speed Gear box	Three speed Gear box
TOP Gear	0.9	0.90
III Gear	0.87	
II Gear	0.85	0.85
I Gear	0.80	0.80

DRIVING FORCE, $DF = EDF + R_T$ ...... Kgf.

where,

EDF - Excess Driving Force in Kgf

R_T - Total Resistance in Kgf

POWER REQUIRED BY THE VEHILE :

A driving horse power at the road wheel is proportional to the total resistance and the EDF to give the required acceleration.

$$\text{Vehicle speed} = \frac{V \times 1000}{3600} \text{ m/sec.}$$

$$\text{Watt output} = \frac{DF \times V \times 1000}{3600} \text{ kg-m/sec.}$$

$$\text{Driving HP} = \frac{DF \times V \times 1000}{3600} \times \frac{1}{75} \text{ HP.}$$

$$DHP = \frac{DF \times V}{270} \text{ HP}$$

$$\text{Brake HP} = 1.1 \times DHP$$

$$\text{Indicated HP} = 1.1 \times BHP$$

$$\therefore IHP > BHP > DHP$$

Relation Between Engine rpm and vehicle speed :

Let, N - The engine speed in rpm.

$$\text{speed of road wheel} = \frac{N}{G r_a} \text{ rpm.}$$

G - Gear ratio

r_a - Axle reduction

1 HP = 735.5 Watts.

$$\left.\begin{array}{l}\text{Distance travelled} \\ \text{by wheel / min}\end{array}\right\} = \frac{N}{G\, r_a} \times 2\pi R_W \quad \text{m/min}$$

R_W = Effective wheel radius.

$$\text{Vehicle speed, } V = \left(\frac{N}{G\, r_a} \times 2\pi R_W\right)\frac{60}{1000} \quad \ldots\ldots\ \text{KmPH}$$

$$V = \left(\frac{N \cdot R_W}{G \cdot r_a}\right)\left(\frac{2\pi \times 60}{1000}\right)$$

$$\frac{N}{V} = \left(\frac{1000}{2\pi \times 60}\right)\frac{G\, r_a}{R_W}$$

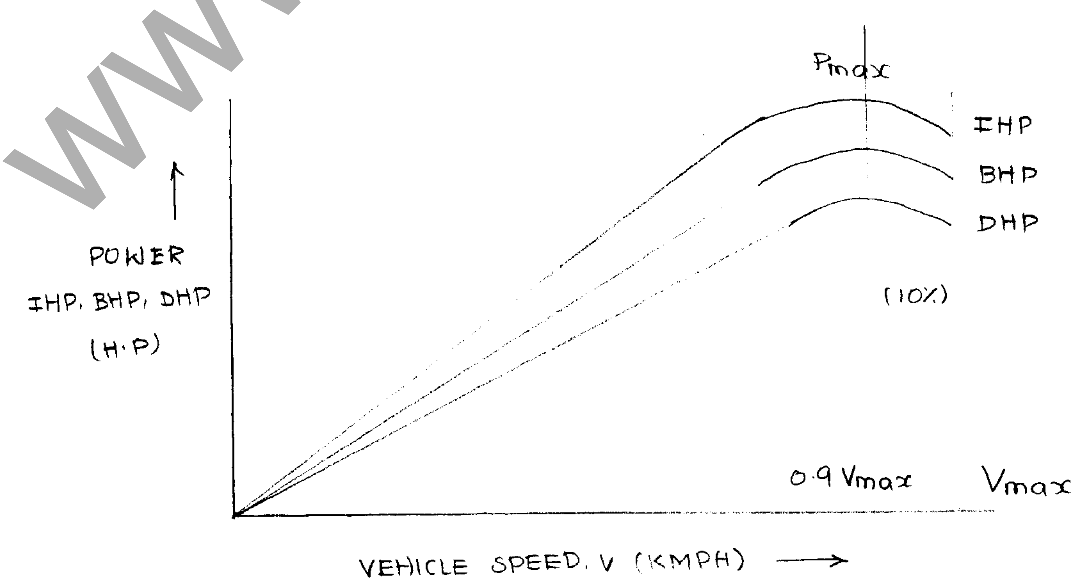
$$\frac{N}{V} = 2.655\,\frac{G\, r_a}{R_W}$$

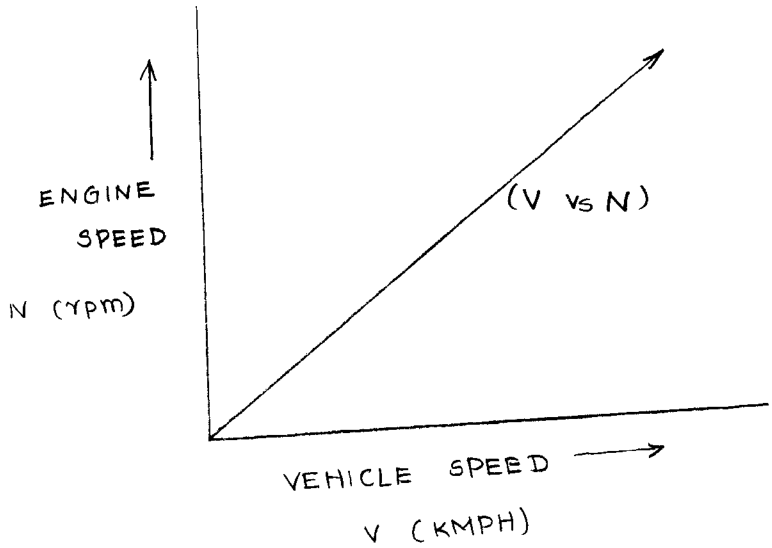
ASSUME. Gear ratio, $G = 1:1$

Axle reduction, $r_a = 3$ or 4

Wheel radius, $R_W = 0.2844 \simeq 0.3$ m.

GRAPHS:





CALCULATION:

vehicle speed, V = 50 KMPH.

1. Excess Driving Force, $EDF = \left(\frac{W}{g}\right)\left(\frac{a}{Ka}\right)$

$$= \frac{1130}{9.81} \times \frac{0.99}{0.9}$$

$$EDF = 126.7 \text{ Kgf.}$$

2. Driving Force, $DF = EDF + RT$

$$= 126.7 + 26.17$$

$$DF = 152.88 \text{ Kgf.}$$

3. Driving horse power, $DHP = \frac{DF \times V}{270}$

$$= \frac{152.88 \times 50}{270}$$

$$DHP = 29.42 \text{ HP.}$$

V KMPH	$R_a = K_a A V^2$ Kgf	$R_r = (a+bV)W$ Kgf	R_T $(R_a + R_r)$ Kgf	a m/s^2	EDF $\left(\frac{W}{g}\right)\left(\frac{a}{K_a}\right)$ Kgf	DF $(EDF + R_T)$ Kgf	DHP $\left(\frac{DF \times V}{270}\right)$ HP	BHP $(1.1 \times DHP)$ HP	IHP $(1.1 \times BHP)$ HP	N $\frac{2.65\, V G r_a}{R_w}$ rpm
0	0	8.588	8.588	0	0	8.588	0	0	0	0
10	0.576	9.22	9.796	0.97	124.15	134	4.961	5.457	6.003	353.33
20	2.304	9.86	12.164	1.0	127.99	140.153	10.382	11.42	12.562	706.67
30	5.184	10.49	15.67	1.04	133.11	148.78	16.531	18.184	20.002	1060.0
40	9.216	11.13	20.35	1.05	134.39	154.74	22.924	25.217	27.738	1413.3
50	14.4	11.77	26.17	0.99	126.71	152.88	28.321	31.142	34.256	1766.7
60	20.736	12.4	33.14	0.89	113.91	147.05	32.678	35.946	39.54	2120.0
70	28.22	13.04	41.26	0.79	101.11	142.371	36.911	40.602	44.662	2473.3
80	36.86	13.67	50.53	0.65	83.193	133.723	39.622	43.584	47.942	2826.7
90	46.66	14.31	60.97	0.54	69.114	130.084	43.361	47.697	52.467	3180.0
100	57.6	14.91	72.54	0.40	51.196	123.74	45.828	50.411	55.452	3533.3
110	63.45	15.45	78.9	0.31	39.56	118.46	47.383	52.172	57.415	3816
120	82.94	16.22	99.16	0	0	99.16	44.07	48.48	53.326	4240

4. Brake horse power, $BHP = 1.1 \times DHP$

$= 1.1 \times 29.42$

$BHP = 32.362$ HP

5. Indicated horse power, $IHP = 1.1 \times BHP$

$= 1.1 \times 32.362$

$IHP = 35.6$ HP

6. Engine speed, $N = \frac{2.65 \times V \times G \times r_a}{R_W}$

$= \frac{2.65 \times 50 \times 1 \times 4}{0.3}$

$N = 1767$ rpm

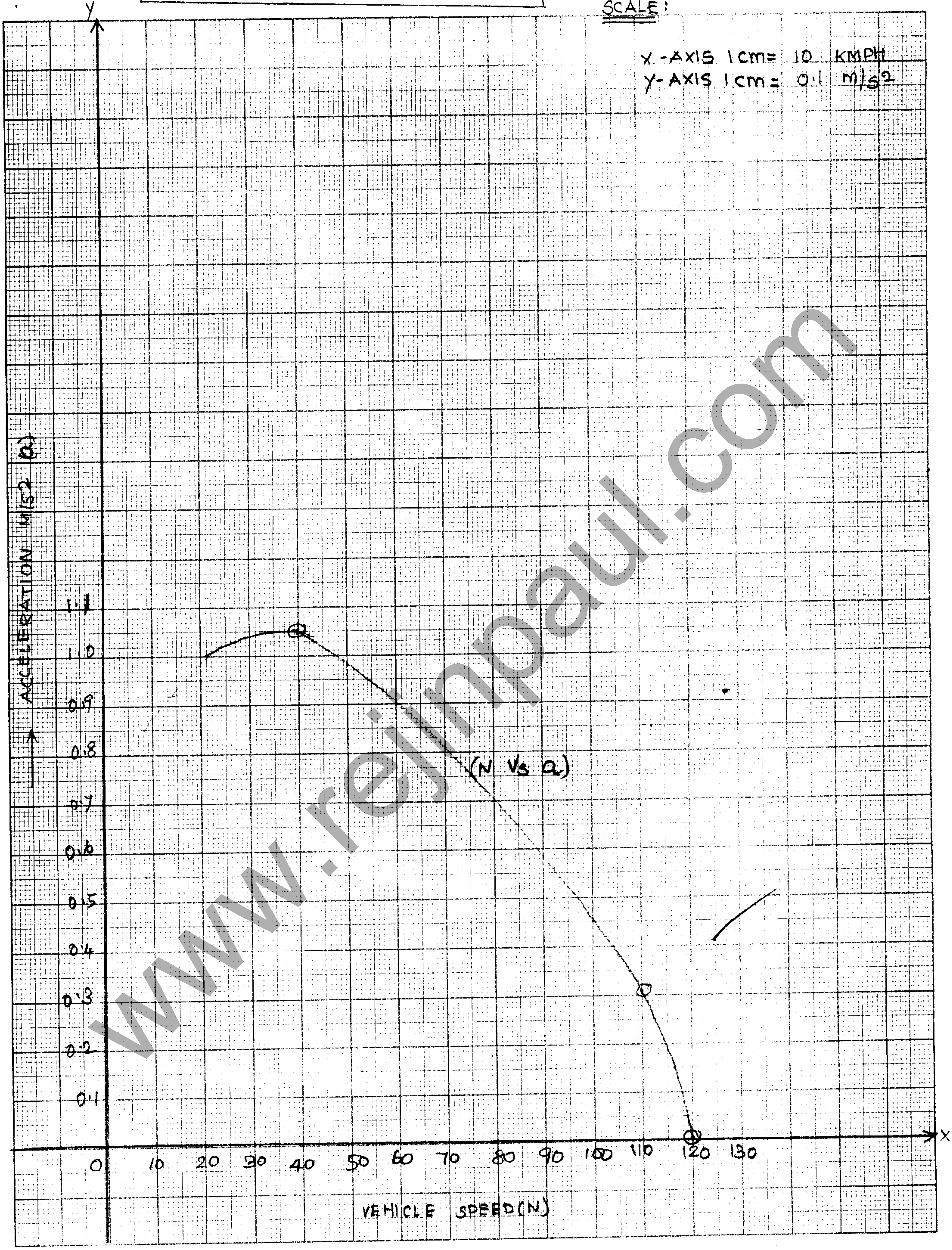
NOTES:

1. The power available at Engine cylinder is called as indicated horse power.

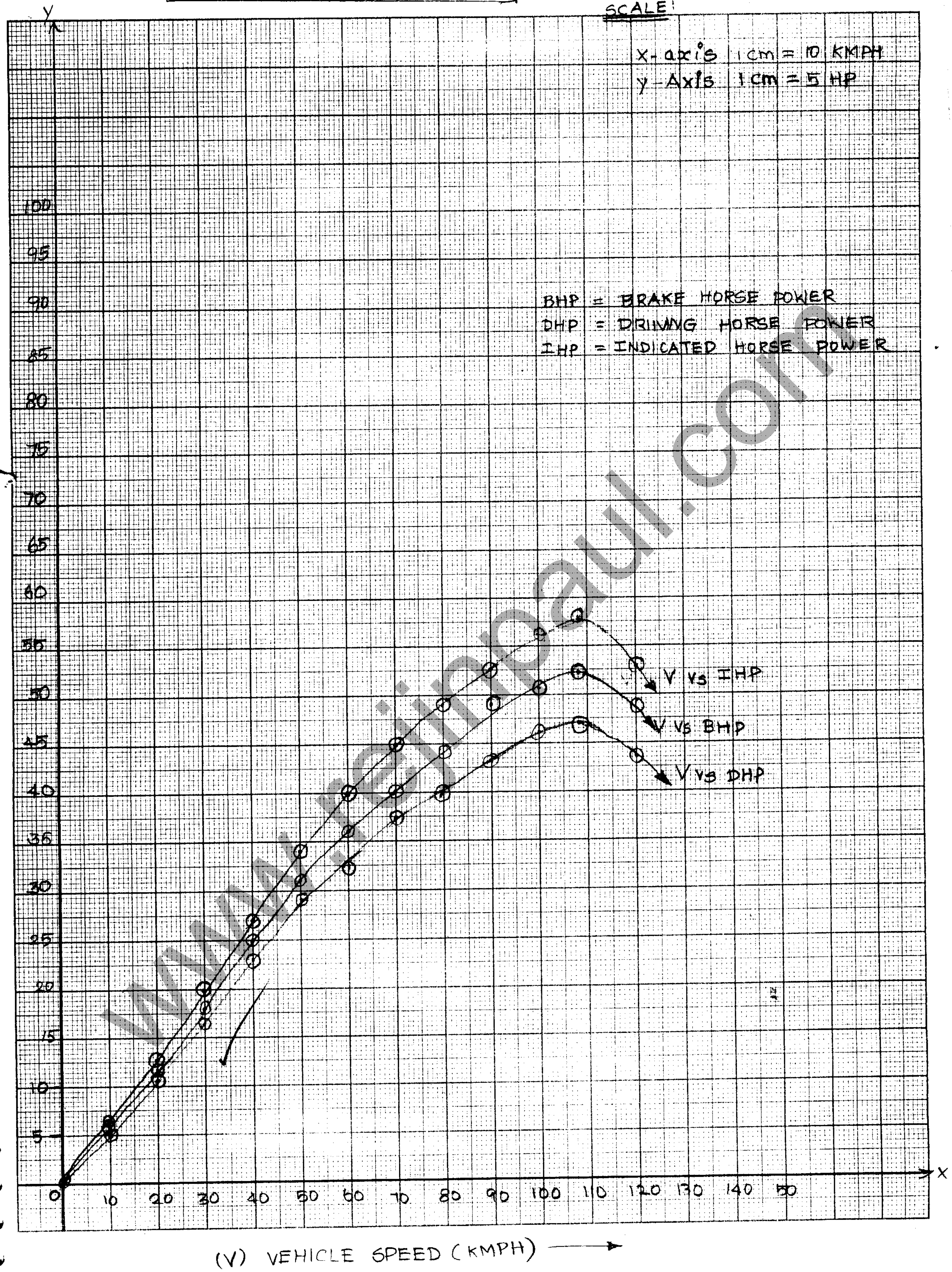
2. The power available at output shaft of an engine is called as Brake power.

3. The power available at road road wheels is called Driving horse power.

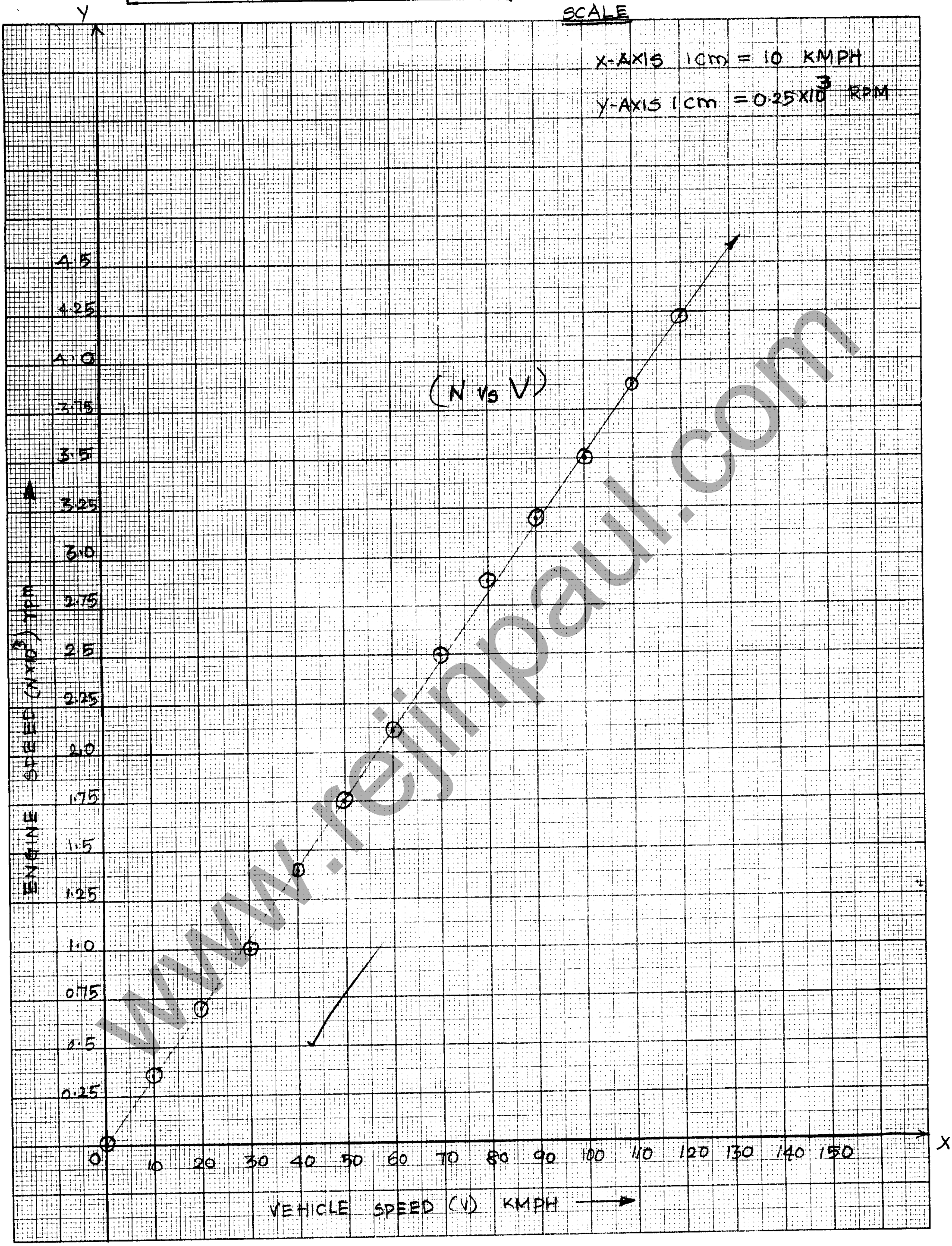
VEHICLE SPEED Vs ACCELERATION



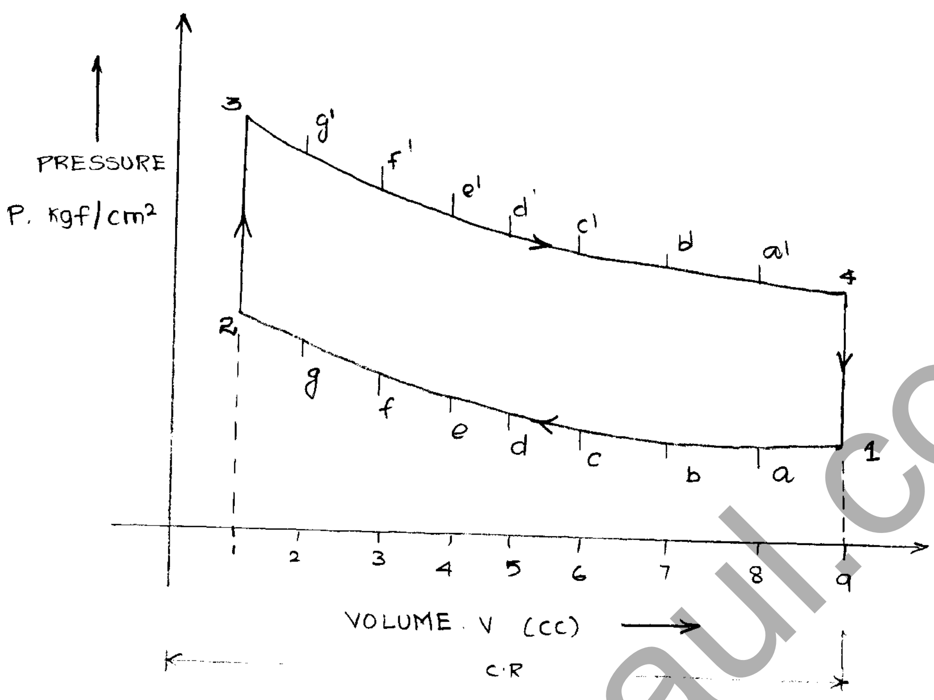
POWER Vs VEHICLE SPEED



VEHICLE SPEED Vs ENGINE SPEED



TO DETERMINE BORE & STROKE :



PV - DIAGRAM OF OTTO CYCLE

Let P_1, P_2, P_3, P_4 are the pressures at corner points.
V_1, V_2, V_3, V_4 are the volumes at corner points.

V_c - clearance volume

V_s - stroke or swept or displacement volume.

NOW,

compression Ratio, $CR = \frac{V_s + V_c}{V_c}$

Assume, the com.Ratio of the engine is 9 and

$V_c = 1$

$C \cdot R = 9 = \frac{V_s + 1}{1}$

$\therefore V_s = 8$

P_1 - suction pressure and must be less than atm. pr.

P_1 = 0.93 to 0.98 kgf/cm² - Petrol Engines.

P_1 = 1 kgf/cm² - Diesel engines.

Atmospheric pressure = 1.032 kgf/cm²

For compression stroke,

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

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{\gamma} = P_1 (C.R)^{\gamma}$$

Take, γ = specific heat ratio = $\frac{C_P}{C_V}$ = 1.32 for comp.

$$P_2 = 0.95 (9)^{1.32}$$

$$P_2 = 17.27 \text{ kgf/cm}^2$$

Explosion ratio, $\alpha = \frac{P_3}{P_2}$ = 4.2 to 4.5 lit

$$\alpha = \frac{P_3}{P_2} = 4.3$$

$$P_3 = 74.270 \text{ kgf/cm}^2$$

For expansion stroke,

$$P_3 V_3^{\gamma} = P_4 V_4^{\gamma}$$

$$P_4 = P_3 \left(\frac{V_3}{V_4}\right)^{\gamma}$$

$$P_4 = P_3 \left(\frac{1}{CR}\right)^{\gamma}$$

Take, $\gamma = 1.34$ for expansion stroke.

$$\therefore \quad P_4 = 74.27 \left(\frac{1}{9}\right)^{1.34}$$

$$P_4 = 3.91 \text{ kgf/cm}^2.$$

Intermediate Points:

a) compression stroke: ($\gamma = 1.32$)

$$P_a V_a^{\gamma} = P_1 V_1^{\gamma}$$

$$P_a = P_1 \left(\frac{V_1}{V_a}\right)^{\gamma}$$

$$= P_1 \left(\frac{9}{8}\right)^{1.32}$$

lly $\quad P_b = P_a \left(\frac{V_a}{V_b}\right)^{\gamma}$

b) For Expansion stroke: ($\gamma = 1.34$)

$$P_3 V_3^{\gamma} = P_{g1} V_{g1}^{\gamma}$$

$$P_{g1} = P_3 \left(\frac{V_3}{V_{g1}}\right)^{\gamma}$$

lly $\quad P_{f1} = P_{g1} \left(\frac{V_{g1}}{V_{f1}}\right)^{\gamma}$

Now, Draw the PV diagram using calculated values.

COMPRESSION STROKE : ($\gamma = 1.32$)

$$P_a = P_1 \left(\frac{V_1}{V_a}\right)^{\gamma} = 0.95 \left(\frac{9}{8}\right)^{1.32} = 1.1 \text{ kgf/cm}^2$$

$$P_b = P_a \left(\frac{V_a}{V_b}\right)^{\gamma} = 1.1 \left(\frac{8}{7}\right)^{1.32} = 1.324 \text{ kgf/cm}^2$$

$$P_c = P_b \left(\frac{V_b}{V_c}\right)^{\gamma} = 1.324 \left(\frac{7}{6}\right)^{1.32} = 1.623 \text{ kgf/cm}^2$$

$$P_d = P_c \left(\frac{V_c}{V_d}\right)^{\gamma} = 1.623 \left(\frac{6}{5}\right)^{1.32} = 2.065 \text{ kgf/cm}^2$$

$$P_e = P_d \left(\frac{V_d}{V_e}\right)^{\gamma} = 2.065 \left(\frac{5}{4}\right)^{1.32} = 2.7723 \text{ kgf/cm}^2$$

$$P_f = P_e \left(\frac{V_e}{V_f}\right)^{\gamma} = 2.7723 \left(\frac{4}{3}\right)^{1.32} = 4.053 \text{ kg/cm}^2$$

$$P_g = P_f \left(\frac{V_f}{V_g}\right)^{\gamma} = 4.053 \left(\frac{3}{2}\right)^{1.32} = 6.922 \text{ kg/cm}^2$$

$$P_2 = 17.27 \text{ kgf/cm}^2$$

$$P_3 = 74.27 \text{ kgf/cm}^2$$

EXPANSION STROKE : ($\gamma = 1.34$)

$$P_{g1} = P_3 \left(\frac{V_3}{V_{g1}}\right)^{\gamma} = 74.27 \left(\frac{1}{2}\right)^{1.34} = 29.34 \text{ kgf/cm}^2$$

$$P_{f1} = P_{g1} \left(\frac{V_{g1}}{V_{f1}}\right)^{\gamma} = 29.34 \left(\frac{2}{3}\right)^{1.34} = 17.041 \text{ kg/cm}^2$$

$$P_{e1} = P_{f1} \left(\frac{V_{f1}}{V_{e1}}\right)^{\gamma} = 17.041 \left(\frac{3}{4}\right)^{1.34} = 1\cancel{8}.5898 \text{ kg/cm}^2$$

$$P_{d1} = P_{e1} \left(\frac{V_{e1}}{V_{d1}}\right)^{\gamma} = 11.898 \left(\frac{4}{5}\right)^{1.34} = 8.5945 \text{ kg/cm}^2$$

$$P_{c1} = P_{d1} \left(\frac{V_{d1}}{V_{c1}}\right)^{\gamma} = 8.6 \left(\frac{5}{6}\right)^{1.34} = 6.7316 \text{ kg/cm}^2$$

$$P_{b1} = P_{c1}\left(\frac{V_{c1}}{V_{b1}}\right)^{\gamma} = 6.7316\left(\frac{6}{7}\right)^{1.34} = 5.475 \text{ kg/cm}^2$$

$$P_{a1} = P_{b1}\left(\frac{V_{b1}}{V_{a1}}\right)^{\gamma} = 5.475\left(\frac{7}{8}\right)^{1.34} = 4.578 \text{ kg/cm}^2$$

$$P_4 = 3.91 \text{ kgf/cm}^2$$

SL. NO.	Volume V (cc)	Compression stroke		Expansion stroke.	
		Point	Pr. P kg/cm2	Point	Pr. P kg/cm2
1	1.0	2	17.27	3	74.27
2	2.0	g	6.922	g_1	29.34
3	3.0	f	4.053	f_1	17.041
4	4.0	e	2.7723	e_1	11.5898
5	5.0	d	2.065	d_1	8.5945
6	6.0	c	1.623	c_1	6.7316
7	7.0	b	1.324	b_1	5.475
8	8.0	a	1.110	a_1	4.578
9	9.0	1	0.950	4	3.910

ACTUAL PV DIAGRAM:

$$IMEP = \frac{\text{(Area of P-V diagram} \times \text{scale factor in y axis} \times \text{D.F}}{\text{Length of diagram}}$$

D.F = Diagram factor.

Indicated Mean effective pressure = 10 to 12 kg/cm²

Assume, Diagram Factor = 0.9

This IMEP is available at maximum BHP point.

1. FMEP = $a + b\,(N/1000) + c\,(N/1000)^2$

where, FMEP - Frictional mean eff Pressure

N - Engine rpm at max BHP.

$a = 0.5622$;

$b = 0.2811$

$c = 0.0527$

2. $$FHP = \frac{FMEP \times LA \times n}{4500 \times 100}$$

where, FHP - Frictional horse power.

$n = \frac{N}{2}$ for 4-S engine.

LA = 1200 - 1300 cc.

3. IHP = BHP + FHP

where, IHP - Indicated horse power

4. To Find LA:

$$IHP = \frac{IMEP \times LA \times n}{4500 \times 100}$$

$n = \frac{N}{2}$

LA = ?

After calculating LA, try to check it up the variation between the assumed value of LA, calculated value of LA. It must be within 5%. If the variation is more change the assumed value of LA suitably and recalculate the calculated value of LA until you get the variation between these two within 5%.

After finding LA fix the no of cylinders.

If LA > 1600 cc Assume no of cylinder as six.

If LA < 1600 cc Assume no of cylinder as Four.

5. TO FIND BORE (B) & STROKE (L):

If $B=L \Rightarrow$ square engine

If $B>L \Rightarrow$ under square engine

If $B<L \Rightarrow$ over square engine.

For under square engine and over square engine the max. ratio between bore and stroke is

$$B \times L = 1.2$$

using this find B & L.

$$\frac{LA}{4} = \frac{\pi}{4} B^2 \times L \Rightarrow B = ?$$

For square engine $L = B = ?$

FHP from FMEP

BHP from Graph.

$$\therefore IHP = BHP + FHP$$

$$\eta_{mech} = \frac{BHP}{IHP}$$

$$BMEP = \frac{BHP \times 4500 \times 100 \times 2}{LAXN}$$

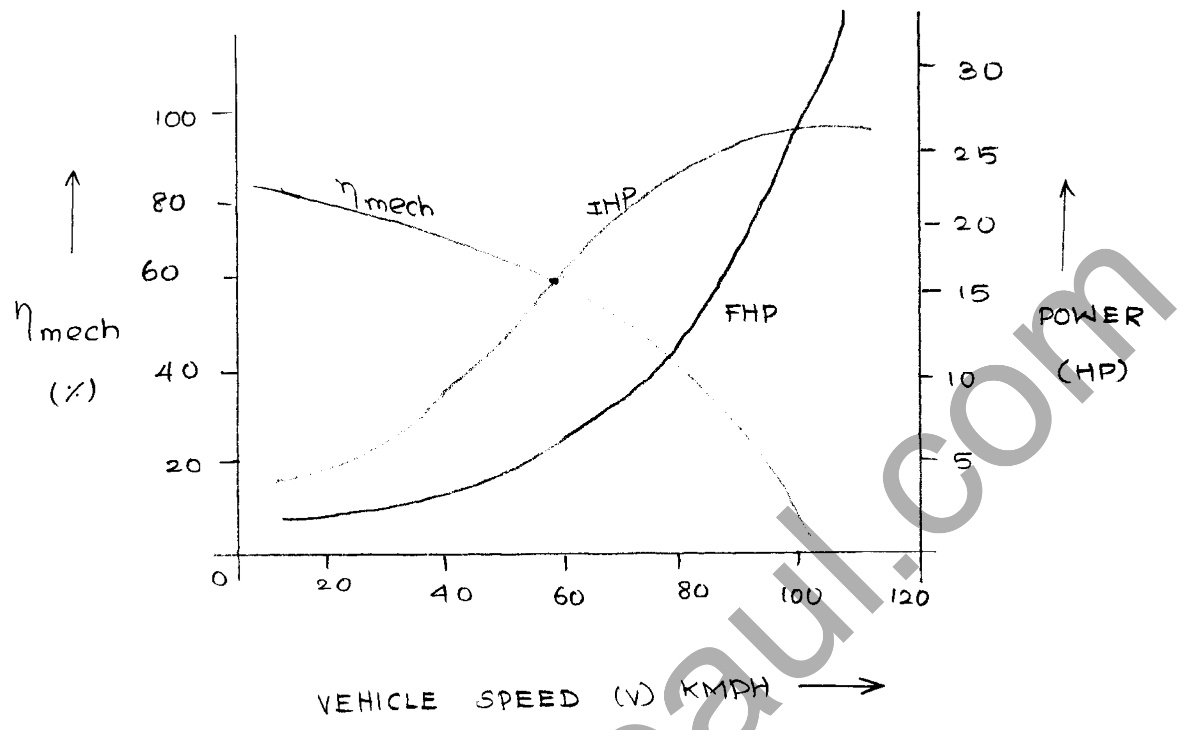
$$Torque = \frac{BHP \times 4500}{2\pi N}$$

GRAPHS:

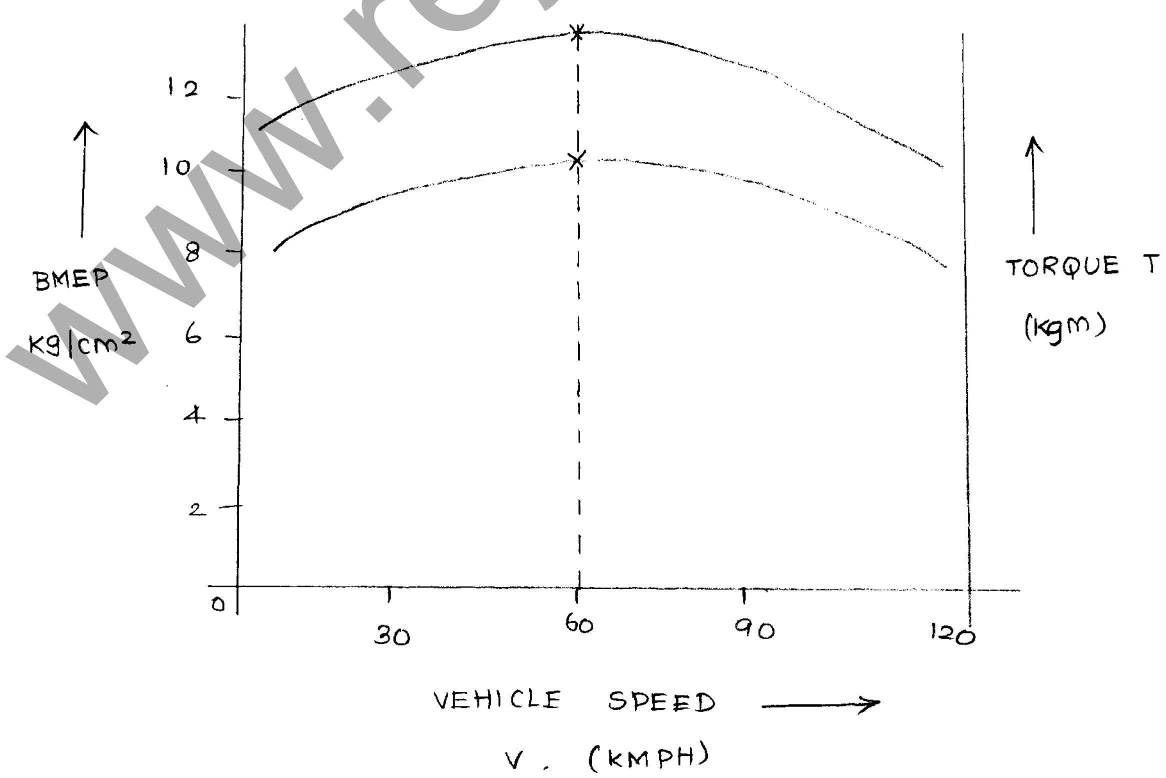
1. V Vs η_{mech}
2. V Vs T
3. V Vs BEMP
4. V Vs DF
5. V Vs BHP, IHP, FHP

NOTES:

1. The max. Torque must be available at 50% of Vmax
2. Driving force and torque curves must be exactly in similar shape.
3. Starting and ending value of torques is same.



100
80
60
40
20
0
η_{mech}
(%)
η_{mech}
IHP
FHP
30
25
20
15
10
5
POWER
(HP)
20
40
60
80
100
120
VEHICLE SPEED (V) KMPH



12
10
8
6
4
2
0
BMEP
Kg/cm²
TORQUE T
(kgm)
30
60
90
120
VEHICLE SPEED
V. (KMPH)

CALCULATION:

1. $$IMEP = \frac{Area \times S.F \times D.F}{Length}$$

$$= \frac{37 \times 5 \times 0.9}{16}$$

$$IMEP = 10.40625 \ kg/cm2$$

2. $$FMEP = a + b(N/1000) + c(N/1000)^2$$

$$= 0.5622 + 0.2811(3816/1000) + 0.0527(3816/1000)^2$$

$$FMEP = 2.403 \ kg/cm2.$$

3. $$FHP = \frac{FMEP \times LA \times n}{4500 \times 100}$$

$$= \frac{2.403 \times 1475 \times 1908}{4500 \times 100}$$

$$FHP = 15.03 \ HP.$$

4. $$IHP = BHP + FHP$$

$$= 52.5 + 12.736$$

$$= 67.5 \ HP$$

5. $$IHP = \frac{IMEP \times LA \times n}{4500 \times 100}$$

$$67.5 = \frac{10.40625 \times LA \times 1908}{4500 \times 100}$$

$$LA = 1530.475 \ cm3$$

6. No of cylinders :

$LA < 1600$ cc

$\therefore$ Four cylinder engine.

7. To Find Bore & stroke:

For square engines, $B = L$

$$\frac{LA}{4} = \frac{\pi B^2}{4} \times L$$

$$\frac{1530.475}{4} = \frac{\pi B^2}{4} \times B$$

$$B = L = 7.869 \text{ cm}$$

FHP = 16.03 HP ; BHP = 52.5 HP ; IHP = 67.5 HP.

8. $$\eta_{mech} = \frac{BHP}{IHP}$$

$$= \frac{52.5}{67.5}$$

$$= 0.778$$

$$\eta_{mech} = 77.80\%$$

9. $$\text{BMEP} = \frac{\text{BHP} \times 4500 \times 100 \times 2}{\text{LA} \times \text{N}}$$

$$= \frac{52.5 \times 4500 \times 100 \times 2}{1530.475 \times 3816}$$

$$\text{BMEP} = 8.09 \text{ kg/cm2}$$

10. Torque, $$T = \frac{\text{BHP} \times 4500}{2\pi N}$$

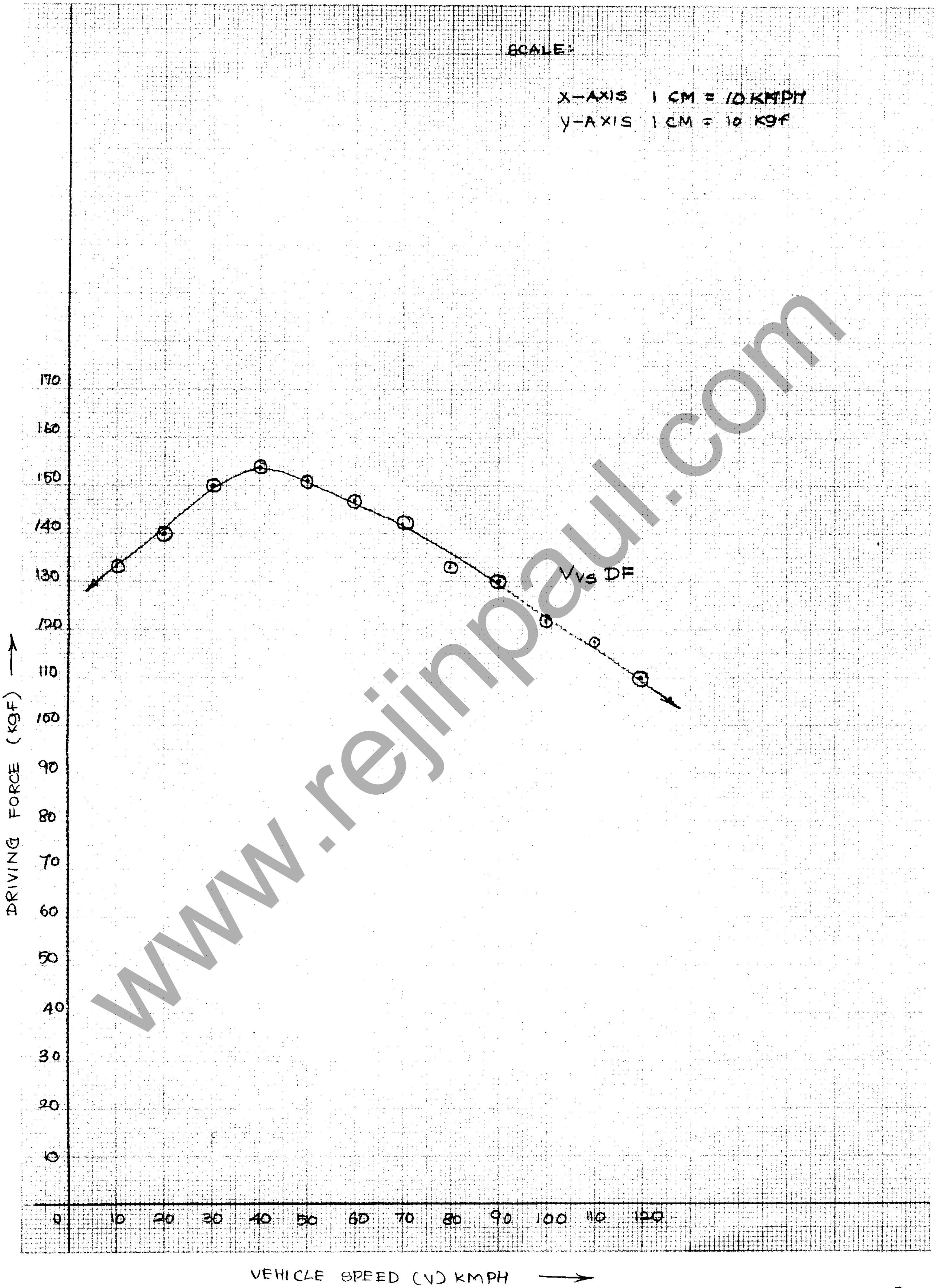
$$= \frac{52.5 \times 4500}{2\pi \times 3816}$$

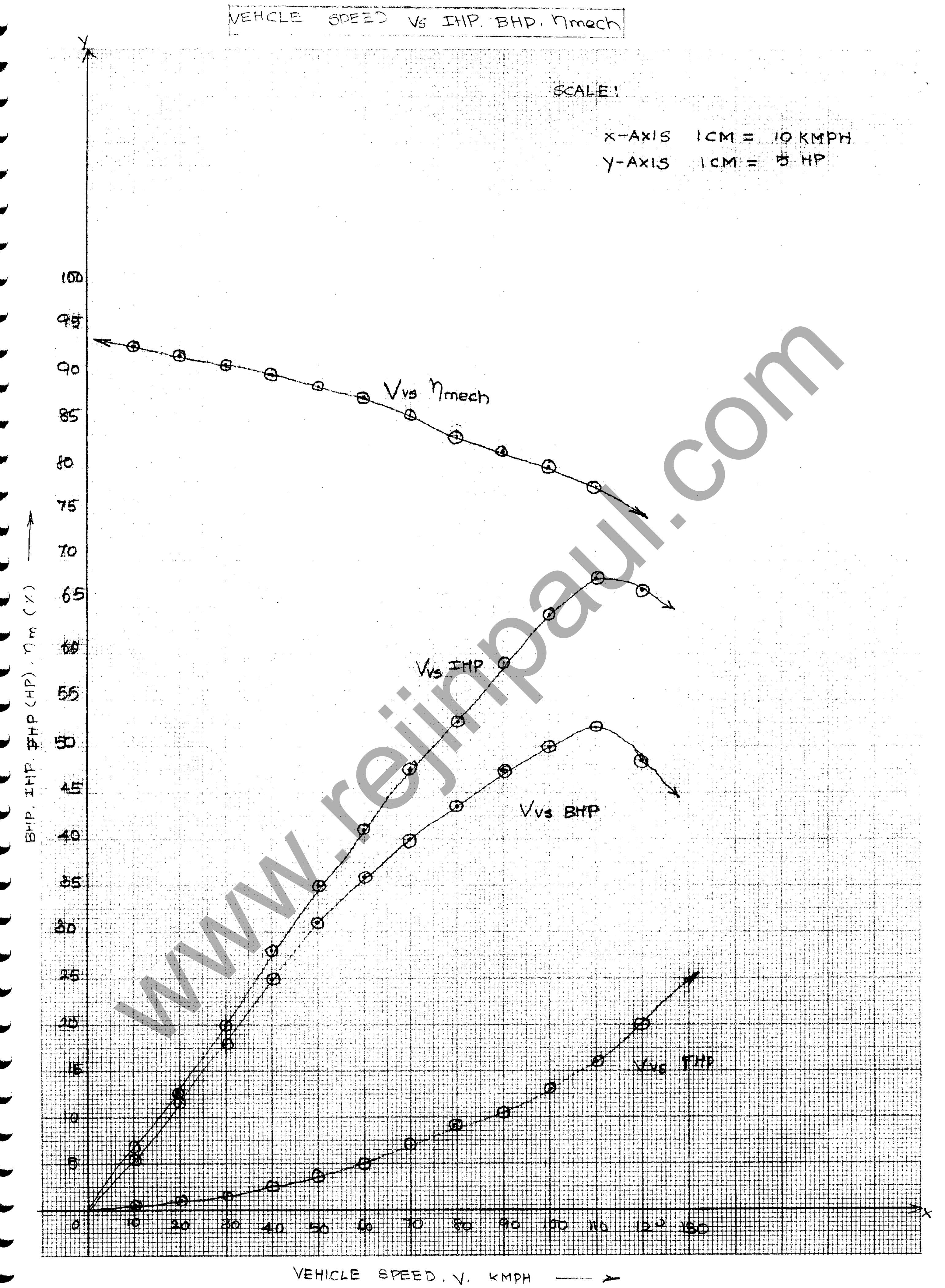
$$T = 9.853 \text{ Nm.}$$

V KMPH	N rpm	BHP (H.P)	FHP (H.P)	IHP (H.P)	η_{mech} (%)	BMEP kgf/cm2	T (kgf-m)
0	0	0	0	0	0	0	0
10	353.33	5.457	0.4014	5.858	93.1547	9.081326	11.06
20	706.67	11.42	0.959	12.379	92.253	9.5023	11.574
30	1060.0	18.184	1.657	19.841	91.65	10.087	12.286
40	1413.3	25.217	2.561	27.778	90.78	10.4915	12.78
50	1766.7	31.142	3.68	34.822	89.432	10.365	12.62
60	2120	35.946	5.028	40.974	87.73	9.97	12.1436
70	2473.3	40.602	6.881	47.483	85.51	9.653	11.757
80	2826.7	43.584	8.548	52.132	83.603	9.0662	11.043
90	3180	47.691	10.756	58.453	81.599	8.82	10.7423
100	3533.3	50.411	13.304	63.715	79.1195	8.389	10.22
110	3816	52.5	15.59	68.09	77.104	8.09	9.853
120	4240	48.48	19.478	67.958	71.34	6.723	8.189

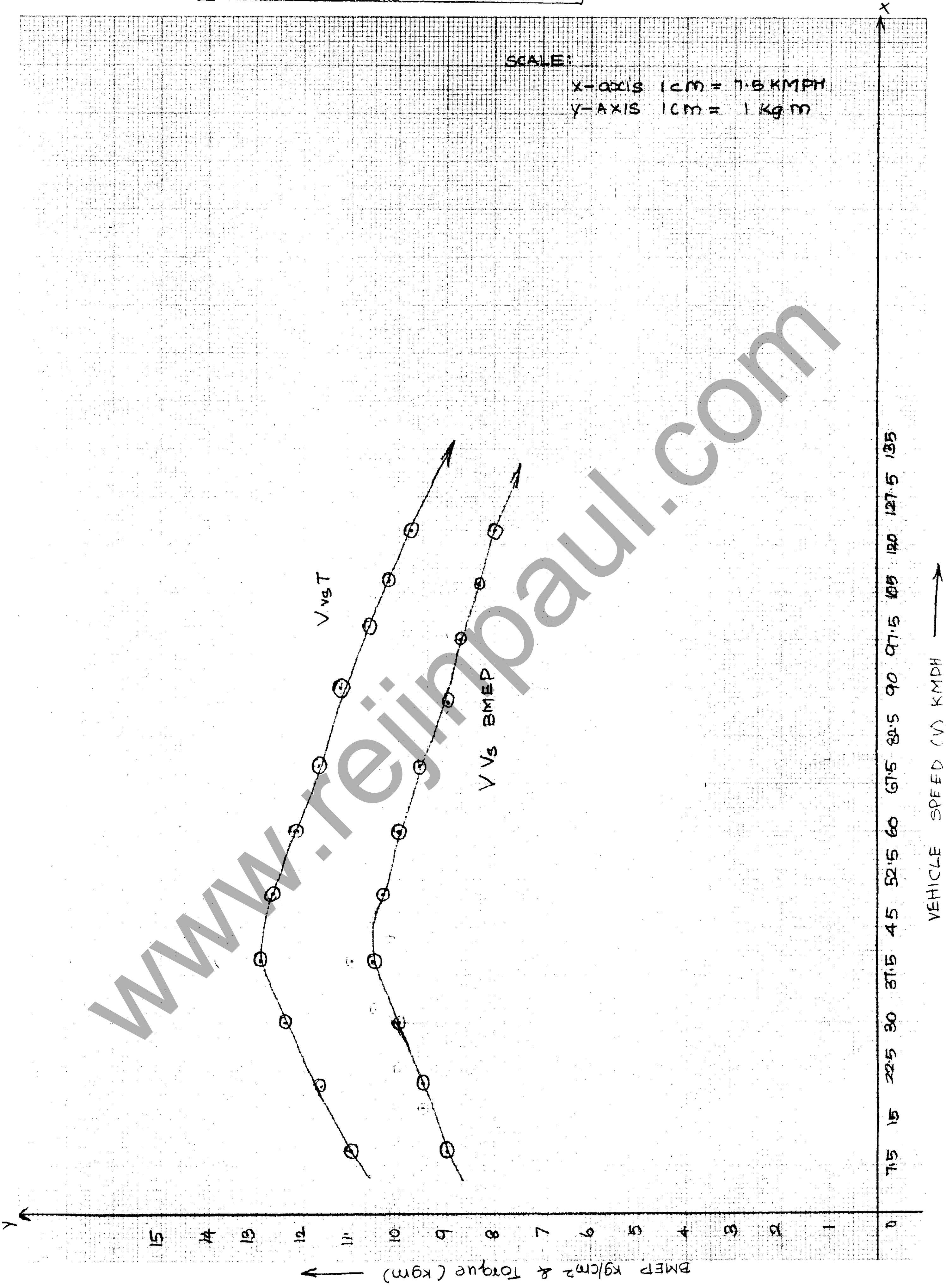
PRESSURE Vs VOLUME
SCALE:
X-AXIS 1cm = 0.5 cc
Y-AXIS 1cm = 5 kgf/cm²
P Vs V
PRESSURE (P) KGF/CM
VOLUME (V) CC
P3
P2
P4
P1

VEHCLE SPEED Vs DRIVING FORCE

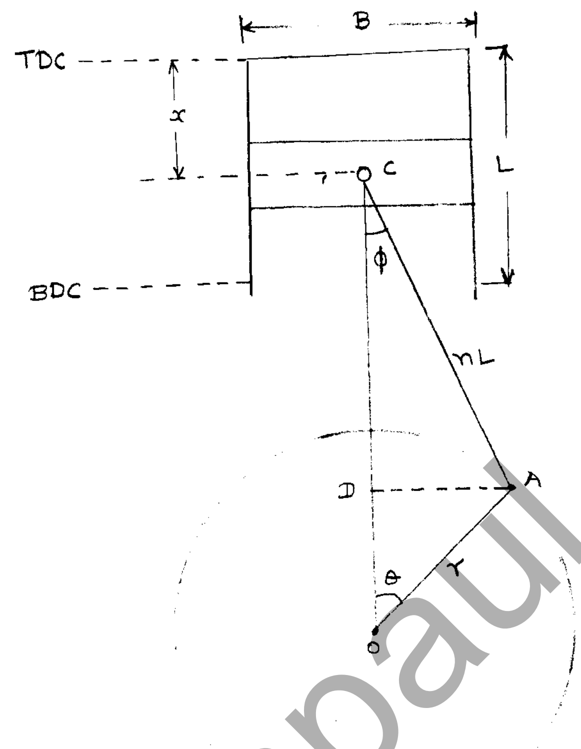



VEHICLE SPEED Vs IHP. BHP. ηmech
SCALE:
X-AXIS 1CM = 10 KMPH
Y-AXIS 1CM = 5 HP
V vs ηmech
V vs IHP
V vs BHP
V vs FHP
BHP, IHP, FHP (HP), ηm (%)
VEHICLE SPEED, V, KMPH

VEHICLE SPEED Vs BMEP . TORQUE



PISTON VELOCITY & ACCELERATION:



Let,

B = Bore diameter

L = stroke length

$n = \dfrac{\text{Length of the connecting rod}}{\text{stroke length (L)}}$

r = crank radius $= \frac{L}{2}$

In the fig. the piston moved from TDC at a distance x

Now, $x = \left(nL + \frac{L}{2}\right) - CO$

From the fig. $CO = CD + DO$

$$CO = \frac{L}{2}\cos\theta + nL\cos\phi$$

where θ and ϕ are shown in fig.

$$x = \left(nL + \frac{L}{2}\right) - \left(\frac{L}{2}\cos\theta + nL\cos\phi\right)$$

$$= \frac{L}{2}(1-\cos\theta) + nL(1-\cos\phi)$$

$$x = \frac{L}{2}(1-\cos\theta) + nL\left(1 - \left(1 - \frac{\sin^2\theta}{8n^2}\right)\right)$$

Where, $\cos\phi = 1 - \dfrac{\sin^2\theta}{8n^2}$

From the figure,

$$AD = \frac{L}{2}\sin\theta$$

$$AD = nL\sin\phi$$

$$\frac{L}{2}\sin\theta = nL\sin\phi$$

$$\sin\phi = \frac{\sin\theta}{2n}$$

$$\sin^2\theta = \frac{\sin^2\theta}{4n^2}$$

$$\cos^2\phi = 1 - \sin^2\phi$$

$$= 1 - \frac{\sin^2\theta}{4n^2}$$

$$\cos\phi = \sqrt{1 - \frac{\sin^2\theta}{4n^2}}.$$

By Binomial theorem.

$$(1-x)^n = 1 - \frac{nx}{1!} + \frac{n(n+1)x^2}{2!} + \dots$$

$$(1-x)^{1/2} = 1 - \frac{1}{2}\frac{\sin^2\theta}{4n^2} + \frac{1}{2}\cdot\frac{3}{2}\cdot\frac{\sin^4\theta}{16n^4 2}$$

$$= 1 - \frac{\sin^2\theta}{8n^2} + \frac{3\sin^4\theta}{8\times 16n^4} + \cdots\cdots$$

$$\cos\phi = 1 - \frac{\sin^2\theta}{8n^2} \quad \because \text{neglecting higher orders.}$$

$$\therefore \quad x = \frac{L}{2}(1-\cos\theta) + nL\frac{\sin^2\theta}{8n^2}$$

$$x = \frac{L}{2}(1-\cos\theta) + \frac{L}{8n}\sin^2\theta$$

Velocity of piston, $V_P = \frac{dx}{dt}$

$$V_p = \frac{L}{2}\left[-(-\sin\theta)\frac{d\theta}{dt}\right] + \frac{L}{8n}(2\sin\theta\cos\theta\, d\theta/dt)$$

$$= \frac{d\theta}{dt}\left[\frac{L}{2}\sin\theta + \frac{L}{8n}\sin 2\theta\right]$$

Now, $\frac{d\theta}{dt} = \frac{2\pi N}{60}$ where N - Engine rpm at max. BHP

$$V_p = \frac{2\pi N}{60}\left[\frac{L}{2}\sin\theta + \frac{L}{8n}\sin 2\theta\right]$$

$$= \frac{\pi NL}{60}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right] \text{...... cm/sec}$$

$$V_p = \frac{\pi NL}{6000}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right] \text{........ m/sec}$$

Acceleration of piston, $a_p = \dfrac{dV_p}{dt}$

$$a_p = \frac{\pi N L}{6000}\left[\cos\theta + \frac{\cos 2\theta \cdot 2}{4n}\right]\frac{d\theta}{dt}$$

$$a_p = \frac{\pi^2 N^2 L}{6000 \times 30}\left[\cos\theta + \frac{\cos 2\theta}{n}\right] \text{ .... } m/s^2$$

where, $\dfrac{d\theta}{dt} = \dfrac{2\pi N}{60} = \dfrac{\pi N}{30}$

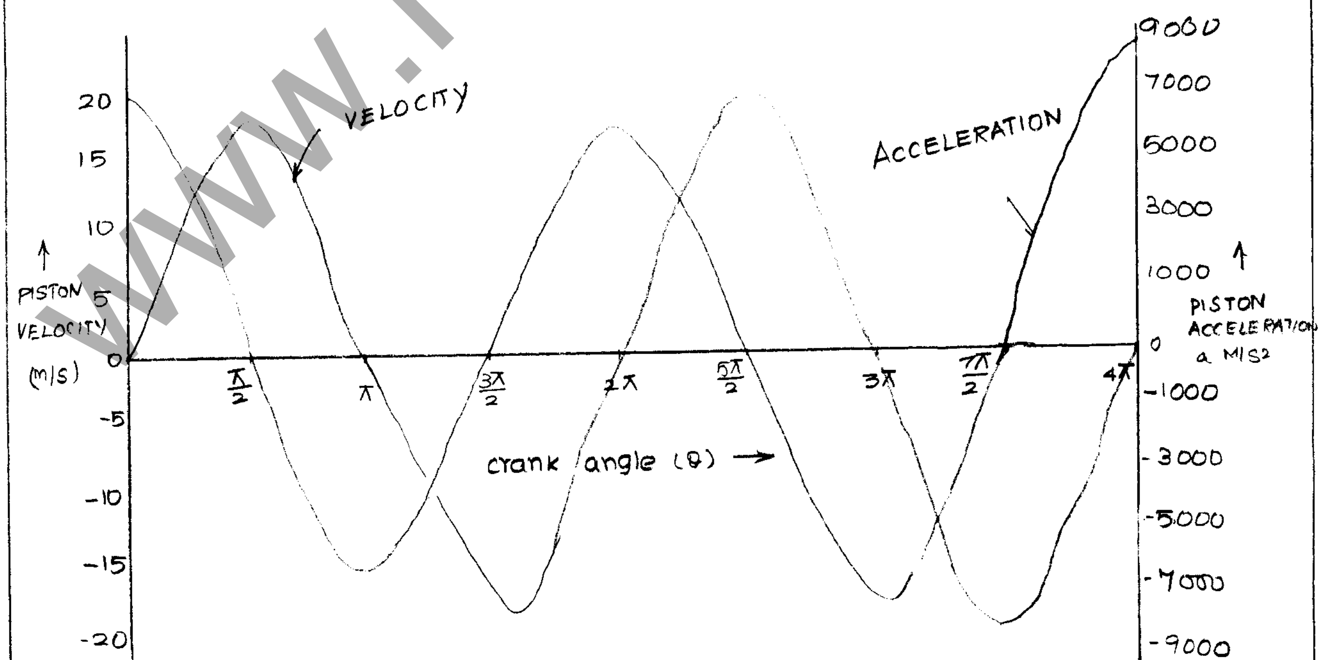
N - Engine speed at max. BHP

L - Length of stroke in cm

$n = 1.2 - 2$ for square and under square.

$n = \simeq 2$ for over square engine.

GRAPH :



crank angle θ. Degree		$\sin\theta$	$\frac{\sin 2\theta}{4n}$	$\sin\theta + \frac{\sin 2\theta}{4n}$	V_p m/s	$\cos\theta$	$\frac{\cos 2\theta}{2n}$	$\cos\theta + \frac{\cos 2\theta}{2n}$	a_p m/s²
0	360	0.0	0.0	0.0	0.0	1.0	0.25	1.25	7853.75
15	375	0.2588	0.0625	0.3213	5.05	0.966	0.2165	1.1825	7429.6
30	390	0.50	0.1083	0.6083	9.564	0.866	0.125	0.991	6226.4
45	405	0.7071	0.125	0.8321	13.083	0.707	0.0	0.7071	4442.04
60	420	0.866	0.1083	0.9743	15.32	0.50	−0.125	0.375	2356.73
75	435	0.9659	0.0625	1.0284	16.17	0.259	−0.2165	0.0425	267.03
90	450	1.00	0.00	1.00	15.723	0.00	−0.25	−0.25	−1570.45
105	465	0.9659	−0.0625	0.9034	14.204	−0.259	−0.2165	−0.4755	−2987.6
120	480	0.866	−0.1083	0.7577	11.913	−0.50	−0.125	−0.625	−3926.9
135	495	0.7071	−0.125	0.5821	9.1522	−0.707	0.00	−0.707	−442.04
150	510	0.50	−0.1083	0.3917	6.1586	−0.866	0.125	−0.741	−4655.7
165	525	0.26	−0.0625	0.1963	3.086	−0.966	0.2165	−0.7495	−4709.1
180	540	0.00	0.00	0.00	0.00	−1.00	0.25	−0.75	−4712.3

crank angle θ degree	sinθ	$\frac{\sin 2\theta}{4n}$	$\sin\theta + \frac{\sin 2\theta}{4n}$	V_p m/sec	cosθ	$\frac{\cos 2\theta}{2n}$	$\cos\theta + \frac{\cos 2\theta}{2n}$	a_p m/sec²
195 555	−0.259	0.0625	−0.1963	−3.086	−0.966	0.2165	−0.7496	−4709.11
210 570	−0.50	0.1083	−0.3917	−6.1586	−0.866	0.125	−0.741	−4665.7
225 585	−0.7071	0.125	−0.5821	−9.1522	−0.707	0.00	−.7071	−4442.71
240 600	−0.866	0.1083	−0.7577	−11.113	−0.50	−0.125	−0.665	−3926.9
255 615	−0.966	0.0625	−0.9034	−14.204	−0.259	−0.2165	−0.4755	−2987.6
270 630	−1.00	0.00	−1.00	−15.723	0.00	−0.25	−0.25	−1570.75
285 645	−0.966	−0.0625	−1.0284	−16.17	0.259	−0.2165	−0.0425	−2987.6
300 660	−0.866	−0.1083	−0.9743	−15.32	0.50	−0.125	0.375	2356.125
315 675	−0.7071	−0.125	−0.8321	−13.083	0.707	0.00	0.707	4442.04
330 690	−0.5	−0.1083	−0.608	−9.564	0.866	0.125	0.991	6226.40
345 705	−0.26	−0.063	−0.3213	−5.05	0.966	0.2165	1.1825	7429.65
360 720	0.0	0.0	0.0	0.0	1.00	0.25	1.25	7853.8

CALCULATION :

$\theta = 45^\circ$

1. velocity of piston ,

$$V_p = \frac{\pi N L}{6000}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right] \cdots\cdots m/s$$

$$= \frac{\pi \times 3816 \times 7.869}{6000} \times 0.8321$$

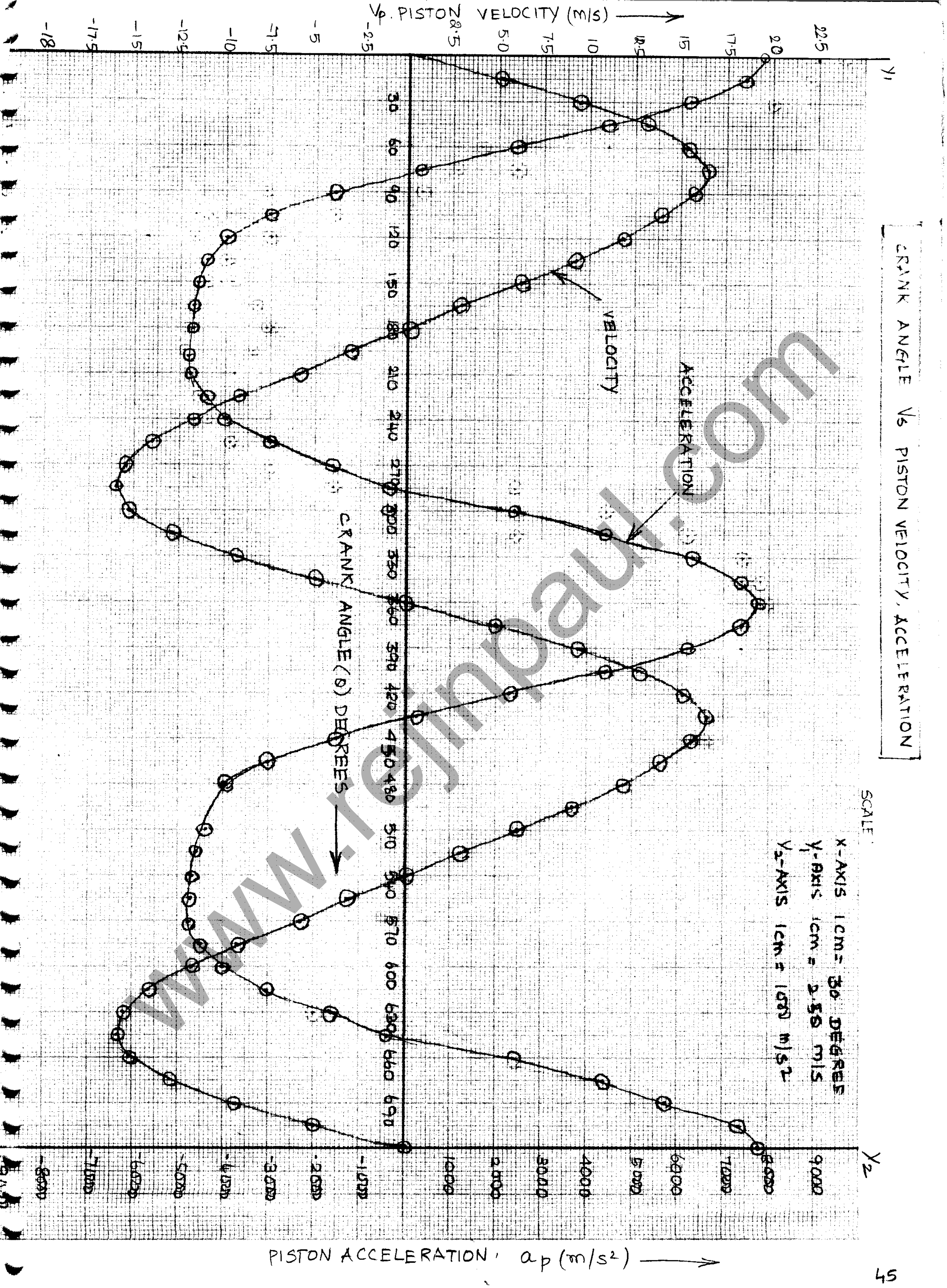
$$V_p = 13.083 \ m/sec.$$

2. Acceleration of Piston,

$$a_p = \frac{\pi^2 \times N^2 \times L}{30 \times 6000}\left[\cos\theta + \frac{\cos 2\theta}{2n}\right] \cdots\cdots m/s^2$$

$$= \frac{\pi^2 \times 3816^2 \times 7.869}{30 \times 6000} \times 0.7071$$

$$a_p = 4442.04 \ m/sec^2.$$


Vp. PISTON VELOCITY (m/s)
PISTON ACCELERATION, ap (m/s²)
CRANK ANGLE Vs PISTON VELOCITY, ACCELERATION
VELOCITY
ACCELERATION
CRANK ANGLE (θ) DEGREES
SCALE
X-AXIS 1cm = 30 DEGREES
Y1-AXIS 1cm = 2.50 m/s
Y2-AXIS 1cm = 1000 m/s²
Y1
Y2

INERTIA FORCE, GAS FORCE & RESULTANT FORCE :

Inertia Force :

Due to the acceleration of reciprocating mass an opposite force is created and it is called as inertia force.

$$\text{Inertia Force} = ma = \frac{W}{g} \cdot a$$

$$IF = -\frac{W}{g} a_p$$

since, inertia force is acting vertically up add a negative sign. Here, a_p is acceleration of the piston in m/s^2.

g - Acceleration due to gravity

W - Weight of reciprocating parts in kgf.

Here, W is the weight of piston, piston pin, piston rings, circlips and one third of the connecting rod weight.

$$I.F = -\frac{W}{g} \frac{\pi^2 N^2 L}{18 \times 10^4} \left(\cos\theta + \frac{\cos 2\theta}{2n} \right) \dots\dots\dots \text{kgf.}$$

where, I.F = Inertia force

W = Weight of reciprocating parts

= [Wt of reciprocating parts/cm^2] x Bore area cm^2

$= [wt/cm^2] \times \frac{\pi}{4} B^2$ B in cm.

$W = \dots\dots$ kgf.

From the following table we can find the weight of the inertia parts.

Cylinder Bore B mm	Weight of Reciprocating parts per cm^2 of Bore Area.	
	Aluminium alloy Pistons in kgf.	C.I pistons kgf
60	0.011	0.016
70	0.012	0.018
80	0.014	0.020
90	0.015	0.022
100	0.017	0.024
110	0.018	0.026
120	0.019	0.028
130	0.02	0.030

GAS FORCES:

Due to the pressure of the gas in the cylinder and combustion chamber a certain force is exerted on the piston. The force due to gas pressure acting on the piston crown is known as gas force.

The gas pressure is acting on the piston crown and combustion chamber and the atmospheric pressure is acting on the bottom side of the piston. The net gas force is equal to the bottom difference between the pressure on the piston crown and the atmospheric pressure at bottom side of the piston.

Cylinder pressure = Gas pr. − Back pressure.

Back pressure = 1.03 kgf/cm^2

Gas force = cylinder pressure × Bore Area

If we know, gas pressure from zero to 720° crank angle we can easily determine gas force. Since piston starts from TDC and at that time $\theta = 0$.

0° − 180° → power stroke

180° − 360° → exhaust stroke

360° − 540° → suction stroke

540° − 720° → compression stroke.

1. During power stroke, press changes from maximum to minimum.

2. During exhaust and suction strokes the pressure is almost constant.

3. During compression stroke the pressure changes from minimum to maximum.

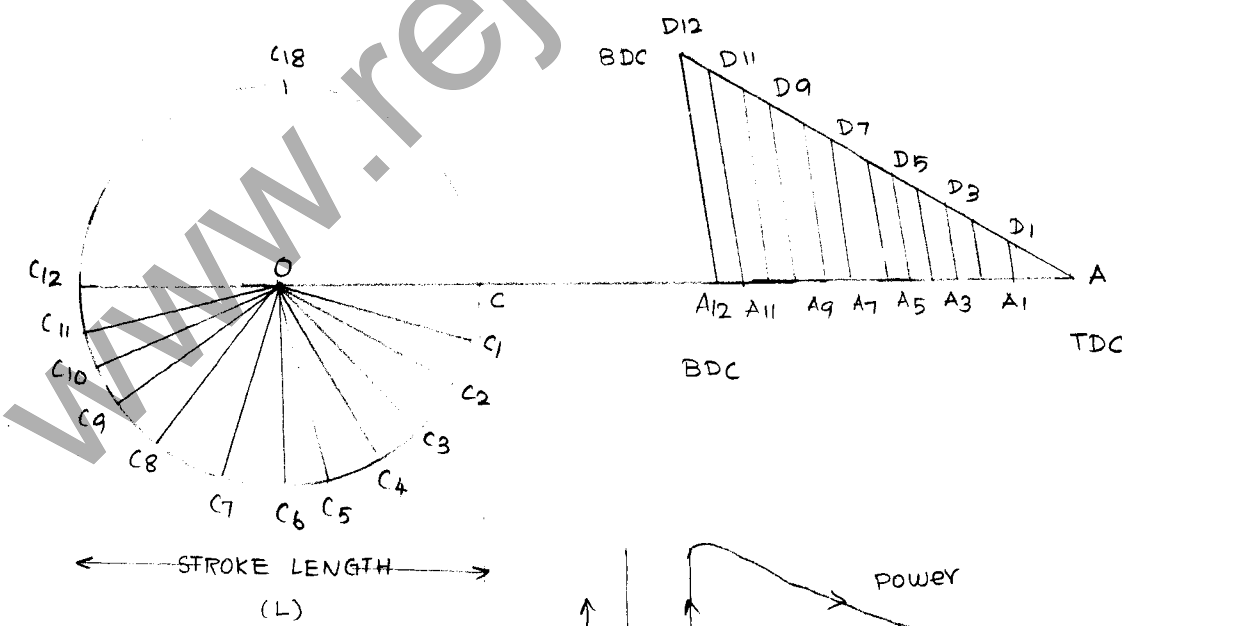
Gas pressure may be assumed as.

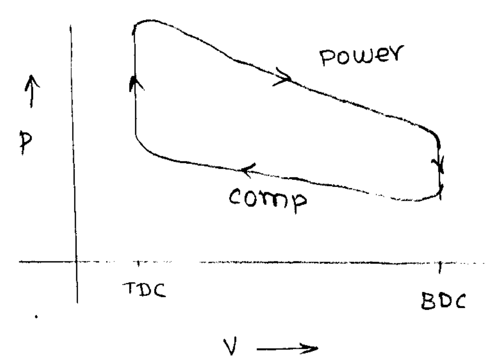
For exhaust stroke $\Rightarrow$ 1.12 to 1.16 kgf/cm^2

For suction stroke $\Rightarrow$ 0.95 to 0.98 kgf/cm^2

For power and compression stroke gas pressure can be determined from the PV diagram.

The absolute gas pressure existing in the cylinder can be obtained from the PV diagram. For this it is necessary to find the distance thr' which the piston has travelled from the top end of the stroke (for power stroke) where the crank has turned through different angles from 0° to 180°. This can be done by constructing the diagram as described below.





CA = Length of connecting Rod = nL

AD = Base length of PV diagram.

A A12 = L

1. Draw line CA as shown in figure. From C draw a circle with stroke length as a diameter at point O.

2. Divide this circle into 24 equal parts, i.e. each segment is 15°. With C1, C2, C3... as centres an CA as a radius cut arcs at A1, A2 ..... A12.

3. Draw a line AD conveniently at any angle from A. such that AB is the base length of the PV diagram. Now join A12 with D.

4. Draw lines parallel to A12D throug A11, A10 ....

5. Now we have points D11, D10 etc on AD.

6. Transforms these point in PV diagram.

7. Corrosponding to these points gas pressure can be determined from PV-diagram in both power and compression stroke.

RESULTANT FORCE:

The algebric sum of the gas force and inertia force gives the resultant force.

$$R.F = G.F + I.F$$

CALCULATION:

$$I.F = -\frac{W}{g} \cdot \frac{\pi^2 N^2 L}{18 \times 10^4} \left(\cos\theta + \frac{\cos 2\theta}{2n} \right)$$

$$= -\frac{0.68}{9.81} \times \frac{\pi^2 \times 3816^2 \times 7.869}{18 \times 10^4} \times 1.25$$

$$I.F = -544.4 \text{ kgf.}$$

$$W = (wt/cm^2) \times \frac{\pi}{4} B^2 \qquad B \text{ in cm}$$

$$= 0.0139 \times \frac{\pi}{4} (7.869)^2$$

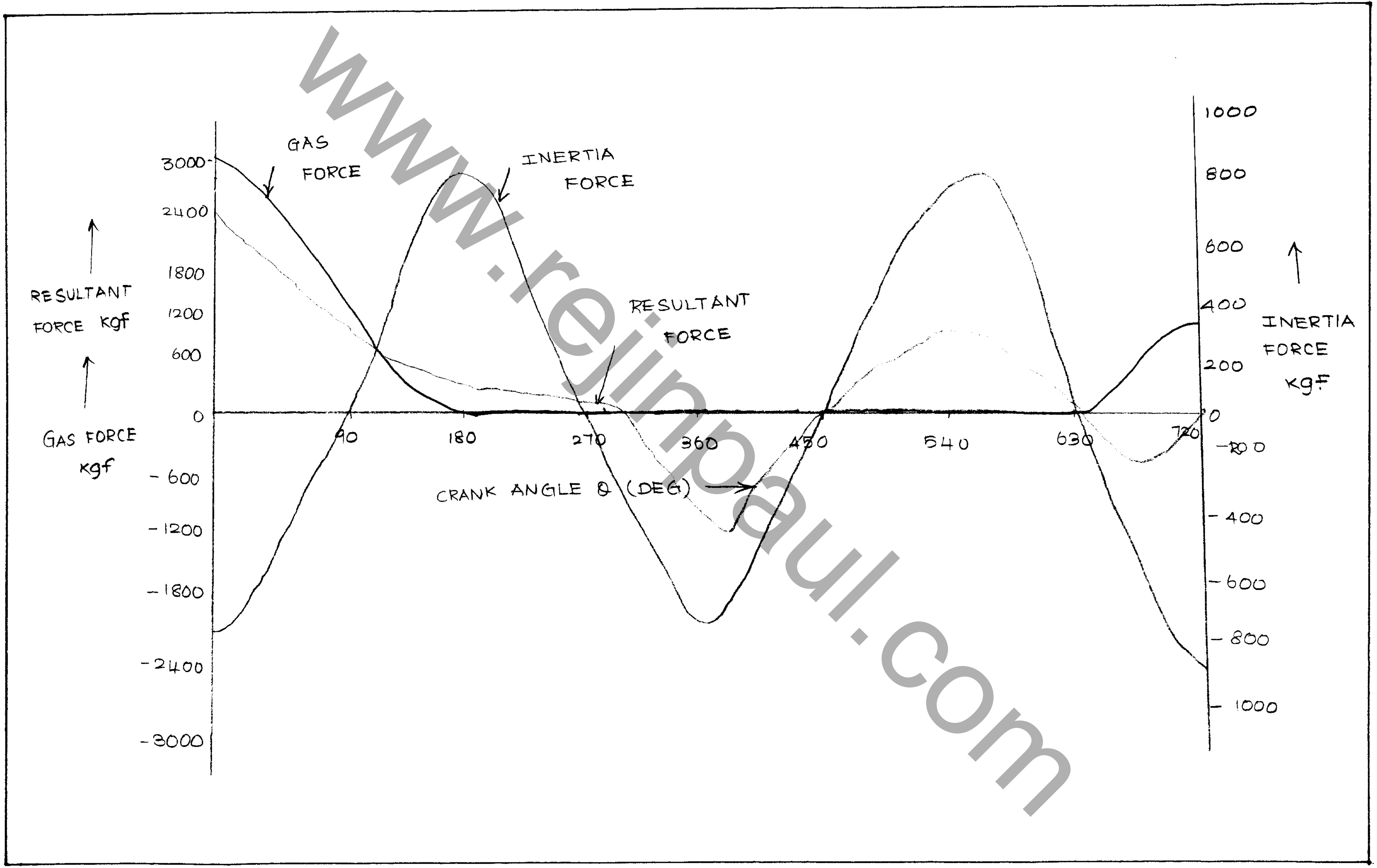
$$W = 0.68 \text{ kgf}$$

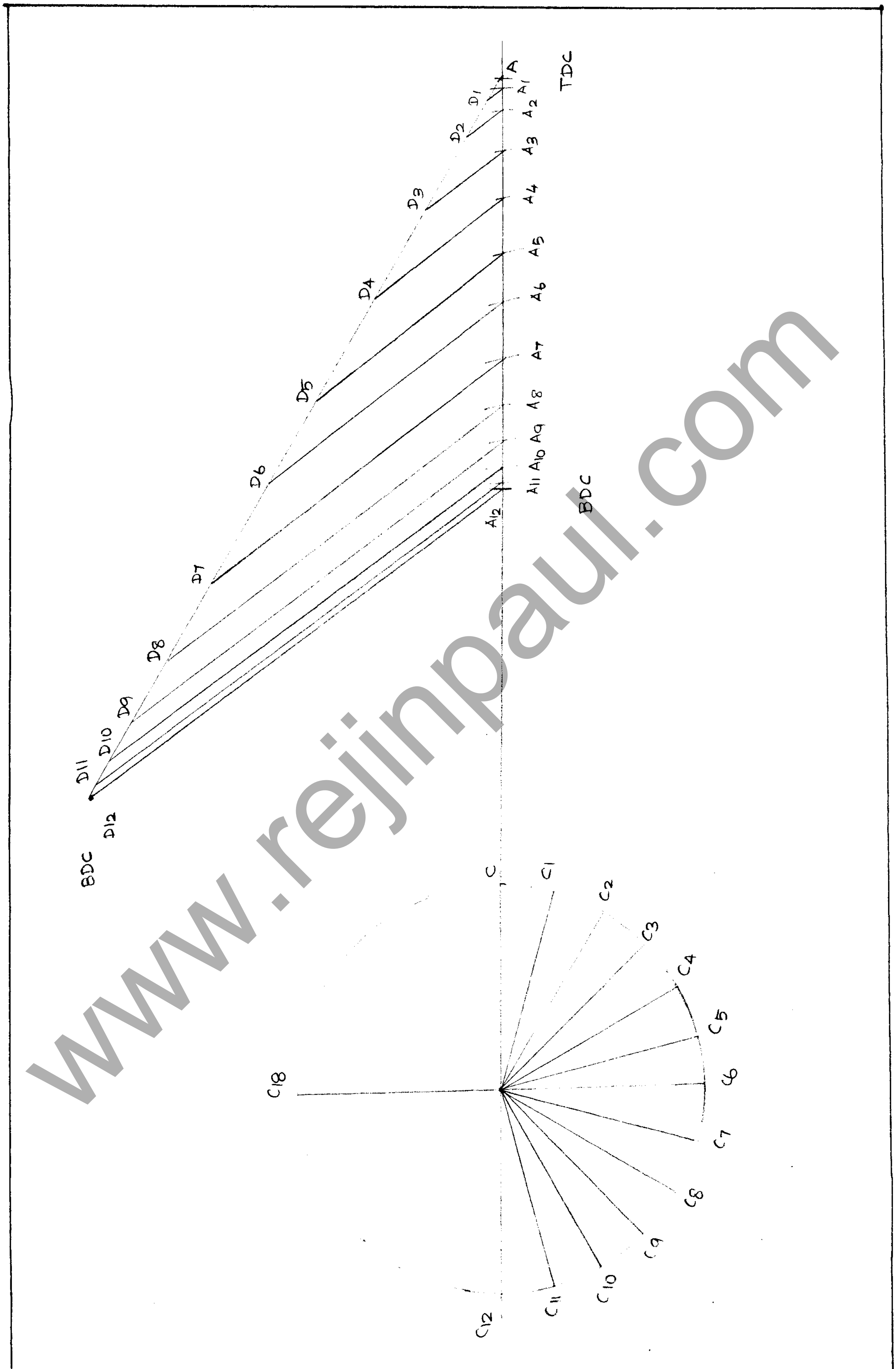
$$G.F = \text{cylinder pr} \times \text{Bore Area}$$

$$= (\text{Gas pr} - \text{Back pr}) \times \frac{\pi}{4} (B)^2$$

$$= (74 - 1.03) \times \frac{\pi}{4} (7.869)^2$$

$$G.F = 3548.733 \ldots \text{ kgf.}$$


GAS
FORCE
INERTIA
FORCE
RESULTANT
FORCE
RESULTANT
FORCE Kgf
GAS FORCE
Kgf
INERTIA
FORCE
Kgf
CRANK ANGLE θ (DEG)
3000
2400
1800
1200
600
0
- 600
- 1200
- 1800
- 2400
- 3000
90
180
270
360
450
540
630
720
1000
800
600
400
200
0
-200
- 400
- 600
- 800
- 1000


TDC
BDC
A
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
BDC
C
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C18

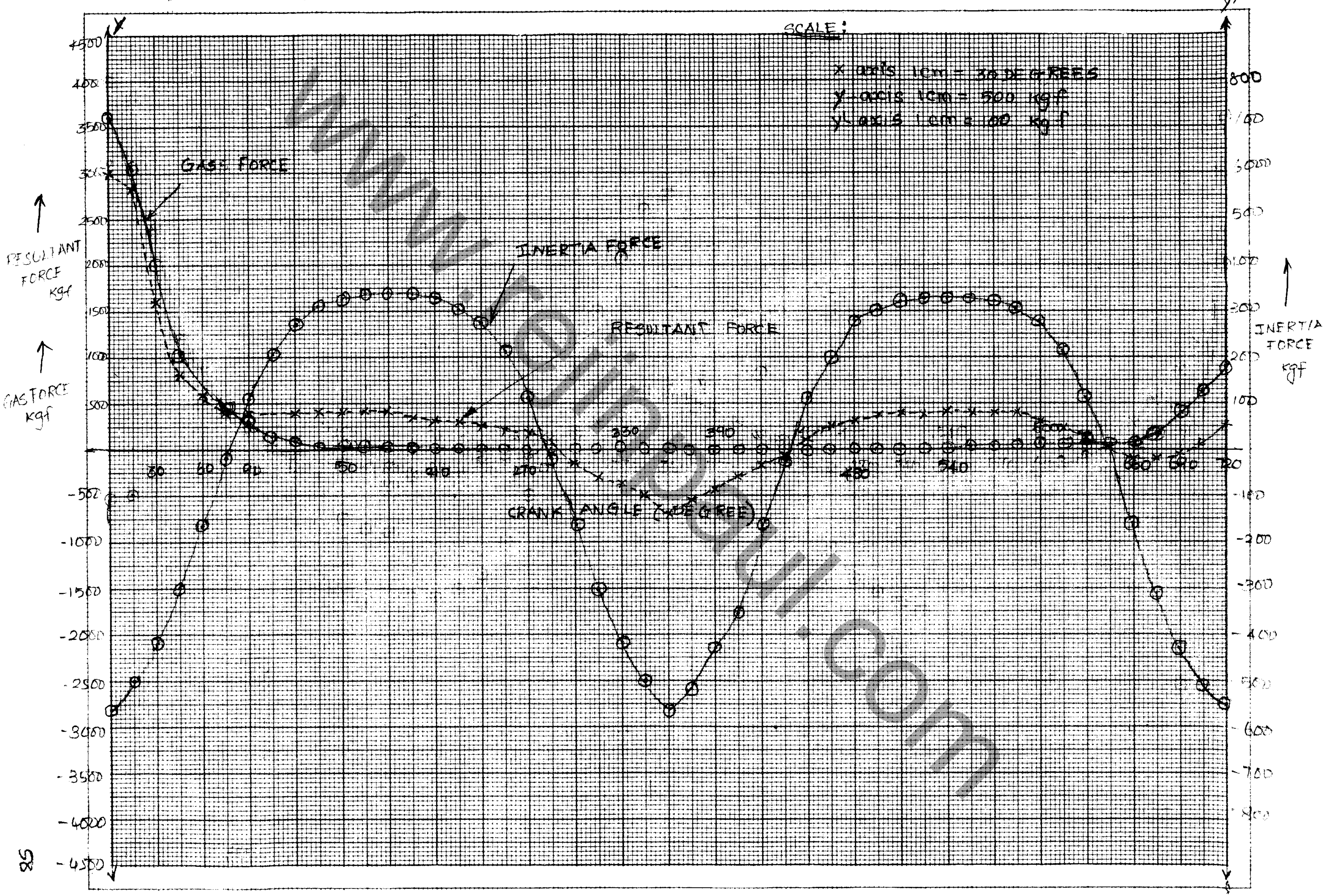
STROKE	Crankangle θ Deg	Gas Pr. Kg/cm²	Back Pr. Kg/cm²	Gas Force Kgf	Inertia Force Kgf	Resultant Force Kgf	Turning Moment Kgf cm
	0	74.0	1.03	3548.733	-544.394	3004.34	0.0
	15	67.5	1.03	3232.62	-514.997	2717.623	3435.5
	30	42.5	1.03	2016.801	-431.596	1585.205	3793.96
	45	24.0	1.03	1117.095	-307.953	809.142	2649.05
POWER	60	15.0	1.03	679.4	-163.32	516.08	1978.33
STROKE	75	10.0	1.03	436.236	-18.509	417.727	1690.224
	90	7.5	1.03	314.654	108.88	423.534	1666.4
	105	6.0	1.03	241.705	207.088	448.793	1595.2
	120	5.0	1.03	191.0721	272.197	463.2691	1381.1
	135	4.75	1.03	180.914	307.93	488.844	1119.6
	150	4.50	1.03	168.76	322.72	491.48	2980.15
	165	4.25	1.03	156.598	326.42	483.02	373.06
	180	4.0	1.03	144.44	326.64	471.08	0.00

STROKE	Crank angle θ (Deg)	Gas pr. Kg/cm2	Back pr. Kg/cm2	Gas Force Kgf	Inertia Force Kgf	Resultant Force Kgf	Turning Moment kg-cm
Exhaust Stroke	195	1.14	1.03	5.35	326.4215	331.7711	-256.241
	210	1.14	1.03	5.35	322.72	328.07	-479.8
	225	1.14	1.03	5.35	307.955	313.305	-717.554
	240	1.14	1.03	5.35	272.201	277.551	-827.43
	255	1.14	1.03	5.35	207.089	212.44	-765.1
	270	1.14	1.03	5.35	108.88	114.23	-449.44
	285	1.14	1.03	5.35	-18.51	-13.1604	53.25
	300	1.14	1.03	5.35	-163.32	-157.97	602.11
	315	1.14	1.03	5.35	-307.91	-302.56	990.55
	330	1.14	1.03	5.35	-431.6	-426.25	1020.2
	345	1.14	1.03	5.35	-515.001	-509.65	644.28
	360	1.14	1.03	5.35	-544.4	-539.494	0.00

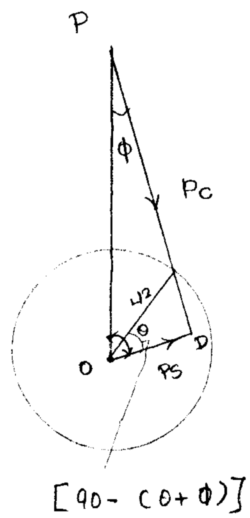
STROKE	crank angle θ (deg)	Gas Pr. kg/cm2	Back Pr. kg/cm2	Gas Force kgf	Resultant Force kgf	Resultant Force kgf	Turning Moment kgf-m.
SUCTION STROKE	375	0.96	1.03	-3.4043	-514.997	-518.4013	-655.34
	390	0.96	1.03	-3.4043	-431.596	-435.0	-1041.1
	405	0.96	1.03	-3.4043	-307.953	-311.36	-1019.4
	420	0.96	1.03	-3.4043	-163.32	-166.72	-639.1
	435	0.96	1.03	-3.4043	-18.509	-21.9133	-88.7
	450	0.96	1.03	-3.4043	108.88	105.4757	414.99
	465	0.96	1.03	-3.4043	207.088	203.7	724.04
	680	0.96	1.03	-3.4043	272.197	268.8	801.34
	495	0.96	1.03	-3.4043	307.93	304.526	697.45
	510	0.96	1.03	-3.4043	322.72	319.316	492.112
	525	0.96	1.03	-3.4043	326.42	323.016	249.48
	540	0.96	1.03	-3.4043	326.64	323.236	0.00

STROKE	Crank angle θ (deg)	Gas Pr. kg/cm2	Back Pr kg/cm2	Gas Force kgf	Inertia Force kgf	Resultant Force kgf	Turning Moment kgf-cm
COMPRESSION STROKE	555	1.20	1.03	8.268	326.42	334.7	-258.5
	570	1.25	1.03	10.7	322.72	333.42	-513.85
	585	1.30	1.03	13.131	307.93	321.061	-735.32
	600	1.35	1.03	15.563	272.20	213.763	-816.13
	615	1.40	1.03	17.994	207.09	225.083	-800.04
	630	1.75	1.03	35.016	108.8996	143.896	-566.17
	645	2.50	1.03	71.49	18.51	89.99	-364.2
	660	3.0	1.03	82.616	-163.32	-80.644	309.14
	675	5.5	1.03	217.39	-307.91	-90.522	296.36
	690	9.8	1.03	426.51	-431.6	-5.09	12.18
	705	14.5	1.03	655.08	-515.0	140.1	-177.1
	720	17.0	1.03	776.7	-544.4	232.3	0.00

CRANK ANGLE Vs RESULTANT, GAS, INERTIA FORCES



TURNING MOMENT :



R - Resultant Force

Pc - force acting on connecting rod

Ps - side force or side thrust.

$\cos\phi = \frac{P}{P_c} \Rightarrow P_c = P/\cos\phi$

$\tan\phi = \frac{P_s}{P} \Rightarrow P_s = P\tan\phi$

R = crank radius = $\frac{L}{2}$

Gas force is transmitted to crank shaft through the connecting rod. At that time side thrust will be acting on the walls of the engine.

Turning Moment = $P_c \times OD$

We can determine Turning moment & side thrust Now.

$$OD = \frac{L}{2}\cos[90 - (\theta + \phi)]$$

$$OD = \frac{L}{2}\sin(\theta + \phi)$$

Turning Moment = $P_c \times OD$

$$= \frac{P}{\cos\phi} \cdot \frac{L}{2}\sin(\theta + \phi)$$

$$\text{Turning Moment} = \frac{PL}{2}\left[\frac{\sin\theta\cos\phi + \cos\theta\sin\phi}{\cos\phi}\right]$$

$$= \frac{PL}{2}\left[\sin\theta + \cos\theta \cdot \tan\phi\right] \quad \because \tan\phi \simeq \frac{\sin\theta}{2n}$$

$$= \frac{PL}{2}\left[\sin\theta + \cos\theta\,\frac{\sin\theta}{2n}\right]$$

$$\cos\theta\sin\theta = \frac{\sin 2\theta}{2}$$

$$= \frac{PL}{2}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right]$$

$$T.M = \frac{PL}{200}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right] \ldots\ldots \text{kgf m}$$

$$T.M = \frac{Pr.AL}{200}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right]$$

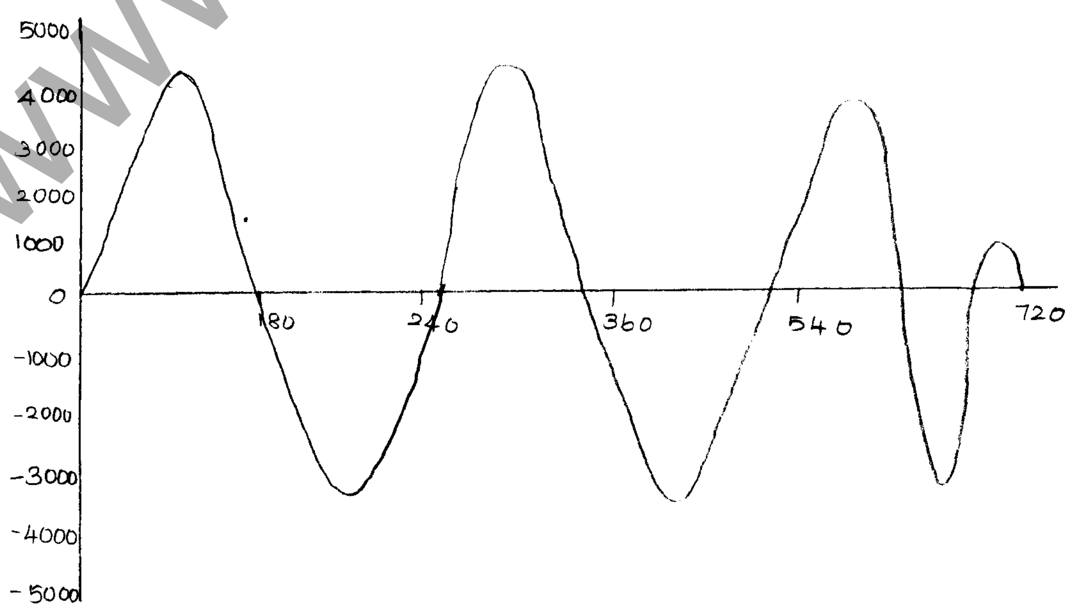
$$= \frac{Pr.D}{200}\left[\sin\theta + \frac{\sin 2\theta}{4n}\right] \ldots\ldots \text{kgf.m}$$

where,

Pr = Resultant pressure kgf/cm2

D = Engine displacement in cc.

T-θ GRAPH:



TURNING MOMENT VS CRANK ANGLE

COMBINED TURNING MOMENT:

For six cylinder engines.

Firing order is 1, 5, 3, 6, 2, 4

Firing interval = $\frac{720°}{6}$ = 120°

Four cylinder engines.

Firing order is 1, 3, 4, 2.

Firing interval = $\frac{720°}{4}$ = 180°.

Four cylinder Engines:

I		II		III		IV		combined T·M kgf-cm
θ	T·M	θ	TM	θ	TM	θ	TM	
0		540		180		360		
15		555		195		375		
.		.		.		.		
.		.		.		.		
.		.		.		.		
180		720		360		540		

SIX CYLINDER ENGINES:

I		II		III		IV		V		VI		combined T.M kgf-cm
θ	TM	θ	TM	θ	TM	θ	TM	θ	TM	θ	TM	
0		480		240		600		120		360		
15		495		255		615		135		375		
.		.		.		.		.		.		
.		.		.		.		.		.		
.		.		.		.		.		.		
120		600		360		720		240		480		

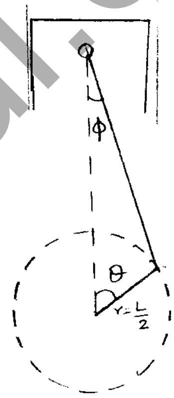
I^st cylinder		II^nd cylinder		III^rd cylinder		IV^th cylinder		Combined
θ deg	TM kgf cm	θ deg	T·M kgf cm	θ deg	T·M kgf cm	θ deg	T·M kgf cm	T·M kgf-cm
0	0·00	540	0·00	180	0·00	360	0·00	0·00
15	3435·5	555	-258·5	195	-256·241	375	-655·4	2265·36
30	3793·96	570	-513·85	210	-479·8	390	-1041·1	1759·21
45	2649.05	585	-735·52	225	-717·54	405	-1019·4	176·59
60	1978·33	600	-816·13	240	-827·43	420	-639·1	-304·33
75	1690·24	615	-800·04	255	-755·1	435	-88·7	46·14
90	1666·4	630	-566·17	270	-449.44	450	414·99	1065·8
105	1595·2	645	-364·12	285	53·25	465	724·04	2008·3
120	1381·1	660	309·14	300	602·11	480	801·84	3093·7
135	1119·6	675	296·36	315	990·55	495	697·45	3103·96
150	2980·15	690	12·18	330	1020·2	510	492·112	4504·64
165	373·06	705	-177·11	345	644·28	525	249·48	2291·65
180	0·00	720	0·00	360	0·00	540	0·000	1620·00

SIDE THRUST:

Side thrust is defined as the force or thrust acting on the cylinder walls due to angularity of the connecting rod.

Since side thrust is maximum only in the power stroke, it is enough to find side thrust only for power stroke. ie, Between 0° to 180°

Side thrust = P_s = $P \tan\phi$



P = Resultant Force.

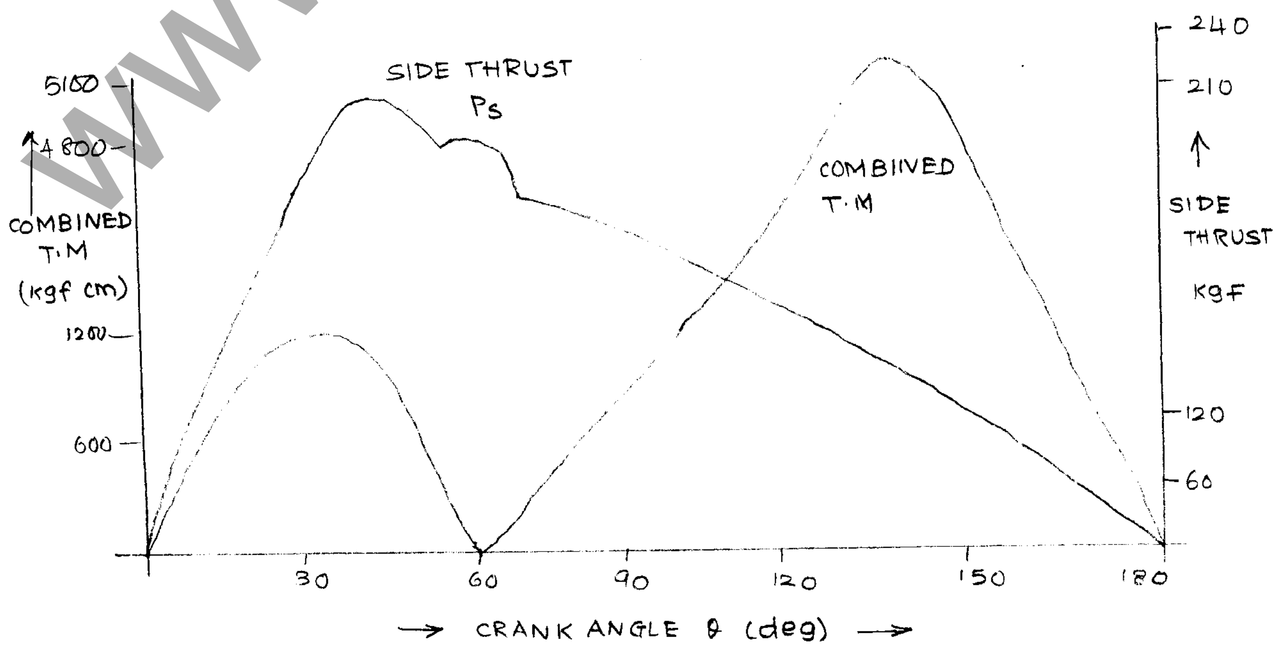
On resolving Force,

$$nL \sin\phi = \frac{L}{2} \sin\theta$$

$$\sin\phi = \frac{\sin\theta}{2n}$$

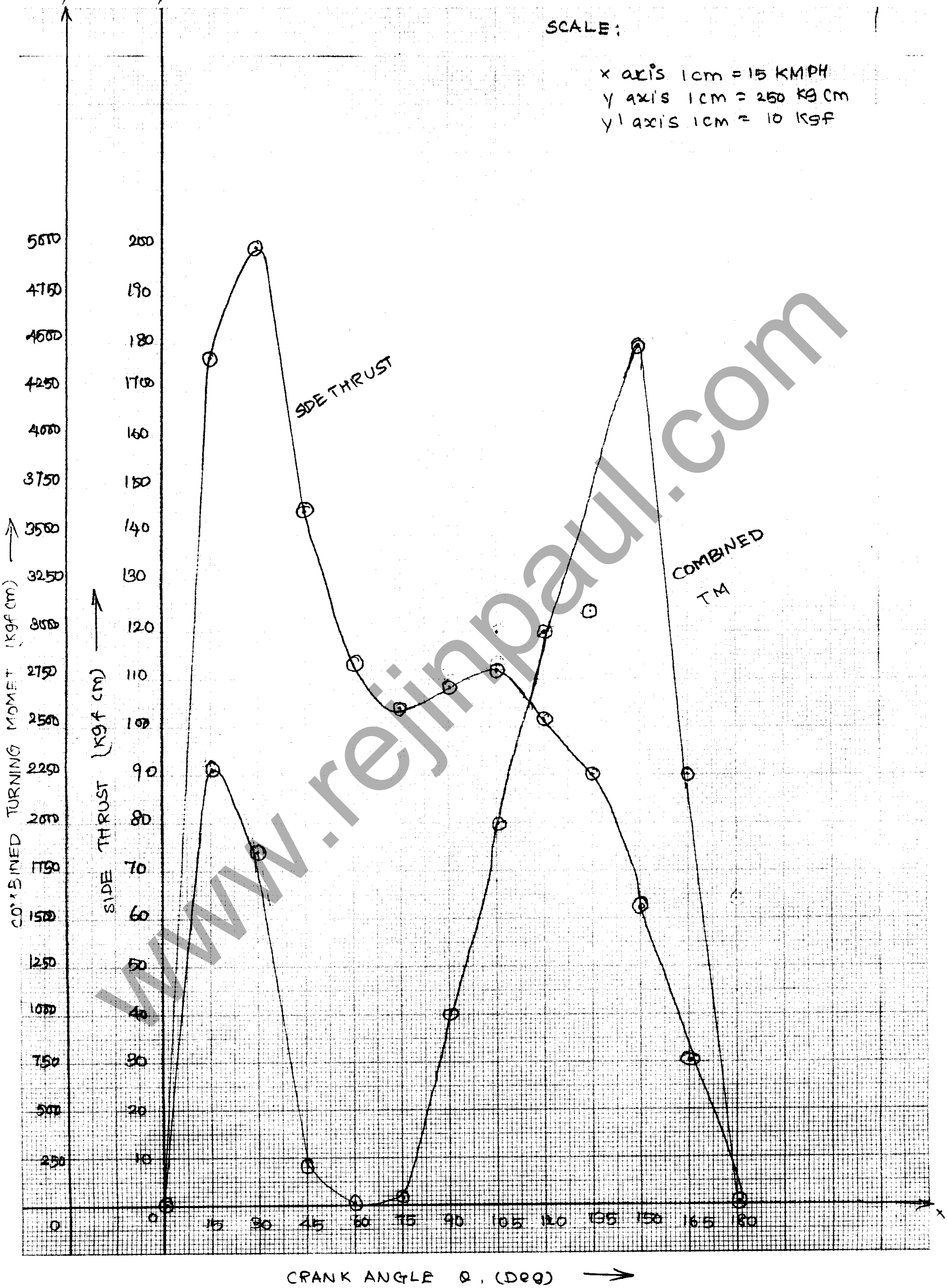
$$\phi = \sin^{-1}\left(\frac{\sin\theta}{2n}\right)$$

GRAPH:

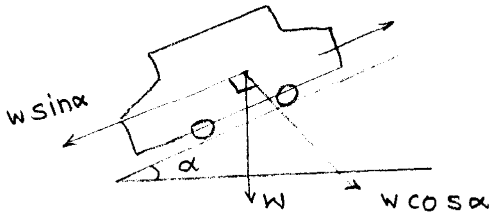


crank angle θ (deg)	$\frac{\sin\theta}{2n}$	$\phi = \sin^{-1}\left(\frac{\sin\theta}{2n}\right)$	$\tan\phi$	side Thrust $P_s = P\tan\phi$ kgF
0	0	0	0	0
15	0.0625	3.71	0.065	176.65
30	0.125	7.2	0.126	199.72
45	0.177	10.18	0.18	145.33
60	0.2165	12.5	0.222	114.45
75	0.241	13.97	0.25	103.95
90	0.25	14.5	0.26	109.36
105	0.2415	13.974	0.25	111.68
120	0.2165	12.504	0.22	102.74
135	0.18	10.18	0.18	87.8
150	0.125	7.181	0.126	61.9
165	0.0625	3.71	0.065	31.32
180	0.00	0.00	0.00	0.00

CRANK ANGLE VS COMBINED T.M & SIDE THRUST



DETERMINATION OF GRADIABILITY, ACCELERATION, GEAR RATIO:



Assume Max. Gradiability as 30 to 40% [38%]

Gradiability = 100 Tan α

Gradient resistance, $R_g = W \sin\alpha$

Assume First gear ratio as 3:1

From the graph T Vs V,

Find V coursponding the the Tmax also Find Tmax

Find the maximum speed in the first gear

$$V_1 = \frac{\text{Vehicle speed for max Torque}}{G_1}$$

Now, Find resistance at First gear.

$$R_{t1} = R_a + R_r = K_a A V_1^2 + (7.6 + 0.056 V_1) W$$

Now, $100 \tan\alpha = 38 \Rightarrow \alpha = ?$

$$R_g = W \sin\alpha \; .... \; \text{kgf}$$

Driving Force, $DF = R_{T1} + R_g \; .... \; \text{kgf}$

$$D.F = \frac{T_e \; G \; r_a \; \eta_t}{R_w}$$

T_e = Engine torque

G = Gear ratio

r_a = Axle reduction

η_t = Transmission efficiency

R_w = Wheel radius.

Find the gear ratio and it should agree with the assumed value within 5% variation.

If $G > 3$, assume 4 speed Gear box

If $G < 3$, assume 3 speed Gear box

3- speed Gear box:

Gear	Gear ratio	Theoretical	practical	
I	G_1	G_1	G_1	$(p2)$
II	G_2	$\sqrt{G_1}$	$0.9\sqrt{G_1}$	$(.9p)$
III	G_3	1:1	1:1	(1:1)

4- speed Gear box:

Gear	Gear ratio	Theoretical	practical	
I	G_1	G_1	G_1	$(p3)$
II	G_2	$(G_1)^{2/3}$	$(G_1)^{2/3}$	$(p2)$
III	G_3	$(G_1)^{1/3}$	$0.9(G_1)^{1/3}$	$(.9p)$
IV	G_4	1:1	1:1	(1:1)

The gear ratios in "Geometrical progression". since the top gear and ~~next~~ gear are used frequently these two gear ratio should be as close as possible.

ACCELERATION:

$$\frac{W}{g} \cdot a \propto EDF$$

$$\frac{W}{g} \cdot a = K \cdot EDF$$

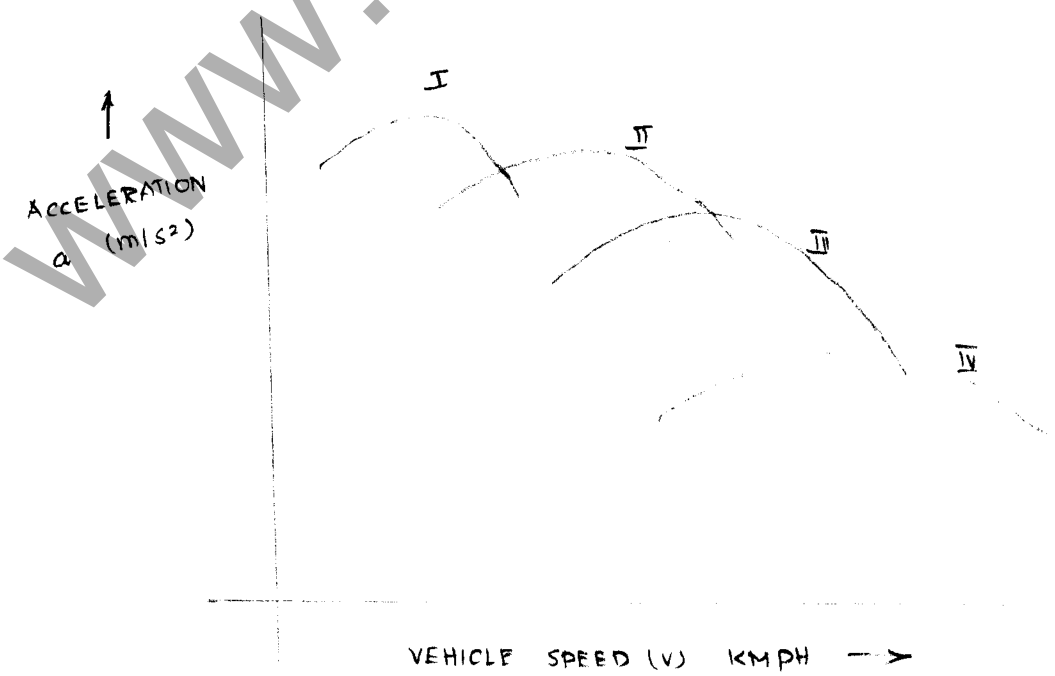
$$a = \frac{kg\ EDF}{W} \ \ldots\ldots\ m/s^2$$

K = 0.75 at I gear
0.80 at II gear
0.85 at III gear
0.91 at IV gear.

and, $EDF = DF - R_t$

$R_t = R_a + R_r + R_g$

W - GVW in Kgf.



FIRST GEAR:

V KMPH	N rpm	T Kgf m	R_L Kgf	DF Kgf	EDF Kgf	a m/s2	sin α $\left(\frac{EDF}{W}\right)$	α	Gradiability 100 Tan α
5	175.0	10.7	8.8	334.75	325.95	2.12	0.2885	16.77	30.135
10	353.33	11.06	9.796	346.016	336.22	2.20	0.298	17.34	31.2
15	525.0	11.38	11.9	356.03	344.13	2.241	0.305	17.76	32.03
20	706.67	11.574	12.164	362.1	349.94	2.28	0.31	18.06	32.61
25	875.0	12.086	14.0	378.115	364.12	2.371	0.32	18.663	33.78
30	1060	12.286	15.67	384.4	368.73	2.401	0.33	19.27	34.961
35	1250	12.58	17.5	393.6	376.1	2.45	0.333	19.451	35.32
40	1413.3	12.78	20.35	400.00	379.65	2.472	0.336	19.63	35.67

SECOND GEAR:

V KMPH	N rpm	T Kgf-cm	Rt kgf	DF kgf	EDF kg f	a m/s2	sinα $\left(\frac{EDF}{W}\right)$	α	Gradiability 100 tanα
10	353.33	11.06	9.796	202.1	192.3	1.34	0.17	9.88	17.42
20	706.67	11.574	12.164	211.5	199.34	1.343	0.176	10.14	17.88
30	1060.0	12.3	15.67	224.5	208.83	1.45	0.185	10.66	18.823
40	1413.3	12.78	20.35	233.52	213.17	1.48	0.189	10.89	19.24
50	1766.7	12.62	26.17	230.6	204.43	1.42	0.181	10.43	18.41
60	2120.0	12.144	33.14	221.9	188.76	1.311	0.167	9.613	16.94
70	2473.3	11.76	41.26	214.824	173.564	1.205	0.154	8.836	15.55

TOP GEAR:

V KMPH	N rpm	T Kgfcm	Rt kgf	DF KgF	EDF Kgf	a m/s²	sin α $\left(\frac{EDF}{W}\right)$	α	Gradiability 100 tan α
20	706.67	11.574	12.164	123.46	101.3	0.748	0.09	5.164	9.04
40	1413.3	12.78	20.35	136.32	115.97	0.856	0.103	5.912	10.4
60	2120.0	12.144	33.14	129.532	96.392	0.71	0.085	4.876	8.4
80	2826.7	11.043	50.53	117.792	67.3	0.5	0.06	3.44	6.01
100	3533.3	10.22	72.54	109.013	36.473	0.27	0.0323	1.851	3.232
120	4240	8.189	99.16	87.35	-11.81	-0.087	-0.01	-0.6	-0.0105

VEHICLE SPEED VS ACCELERATION