

## 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, gradability 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 or 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 unladen weight (ULW).

#### 3. Normal laden 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 <sup>2</sup> | Max. permissible speed KMPH |
|---------|-------------------|-----------------------------|-------------------------------|-----------------------------|
| 1.      | Small cars        | 800 - 1000<br>(M-800)       | 0.73 - 0.9                    | 110 - 115                   |
| 2.      | small Medium cars | 1000 - 1200<br>(FIAT)       | 0.9 - 1.05                    | 115 - 130                   |
| 3.      | Medium cars       | 1200 - 1500<br>(AMBASSADOR) | 1.05 - 1.2                    | 130                         |
| 4.      | Medium large cars | 1500 - 2000<br>(CANTASSA)   | 1.05 - 1.20                   | 130 - 160                   |
| 5.      | Large cars        | 2500 - 3000<br>(BENZ)       | 1.05 - 1.50                   | 160 - 190                   |
| 6.      | Luxury cars       | 3000 - 4000<br>(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. In addition gradient resistance when the vehicle is moving up in a slope because the weight of vehicle is carried over a vertical distance. Therefore HP depends on the total resistance and the forward speed of vehicle.

## RESISTANCES:

### D Air Resistance ( $R_a$ ):

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 due to gravity ( $g$ )

$$\therefore R_a = \frac{c \rho A V^2}{2g} \dots\dots \text{kgf.}$$

$$\Rightarrow R_a = k_a A V^2 \dots\dots \text{kgf.}$$

where,

$$k_a = \frac{c \rho}{2g} = \text{Aerodynamic constant} = 0.0032$$

$A$  = projected frontal area ( $\text{m}^2$ )

$V$  = vehicle speed (KMPH)

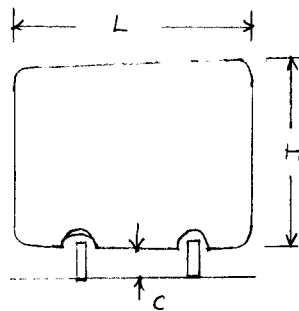
$c$  = drag coefficient = 0.45

$\rho$  = density of air.

value of  $K_a$ :

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

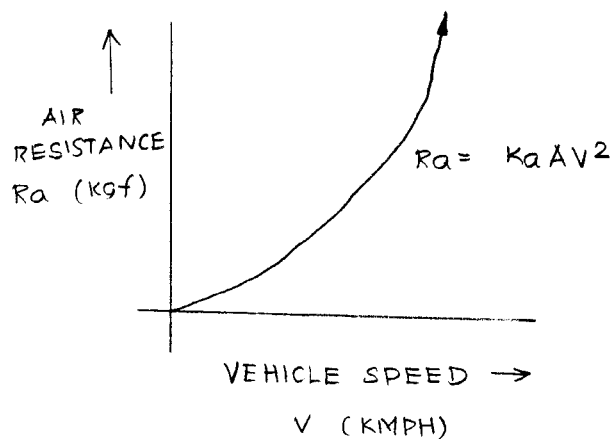
Frontal Area:



H = height  
L = width  
c = Ground clearance

$$\text{Frontal Area} = A = (H - c) \times L$$

FOR passenger cars,  $A = 1.7$  to  $1.8 \text{ m}^2$



### 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.

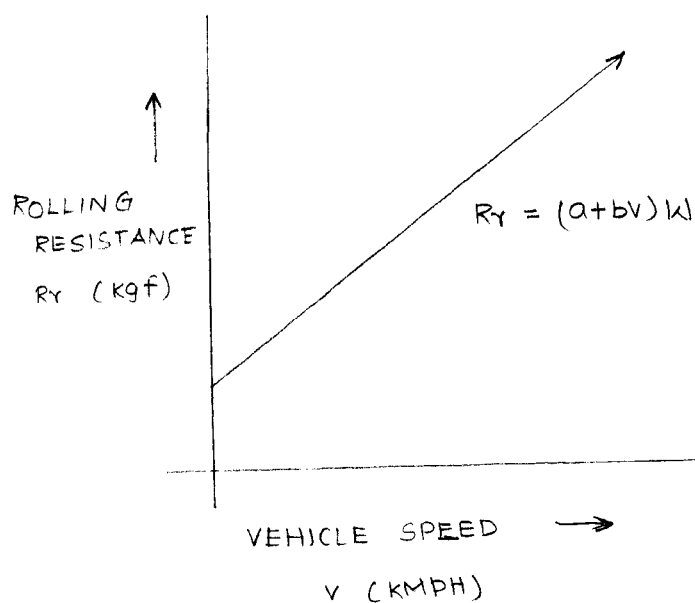
$$R_r = (a + bv) W \dots \dots \text{kgf}$$

where,  $a = 7.6$  constant.

$b = 0.05625$  constant.

$v =$  vehicle speed in KMPH.

$W =$  NLW or GLW in tonnes.

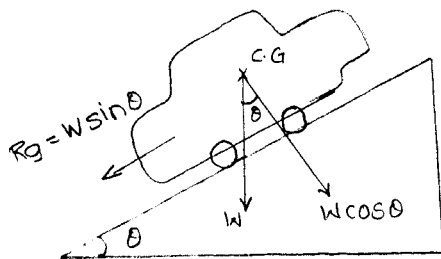


Value of  $R_r$  (Kgf/Tonnes) :

- |                       |          |
|-----------------------|----------|
| 1. Rail road          | - 4.55   |
| 2. Good 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 ( $R_g$ ) :

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



$$R_g = W \sin \theta \dots \dots \text{Kgf}$$

where,  $\theta$  - Angle of slope

$W$  - GVW or NLW

Total Resistance:

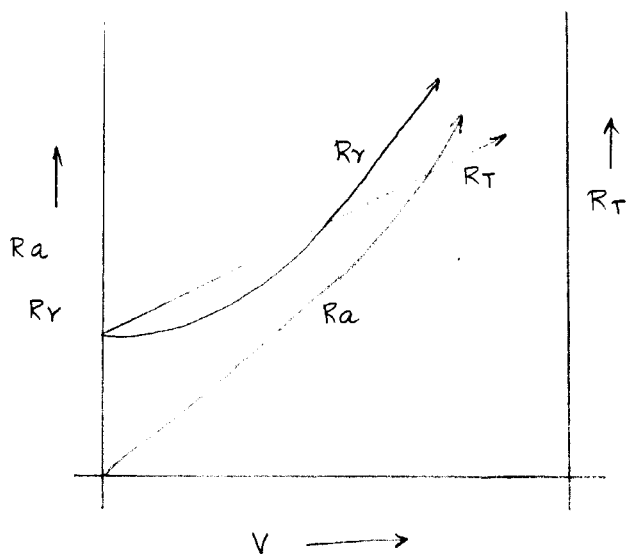
Total resistance is the sum of all the resistance, air resistance, gradient resistance, Rolling resistance.

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

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

ASSUME FOLLOWING DATA :

1. Kerb weight (ULW) - 810 Kg.
2. Max. payload - 320 kg.
3. Normal ladden wt - 1130 Kg.
4. Maximum speed - 120 KMPH.
5. Frontal Area - 1.8 m<sup>2</sup>.



| Vehicle speed<br>V (KMPH) | $R_a$<br>$K_a A V^2$<br>kgf | $R_r$<br>$(a+bV)W$<br>kgf | $R_t$<br>$R_a + R_r$<br>kgf |
|---------------------------|-----------------------------|---------------------------|-----------------------------|
| 0                         | 0                           | 8.688                     | 8.688                       |
| 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                      | 15.68                     | 85.3                        |
| 120                       | 82.944                      | 16.2                      | 99.17                       |

CALCULATION:

$$V = 50 \text{ KMPH.}$$

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

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

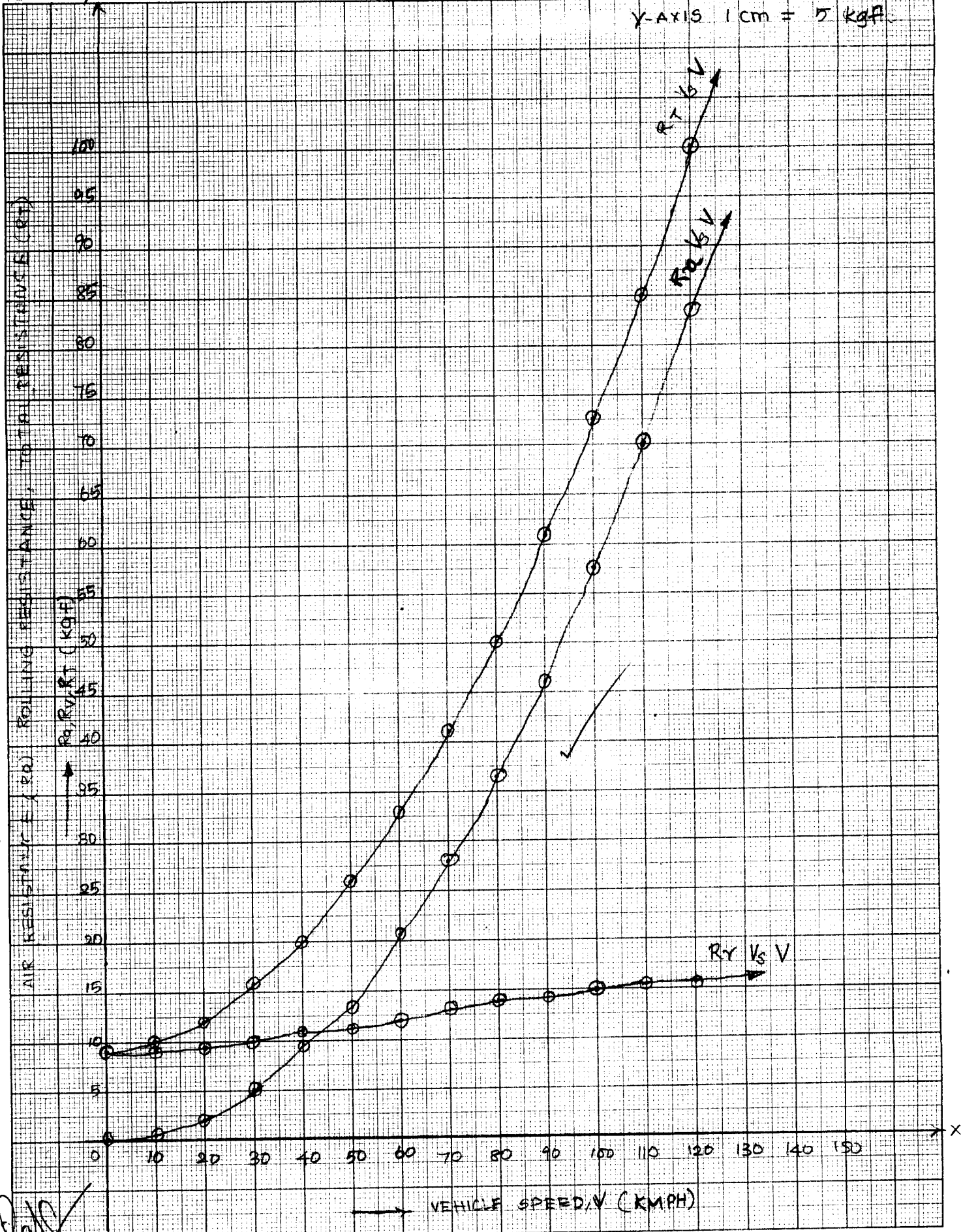
$$(iii) R_t = R_a + R_r = 14.4 + 11.76 = 26.16 \text{ kgf.}$$

RESISTANCES Vs VEHICLE SPEEDS

SCALE:

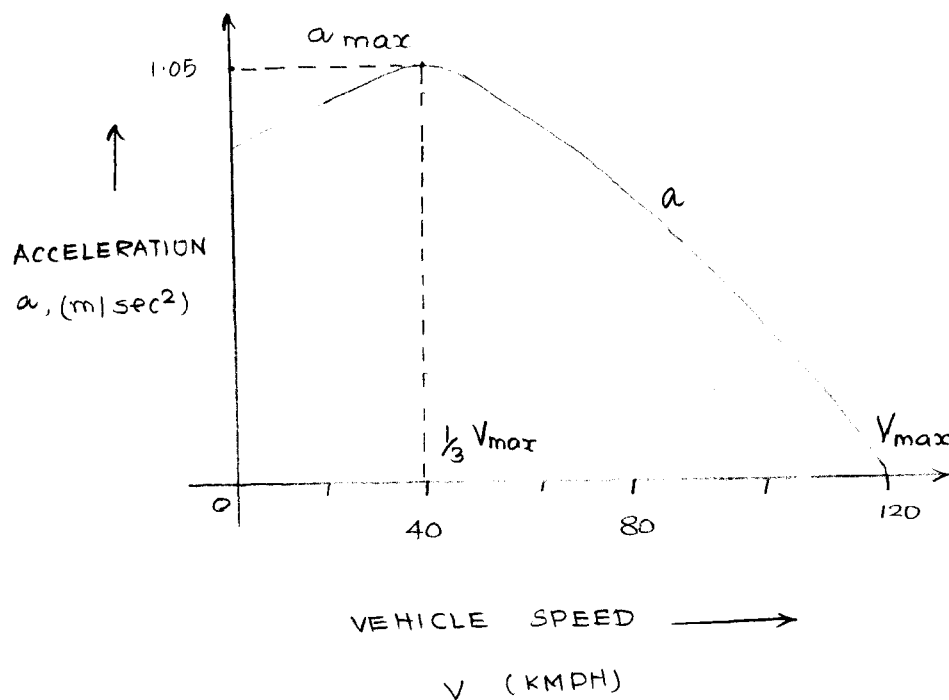
X-AXIS 1 cm = 10 KMPH

Y-AXIS 1 cm = 5 kgf



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## VEHICLE ACCELERATION :



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

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

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

Assume max. acceleration from vehicle data it is  $0.9$  to  $1.05 \text{ m/s}^2$ . for the vehicle which is having maximum vehicle speed  $120 \text{ KMPH}$ . The max. acceleration always occurs at  $\frac{1}{3}$  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,

$$EDF = \frac{W}{g} \times \frac{a}{K_a} \dots\dots\dots \text{kgf}$$

where,  $W = NLW$

$a =$  Acceleration

$K_a =$  Acceleration constant (0.9)

$g =$  Acceleration due to gravity

| value of $K_a$ | Four speed Gear box | Three speed Gear box |
|----------------|---------------------|----------------------|
| TOP Gear       | 0.9                 |                      |
| III gear       | 0.87                | 0.90                 |
| II Gear        | 0.85                | 0.85                 |
| I Gear         | 0.80                | 0.80                 |

$$\text{DRIVING FORCE, } DF = EDF + R_T \dots\dots\dots \text{kgf.}$$

where,

$EDF =$  Excess Driving Force in kgf

$R_T =$  Total Resistance in kgf

## POWER REQUIRED BY THE VEHICLE :

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

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

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

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

$$\text{DHP} = \frac{DFXV}{270} \text{ HP}$$

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

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

$$\therefore \text{IHP} > \text{BHP} > \text{DHP}$$

## Relation Between Engine rpm and vehicle speed :

Let,  $N$  - the engine speed in rpm.

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

$G$  - Gear ratio

$\gamma_a$  - Axle reduction

$$1 \text{ HP} = 735.5 \text{ Watts.}$$

$$\left. \begin{array}{l} \text{distance travelled} \\ \text{by wheel / min} \end{array} \right\} = \frac{N}{G \gamma_a} \times 2\pi R_w \quad \text{m/min}$$

$R_w$  = Effective wheel radius.

$$\text{Vehicle speed, } v = \left( \frac{N}{G \gamma_a} \times 2\pi R_w \right) \frac{60}{1000} \quad \dots\dots\dots \text{ km/PH}$$

$$v = \left( \frac{N \cdot R_w}{G \cdot \gamma_a} \right) \left( \frac{2\pi \times 60}{1000} \right)$$

$$\frac{N}{v} = \left( \frac{1000}{2\pi \times 60} \right) \frac{G \gamma_a}{R_w}$$

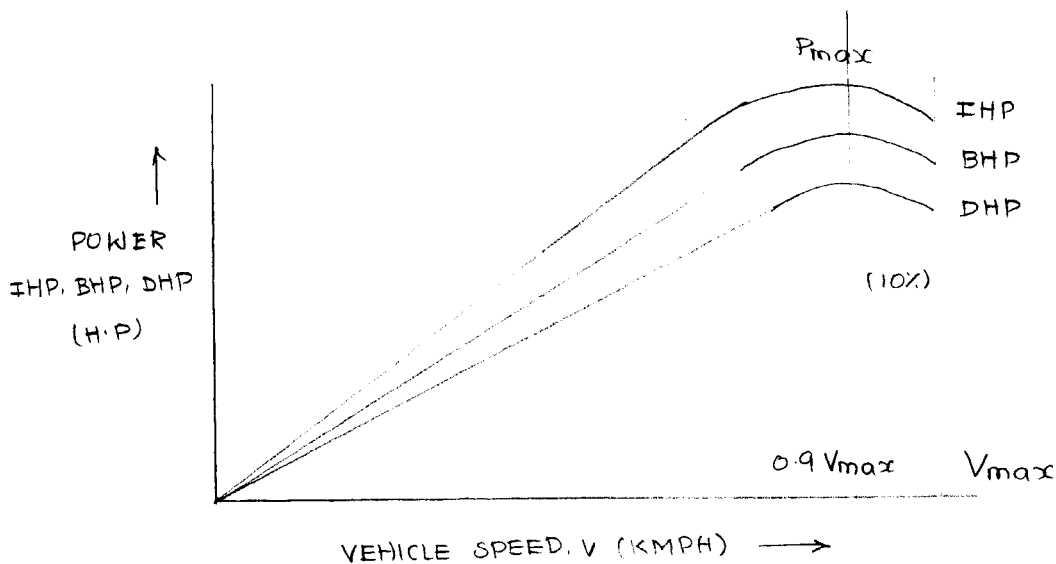
$$\frac{N}{v} = 2.655 \frac{G \gamma_a}{R_w}$$

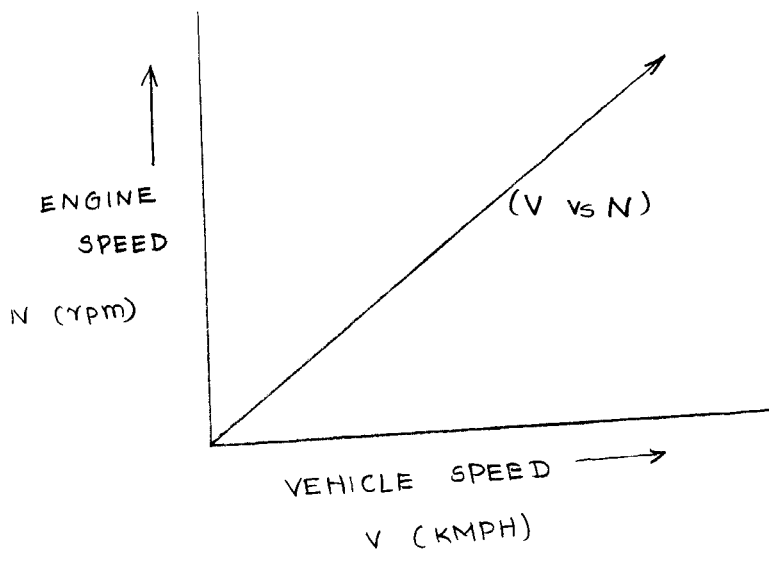
ASSUME, Gear ratio,  $G = 1:1$

Axle reduction,  $\gamma_a = 3$  or  $4$

Wheel radius,  $R_w = 0.2844 \approx 0.3 \text{ m}$ .

GRAPHS:





CALCULATION:

vehicle speed,  $V = 50$  KMPH.

1. EXCESS DRIVING FORCE,  $EDF = \left(\frac{W}{g}\right) \left(\frac{a}{K_a}\right)$

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

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

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<br>KMPH | $R_a = K_a A V^2$<br>Kgf | $R_T = (R_a + R_f) W$<br>Kgf | $R_T$<br>( $R_a + R_f$ )<br>Kgf | $a$<br>m/s <sup>2</sup> | $E_{DF}$<br>$(\frac{W}{g})(\frac{a}{R_a})$<br>Kgf | DF<br>( $E_{DF} + R_T$ )<br>Kgf | DHP<br>$(\frac{DF \times V}{270})$<br>HP | BHP<br>( $1.1 \times DHP$ )<br>HP | IHP<br>( $1.1 \times BHP$ )<br>HP | N<br>$\frac{2.65 V G Y a}{R_w}$<br>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  | 148.76                          | 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  | 152.68                          | 28.321                                   | 31.142                            | 34.256                            | 1766.7                                 |
| 60        | 20.736                   | 12.4                         | 33.14                           | 0.69                    | 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  | 130.584                         | 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,  $BHP = 1.1 \times DHP$

$$= 1.1 \times 29.42$$

$$BHP = 32.362 \text{ HP}$$

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

$$= 1.1 \times 32.362$$

$$IHP = 35.6 \text{ HP}$$

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

$$= \frac{2.65 \times 60 \times 1 \times 4}{0.3}$$

$$N = 1767 \text{ rpm}$$

#### 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

SCALE:

X-AXIS 1cm = 10 KMPH  
Y-AXIS 1cm = 0.1 m/s<sup>2</sup>

ACCELERATION (m/s<sup>2</sup>)

↑

1.1  
1.0  
0.9  
0.8  
0.7  
0.6  
0.5  
0.4  
0.3  
0.2  
0.1

0

10

20

30

40

50

60

70

80

90

100

110

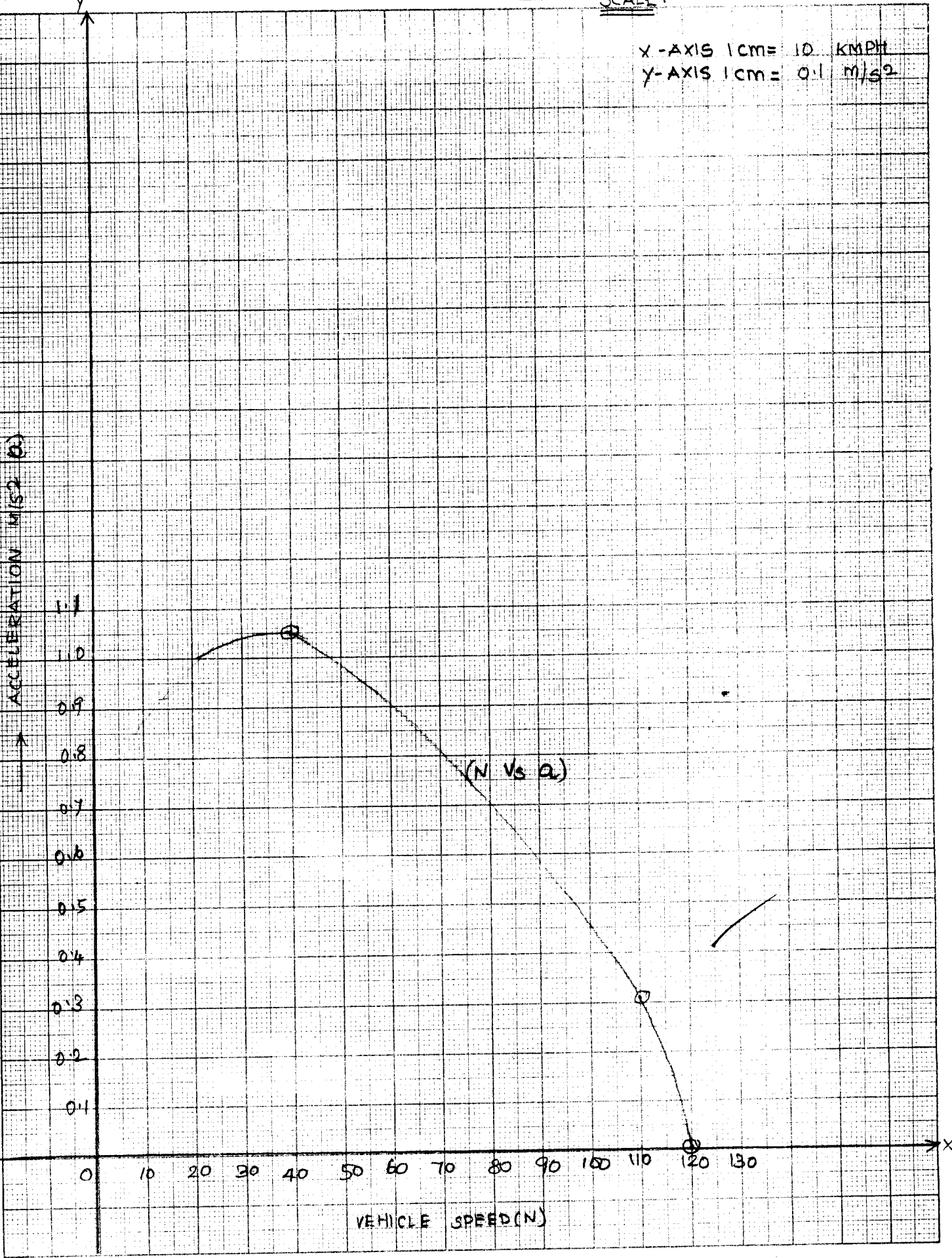
120

130

VEHICLE SPEED (N)

x

(N vs a)

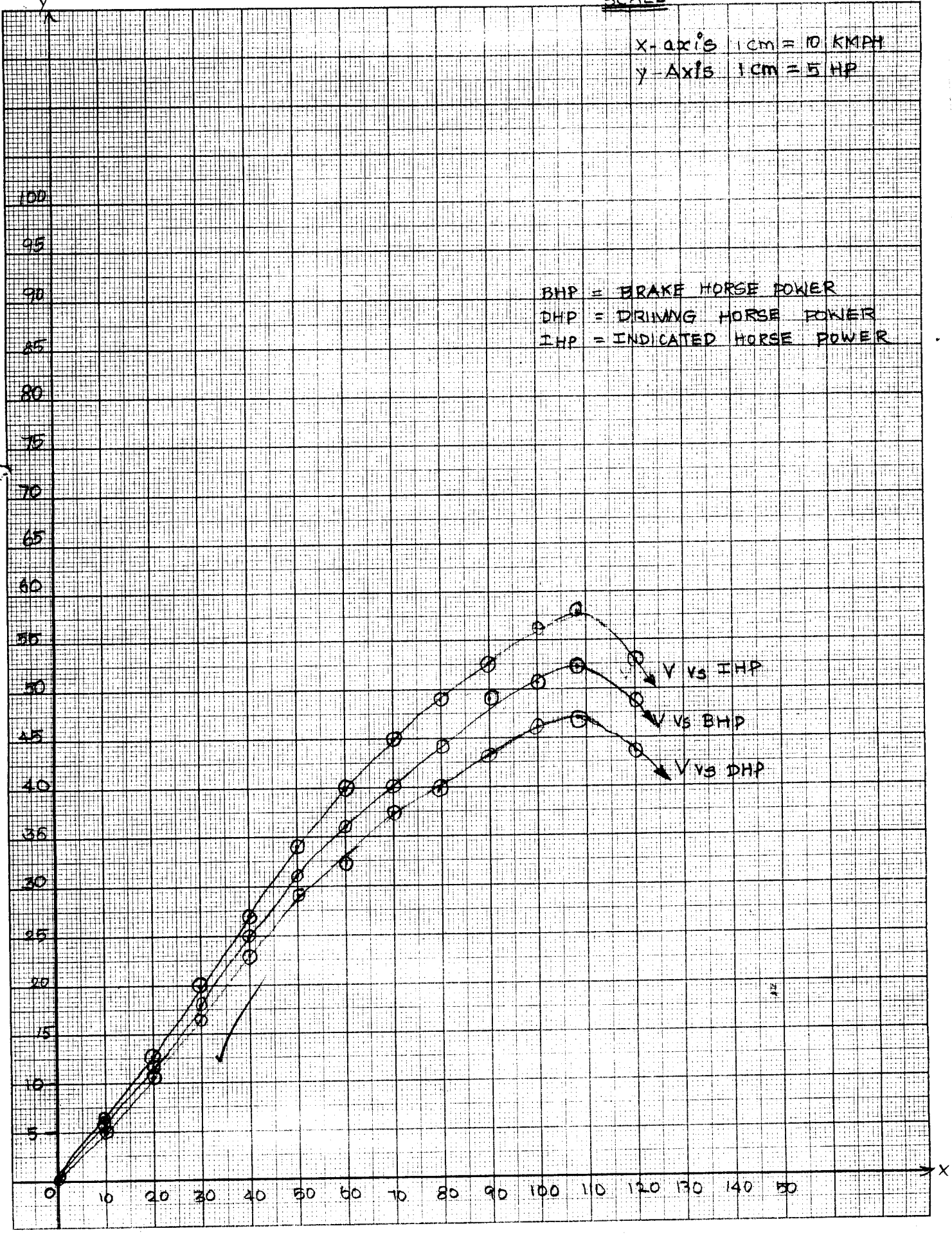


POWER Vs VEHICLE SPEED

SCALE:

X-axis 1cm = 10 KMPH  
 y-Axis 1cm = 5 HP

BHP = BRAKE HORSE POWER  
 DHP = DRIVING HORSE POWER  
 IHP = INDICATED HORSE POWER



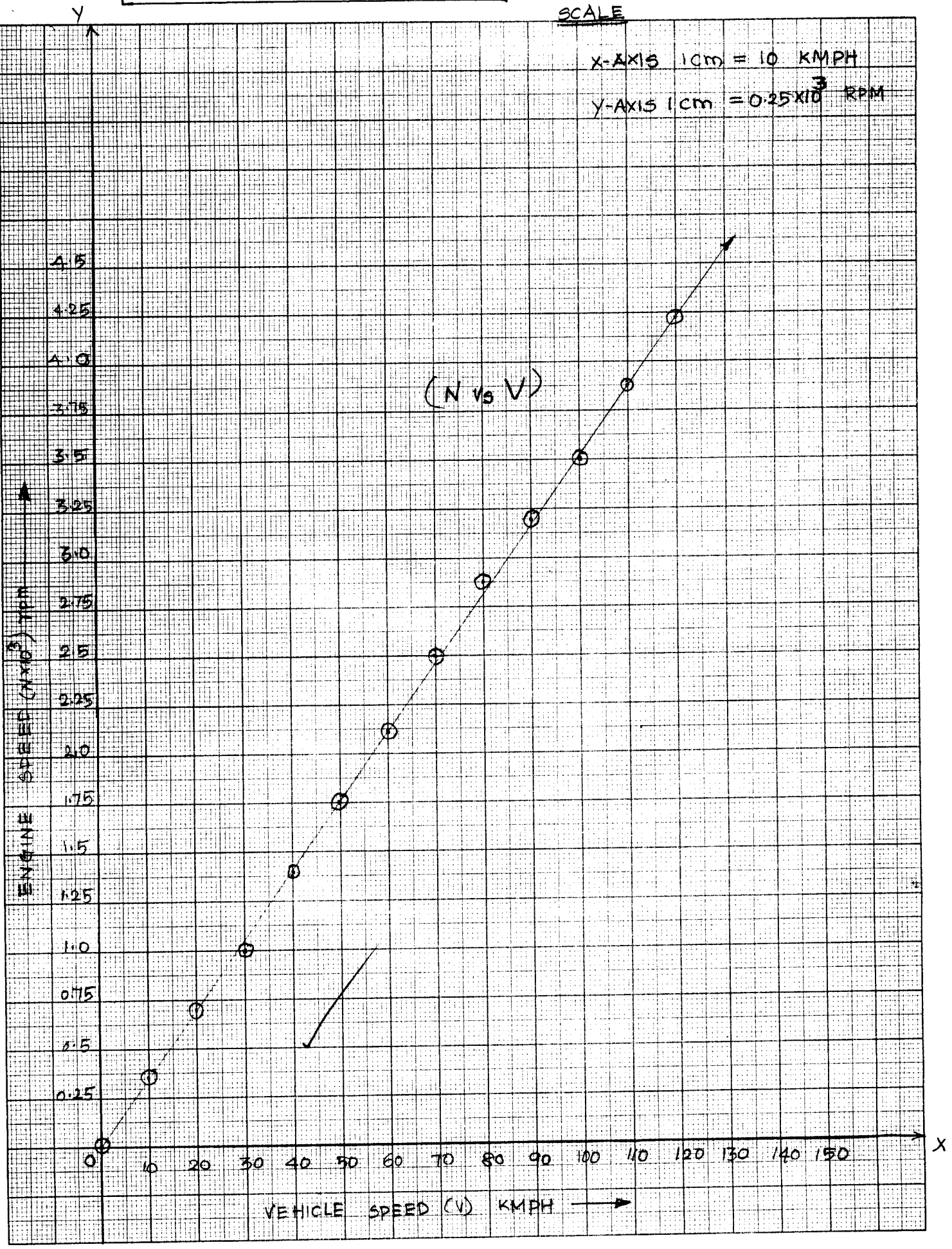
(V) VEHICLE SPEED (KMPH) →

VEHICLE SPEED  $V_s$  ENGINE SPEED

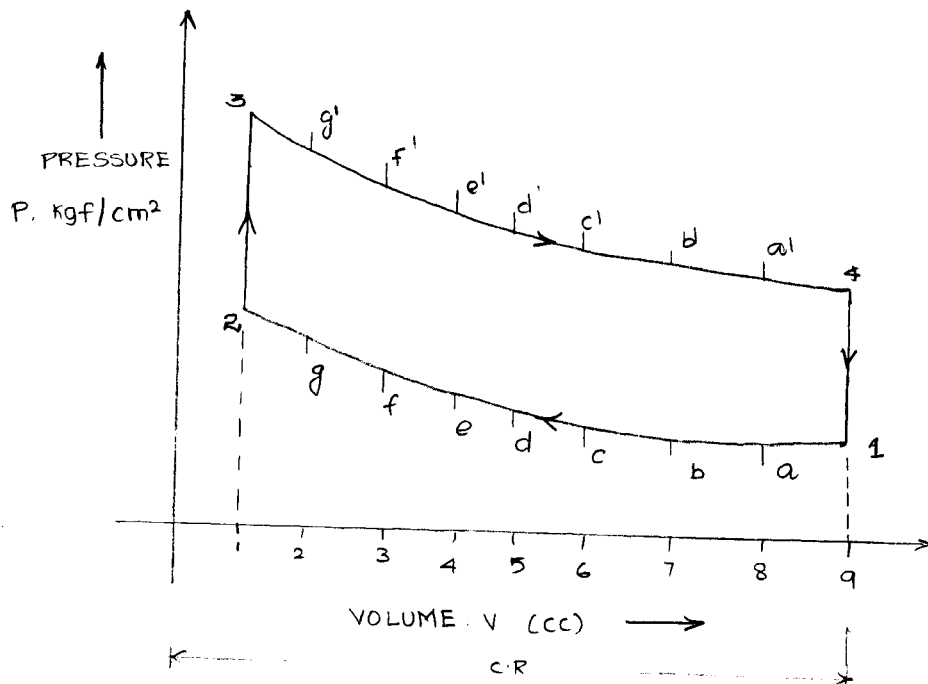
SCALE

X-AXIS 1cm = 10 KMPH

Y-AXIS 1cm =  $0.25 \times 10^3$  RPM



TO DETERMINE BORE & STROKE :



PV-DIAGRAM OF OTTD 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,

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

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

$$V_c = 1$$

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

$$\therefore V_s = 8$$

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

$P_1 = 0.93$  to  $0.98$  kgf/cm<sup>2</sup> - Petrol Engines.

$P_1 = 1$  kgf/cm<sup>2</sup> - Diesel engines.

Atmospheric pressure =  $1.032$  kgf/cm<sup>2</sup>.

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,  $\gamma =$  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.

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

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

Intermediate Points:

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

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

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

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

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

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

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

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

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

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 : ( $\gamma = 1.34$ )

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

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

$$P_{e1} = P_{f1} \left( \frac{V_{f1}}{V_{e1}} \right)^\gamma = 17.041 \left( \frac{3}{4} \right)^{1.34} = 11.5898 \text{ kg/cm}^2$$

$$P_{d1} = P_{e1} \left( \frac{V_{e1}}{V_{d1}} \right)^\gamma = 11.5898 \left( \frac{4}{5} \right)^{1.34} = 8.5945 \text{ kg/cm}^2$$

$$P_{c1} = P_{d1} \left( \frac{V_{d1}}{V_{c1}} \right)^\gamma = 8.5945 \left( \frac{5}{6} \right)^{1.34} = 6.7316 \text{ kg/cm}^2$$

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

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

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

| Sl. NO. | Volume V (cc) | Compression stroke |                          | Expansion stroke. |                          |
|---------|---------------|--------------------|--------------------------|-------------------|--------------------------|
|         |               | Point              | Pr. P kg/cm <sup>2</sup> | Point             | Pr. P kg/cm <sup>2</sup> |
| 1       | 1.0           | 2                  | 17.27                    | 3                 | 74.27                    |
| 2       | 2.0           | g                  | 6.922                    | 9i                | 29.34                    |
| 3       | 3.0           | f                  | 4.053                    | fi                | 17.041                   |
| 4       | 4.0           | e                  | 2.7723                   | ei                | 11.5898                  |
| 5       | 5.0           | d                  | 2.065                    | di                | 8.5945                   |
| 6       | 6.0           | c                  | 1.623                    | ci                | 6.7316                   |
| 7       | 7.0           | b                  | 1.324                    | bi                | 5.475                    |
| 8       | 8.0           | a                  | 1.110                    | ai                | 4.578                    |
| 9       | 9.0           | 1                  | 0.950                    | 4                 | 3.910                    |

ACTUAL PV DIAGRAM:

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

D.F = Diagram factor.

Indicated Mean effective pressure = 10 to 12 kg/cm<sup>2</sup>

Assume, Diagram Factor = 0.9

This IMEP is available at maximum BHP point.

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

where, FMEP - Frictional mean eff Pressure

N - Engine rpm at max BHP.

$$a = 0.5622 ;$$

$$b = 0.2811$$

$$c = 0.0527$$

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

where, FHP - Frictional horse power.

$$\eta = \frac{N}{2} \text{ for 4-s engine.}$$

$$\text{LA} = 1200 - 1300 \text{ cc.}$$

$$3. \text{ IHP} = \text{BHP} + \text{FHP}$$

where, IHP - Indicated horse power

4. To Find LA:

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

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

$$\text{LA} = ?$$

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.

$$\therefore \text{IHP} = \text{BHP} + \text{FHP}$$

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

$$\text{BMEP} = \frac{\text{BHP} \times 4500 \times 100 \times 2}{L \times N}$$

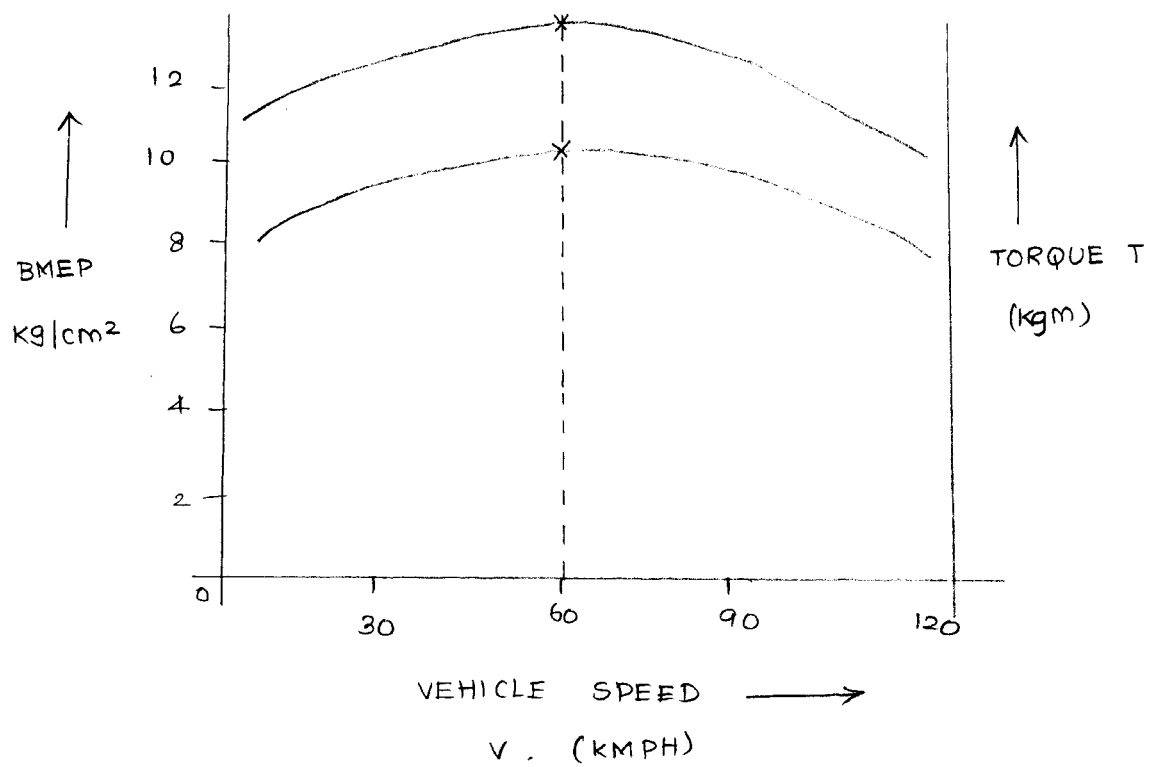
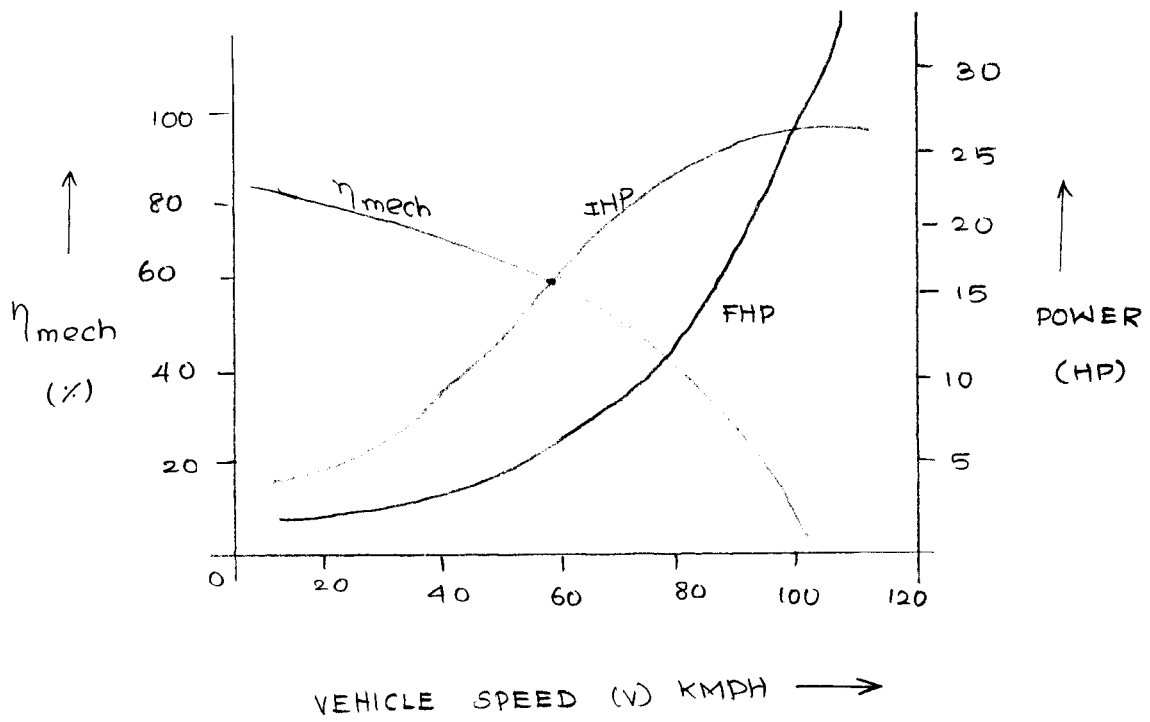
$$\text{Torque} = \frac{\text{BHP} \times 4500}{2\pi N}$$

GRAPHS:

1.  $V$  vs  $\eta_{\text{mech}}$
2.  $V$  vs  $T$
3.  $V$  vs BMEP
4.  $V$  vs DF
5.  $V$  vs BHP, IHP, FHP

NOTES:

1. The max. torque must be available at 50% of  $V_{\text{max}}$
2. driving force and torque curves must be exactly in similar shape.
3. starting and ending value of torques is same,



CALCULATION:

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

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

$$\text{IMEP} = 10.40625 \text{ kg/cm}^2$$

$$2. \quad \text{FMEP} = a + b(N/1000) + c(N/1000)^2$$

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

$$\text{FMEP} = 2.403 \text{ kg/cm}^2$$

$$3. \quad \text{FHP} = \frac{\text{FMEP} \times \text{LA} \times \eta}{4500 \times 100}$$

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

$$\text{FHP} = 15.03 \text{ HP}$$

$$4. \quad \text{IHP} = \text{BHP} + \text{FHP}$$

$$= 52.5 + 12.736$$

$$= 67.5 \text{ HP}$$

$$5. \quad \text{IHP} = \frac{\text{IMEP} \times \text{LA} \times \eta}{4500 \times 100}$$

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

$$\text{LA} = 1530.475 \text{ cm}^3$$

6. No of cylinders:

$$LA < 1600 \text{ cc}$$

$\therefore$  Four cylinder engine.

7. To Find Bore & stroke:

For square engines,  $B=L$

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

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

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

$$\text{FHP} = 16.03 \text{ HP}; \quad \text{BHP} = 52.5 \text{ HP}; \quad \text{IHP} = 67.5 \text{ HP}.$$

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

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

$$= 0.778$$

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

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

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

$$\text{BMEP} = 8.09 \text{ kg/cm}^2$$

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

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

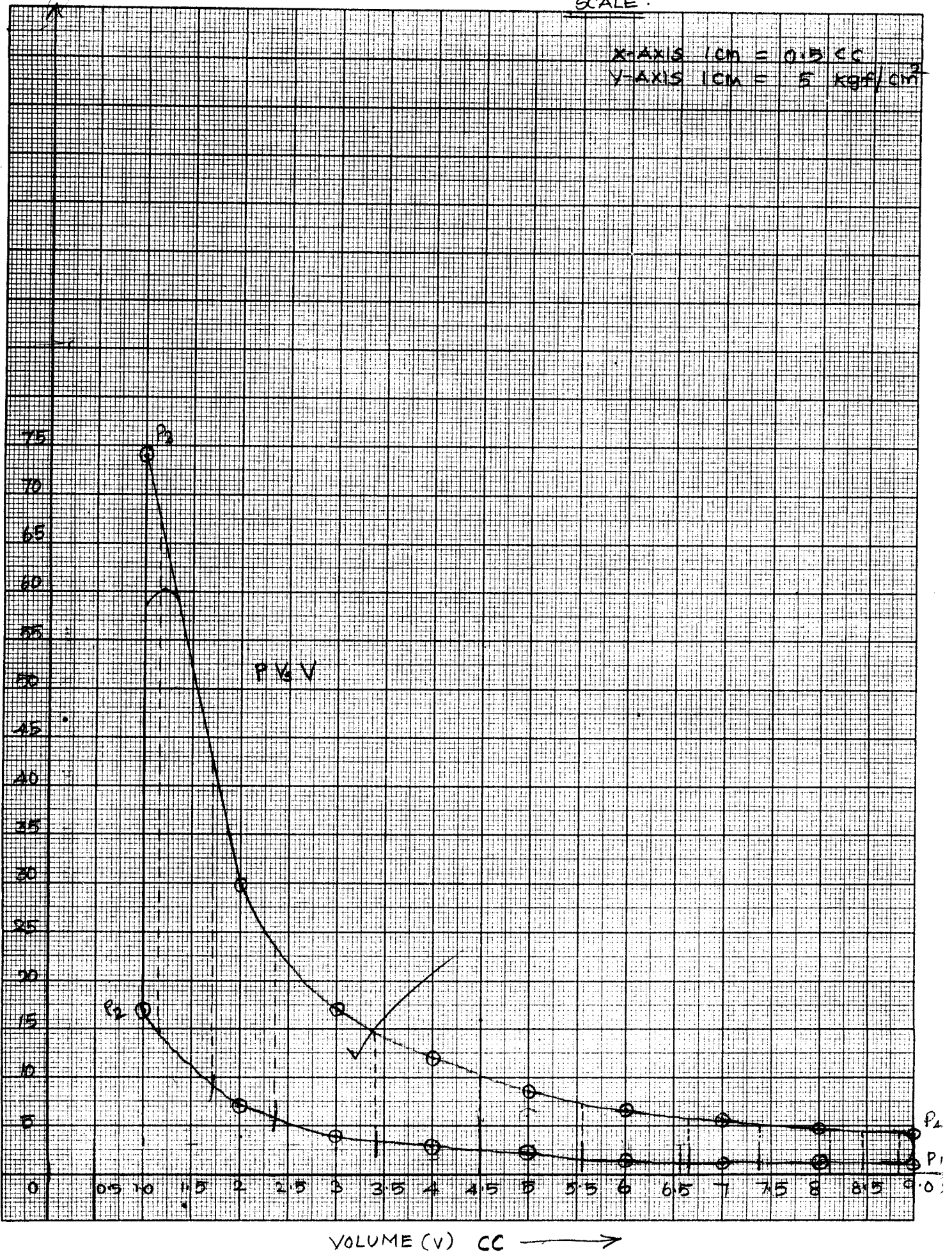
$$T = 9.853 \text{ Nm.}$$

| V<br>км/ч | N<br>rpm | BHP<br>(H.P) | FHP<br>(H.P) | IHP<br>(H.P) | $\eta_{mech}$<br>(%) | BMEP<br>kgf/cm <sup>2</sup> | T<br>(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        | 12.279       | 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     | 47.697       | 10.756       | 58.453       | 81.599               | 8.82                        | 10.7423      |
| 100       | 3533.3   | 50.411       | 13.304       | 63.716       | 79.1195              | 8.389                       | 10.22        |
| 108       | 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 :

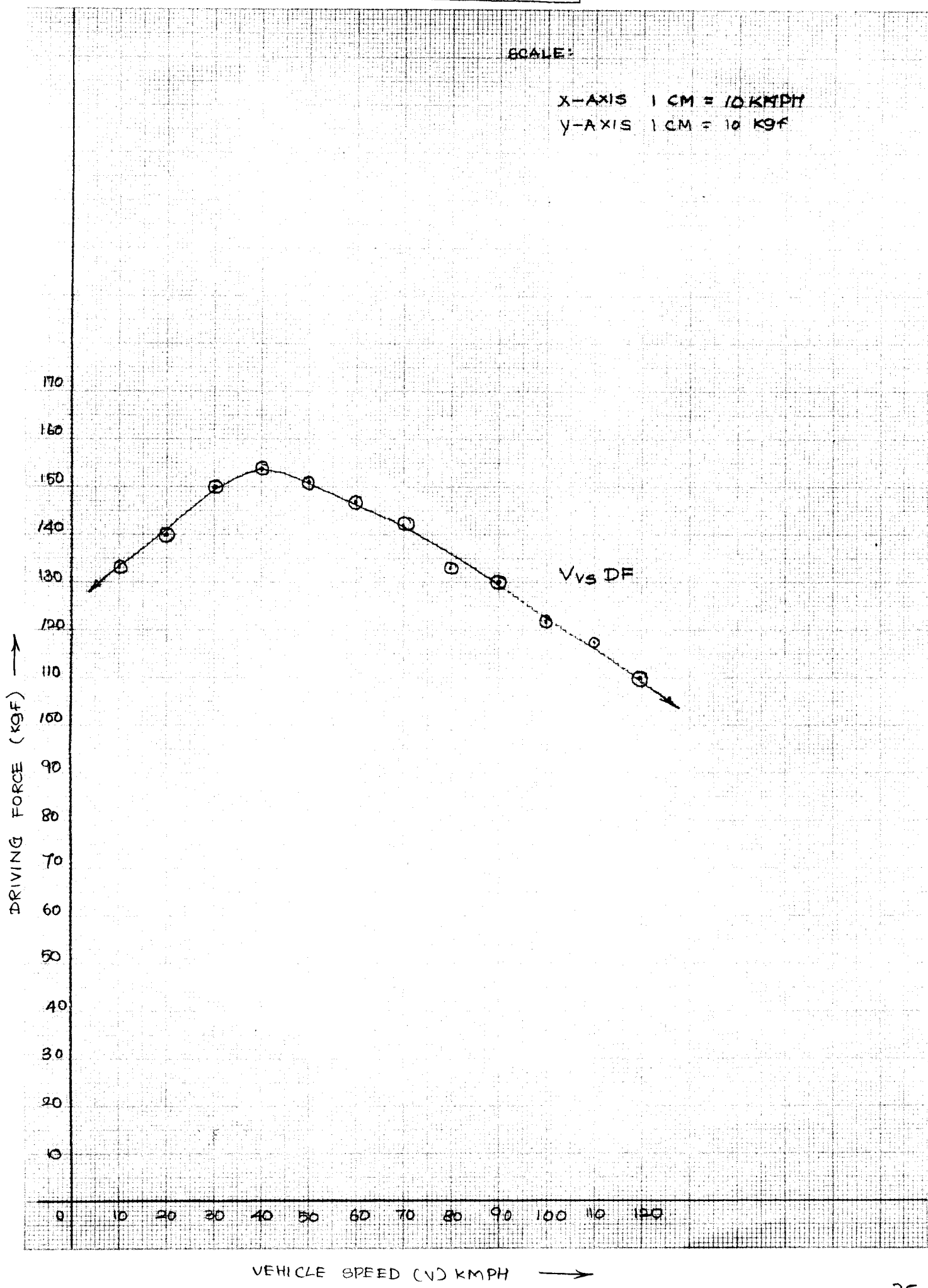
X-AXIS 1CM = 0.5 CC  
 Y-AXIS 1CM = 5 KGf/cm<sup>2</sup>



VEHICLE SPEED VS DRIVING FORCE

SCALE:

X-AXIS 1 CM = 10 KMPH  
Y-AXIS 1 CM = 10 KGF

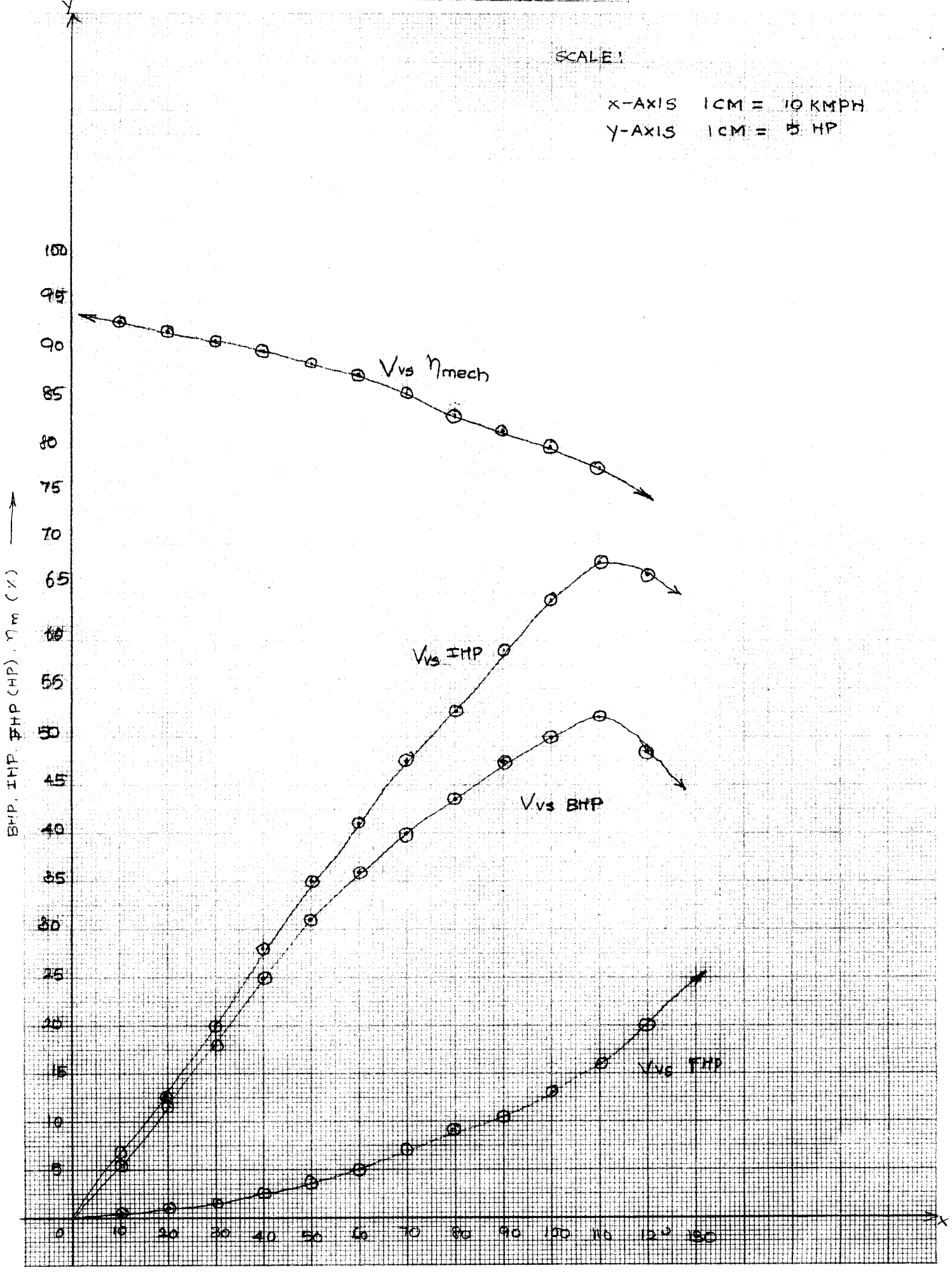


VEHICLE SPEED (V) KMPH →

VEHICLE SPEED VS IHP, BHP,  $\eta_{mech}$

SCALE:

X-AXIS 1CM = 10 KMPH  
 Y-AXIS 1CM = 5 HP



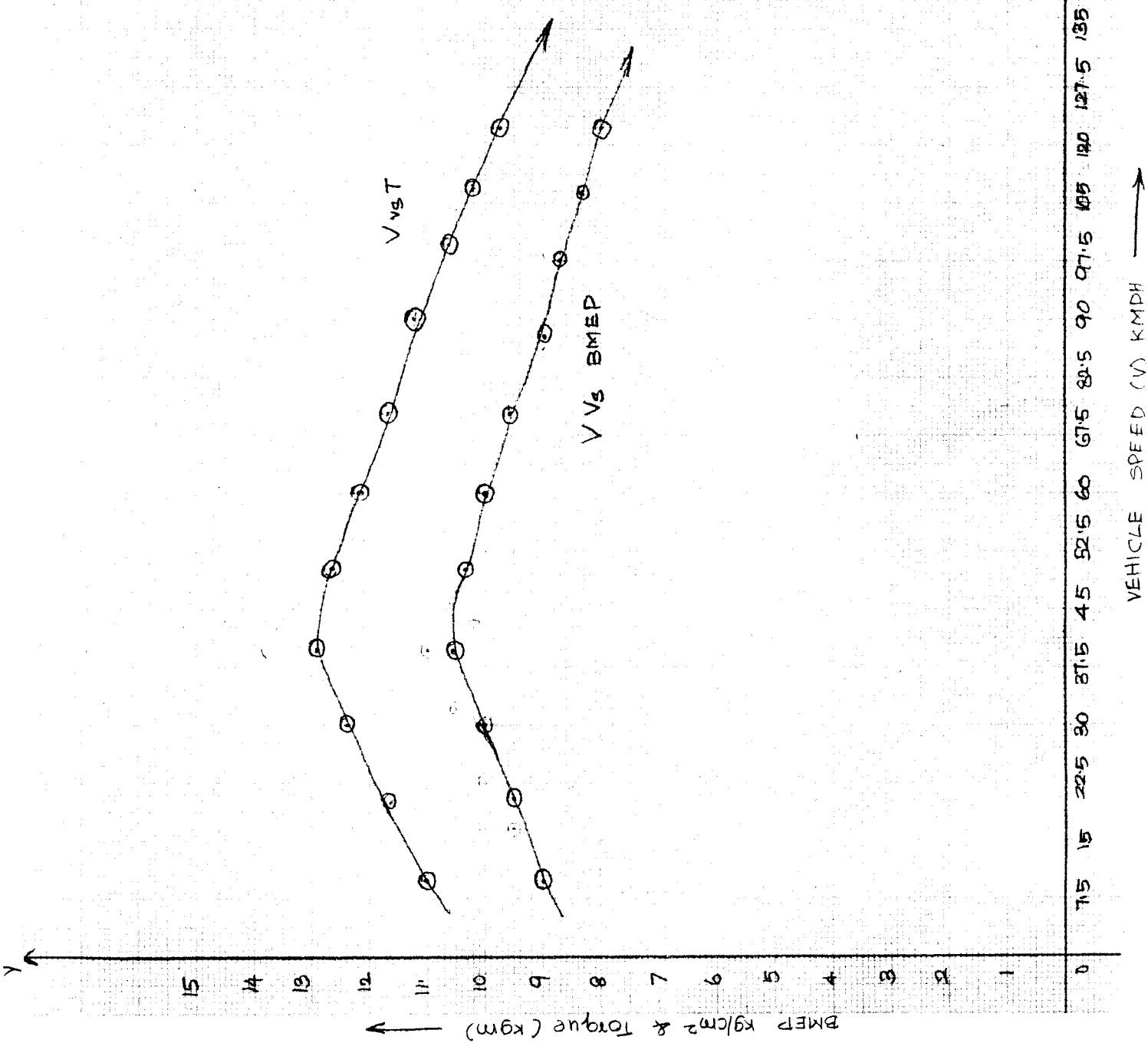
VEHICLE SPEED, V, KMPH →

VEHICLE SPEED VS BMEP, TORQUE

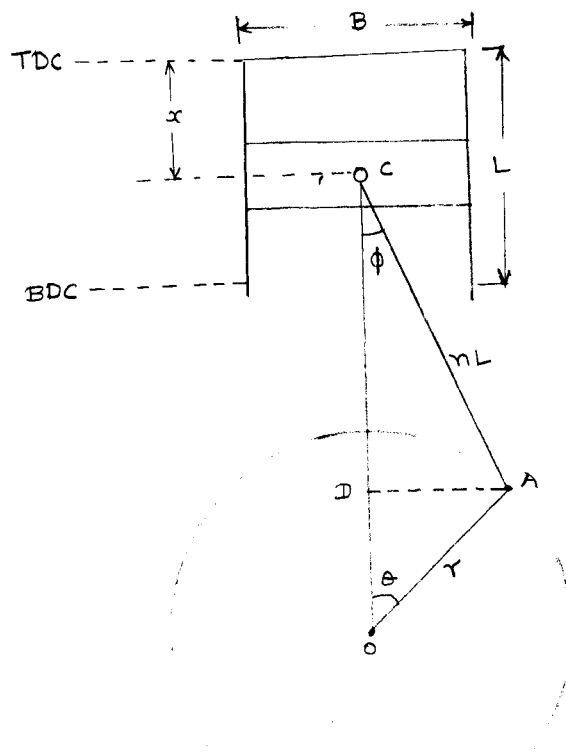
SCALE:

X-AXIS 1cm = 7.5 KMPH

Y-AXIS 1cm = 1 Kg m



## PISTON VELOCITY & ACCELERATION:



Let,

$B$  = Bore diameter

$L$  = stroke length

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

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

In the fig, the piston moved from TDC at a distance  $x$

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

$$\text{From the fig, } CO = CD + DO$$

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

where  $\theta$  and  $\phi$  are shown in fig.

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

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

$$x = \frac{L}{2} (1 - \cos \theta) + nL \left( 1 - \left( 1 - \frac{\sin^2 \theta}{4n^2} \right) \right)$$

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

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

Acceleration of piston,  $a_p = \frac{dv_p}{dt}$

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

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

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

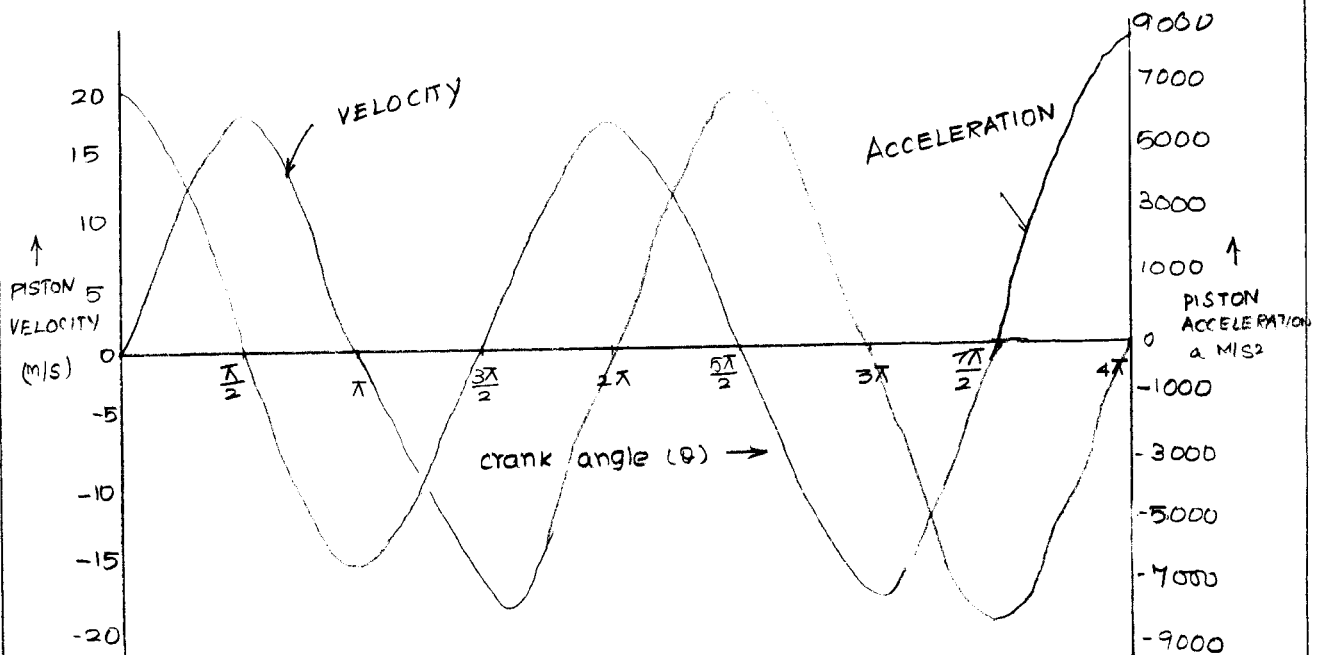
N - Engine speed at max. BHP

L - Length of stroke in cm

n = 1.2 - 2 for square and under square.

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

GRAPH:



| crank angle<br>$\theta$ , degree | $\sin \theta$ | $\frac{\sin 2\theta}{4n}$ | $\sin \theta + \frac{\sin 2\theta}{4n}$ | $V_p$<br>m/s | $\cos \theta$ | $\frac{\cos 2\theta}{2n}$ | $\cos \theta + \frac{\cos 2\theta}{2n}$ | $a_p$<br>m/s <sup>2</sup> |
|----------------------------------|---------------|---------------------------|---|--------------|---------------|---------------------------|---|---------------------------|
| 0                                | 0.0           | 0.0                       | 0.0                                     | 0.0          | 1.0           | 0.25                      | 1.25                                    | 7853.75                   |
| 15                               | 0.2588        | 0.0625                    | 0.3213                                  | 5.05         | 0.966         | 0.2165                    | 1.1825                                  | 7429.6                    |
| 30                               | 0.50          | 0.1083                    | 0.6083                                  | 9.564        | 0.866         | 0.125                     | 0.991                                   | 6226.4                    |
| 45                               | 0.7071        | 0.125                     | 0.8321                                  | 13.083       | 0.707         | 0.0                       | 0.7071                                  | 4442.04                   |
| 60                               | 0.866         | 0.1083                    | 0.9743                                  | 15.32        | 0.50          | -0.125                    | 0.375                                   | 2356.73                   |
| 75                               | 0.9659        | 0.0625                    | 1.0284                                  | 16.17        | 0.259         | -0.2165                   | 0.0425                                  | 267.03                    |
| 90                               | 1.00          | 0.00                      | 1.00                                    | 15.723       | 0.00          | -0.25                     | -0.25                                   | -1570.45                  |
| 105                              | 0.9659        | -0.0625                   | 0.9034                                  | 14.204       | -0.259        | -0.2165                   | -0.4755                                 | -2987.6                   |
| 120                              | 0.866         | -0.1083                   | 0.7577                                  | 11.913       | -0.50         | -0.125                    | -0.625                                  | -3926.9                   |
| 135                              | 0.7071        | -0.125                    | 0.5821                                  | 9.1522       | -0.707        | 0.00                      | -0.707                                  | -442.04                   |
| 150                              | 0.50          | -0.1083                   | 0.3917                                  | 6.1586       | -0.866        | 0.125                     | -0.741                                  | -4655.7                   |
| 165                              | 0.26          | -0.0625                   | 0.1963                                  | 3.086        | -0.966        | 0.2165                    | -0.7495                                 | -4709.1                   |
| 180                              | 0.00          | 0.00                      | 0.00                                    | 0.00         | -1.00         | 0.25                      | -0.75                                   | -4712.3                   |

| crank angle<br>$\theta$ degree | $\sin \theta$ | $\frac{\sin 2\theta}{4h}$ | $\sin \theta + \frac{\sin 2\theta}{4h}$ | $V_p$<br>m/sec | $\cos \theta$ | $\frac{\cos 2\theta}{2h}$ | $\cos \theta + \frac{\cos 2\theta}{2h}$ | $a_p$<br>m/sec <sup>2</sup> |
|--------------------------------|---------------|---------------------------|---|----------------|---------------|---------------------------|---|-----------------------------|
| 195                            | -0.259        | 0.0625                    | -0.1963                                 | -3.086         | -0.966        | 0.2165                    | -0.7496                                 | -4709.11                    |
| 210                            | -0.50         | 0.1083                    | -0.3917                                 | -6.1586        | -0.866        | 0.125                     | -0.741                                  | -4665.7                     |
| 225                            | -0.7071       | 0.125                     | -0.5821                                 | -9.1522        | -0.707        | 0.00                      | -0.7071                                 | -4442.71                    |
| 240                            | -0.866        | 0.1083                    | -0.7577                                 | -11.113        | -0.50         | -0.125                    | -0.665                                  | -3926.9                     |
| 255                            | -0.966        | 0.0625                    | -0.9034                                 | -14.204        | -0.259        | -0.2165                   | -0.4755                                 | -2987.6                     |
| 270                            | -1.00         | 0.00                      | -1.00                                   | -15.723        | 0.00          | -0.25                     | -0.25                                   | -1570.75                    |
| 285                            | -0.966        | -0.0625                   | -1.0284                                 | -16.17         | 0.259         | -0.2165                   | -0.0425                                 | -2987.6                     |
| 300                            | -0.866        | -0.1083                   | -0.9743                                 | -15.32         | 0.50          | -0.125                    | 0.375                                   | 2356.125                    |
| 315                            | -0.7071       | -0.125                    | -0.8321                                 | -13.083        | 0.707         | 0.00                      | 0.707                                   | 4442.04                     |
| 330                            | -0.5          | -0.1083                   | -0.608                                  | -9.564         | 0.866         | 0.125                     | 0.991                                   | 6226.40                     |
| 345                            | -0.26         | -0.063                    | -0.3213                                 | -5.05          | 0.966         | 0.2165                    | 1.025                                   | 7429.65                     |
| 360                            | 0.0           | 0.0                       | 0.0                                     | 0.0            | 1.00          | 0.25                      | 1.25                                    | 7853.8                      |

CALCULATION :

$$\theta = 45^\circ$$

1. velocity of piston ,

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

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

$$V_p = 13.083 \text{ m/sec.}$$

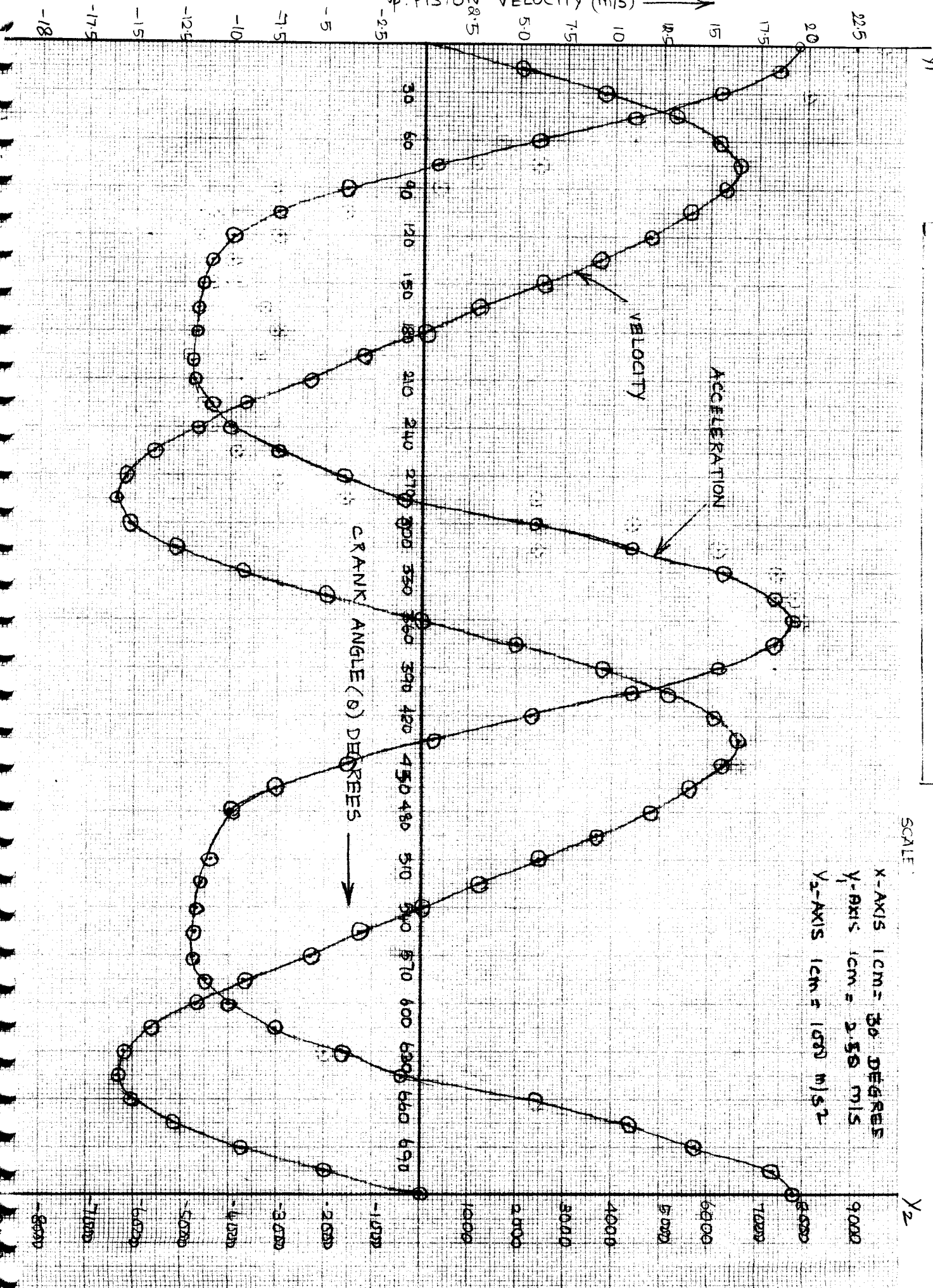
2. Acceleration of Piston,

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

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

$$a_p = 4442.04 \text{ m/sec}^2.$$

CRANK ANGLE VS PISTON VELOCITY, ACCELERATION



SCALE

X-AXIS 1CM = 30 DEGREES  
 Y1-AXIS 1CM = 2.50 M/S  
 Y2-AXIS 1CM = 1000 M/S<sup>2</sup>

PISTON ACCELERATION:  $a_p$  (m/s<sup>2</sup>)

## 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  $\text{m/s}^2$ .

$g$  - 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.

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

where,  $I.F$  = Inertia force

$W$  = Weight of reciprocating parts

$$= [\text{Wt of reciprocating parts/cm}^2] \times \text{Bore area cm}^2$$

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

$$W = \dots \text{kgf.}$$

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

| Cylinder Bore<br>B mm | Weight of Reciprocating Parts per<br>cm <sup>2</sup> of Bore Area. |                     |
|-----------------------|--|---------------------|
|                       | Aluminium alloy<br>Pistons in kgf.                                 | C.I. pistons<br>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.

$$\text{Cylinder pressure} = \text{Gas Pr.} - \text{Back pressure.}$$

$$\text{Back pressure} = 1.03 \text{ kgf/cm}^2$$

$$\text{Gas force} = \text{cylinder pressure} \times \text{Boye Area}$$

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

$0^\circ - 180^\circ \rightarrow$  power stroke

$180^\circ - 360^\circ \rightarrow$  exhaust stroke

$360^\circ - 540^\circ \rightarrow$  suction stroke

$540^\circ - 720^\circ \rightarrow$  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.

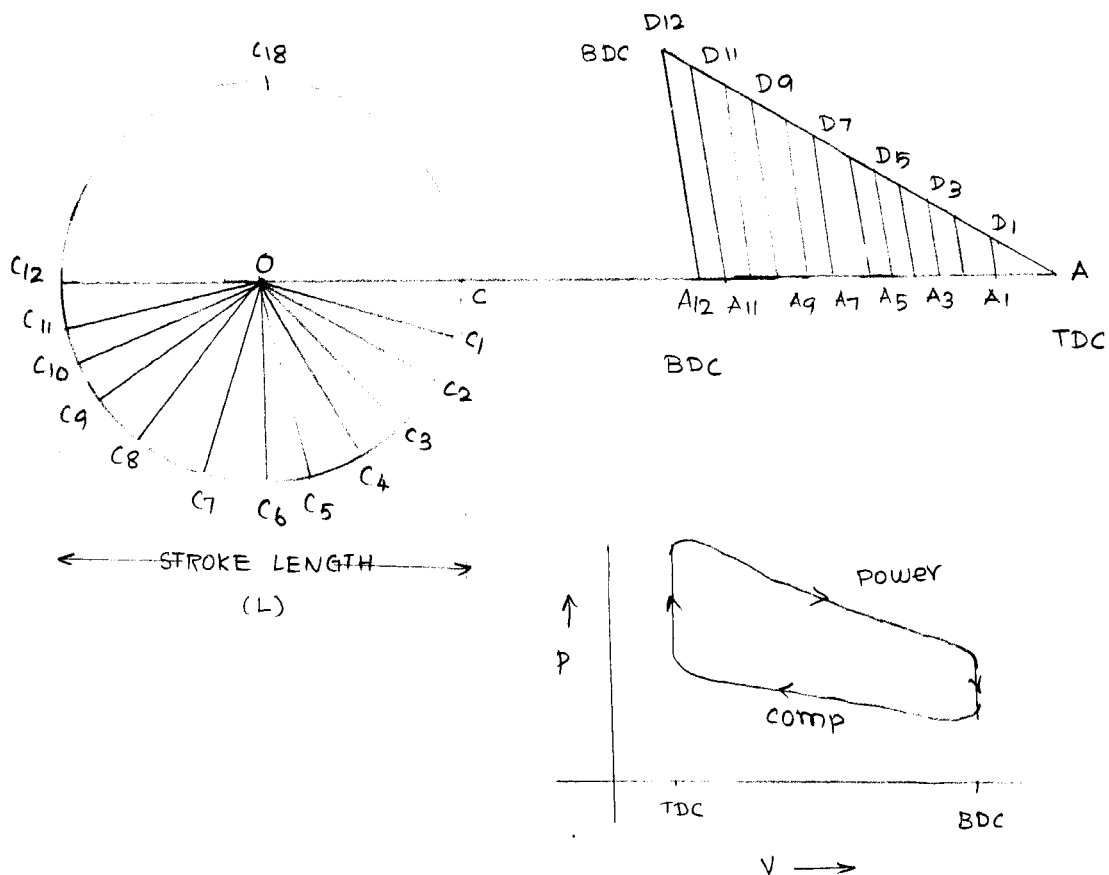
Gas pressure may be assumed as.

FOR exhaust STROKE  $\Rightarrow$  1.12 to 1.16 kgf/cm<sup>2</sup>

FOR suction STROKE  $\Rightarrow$  0.95 to 0.98 kgf/cm<sup>2</sup>

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 thro' 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.



$CA = \text{Length of connecting Rod} = rL$

$AD = \text{Base length of PV diagram.}$

$AA_{12} = L$

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  $15^\circ$ . With  $C_1, C_2, C_3 \dots$  as centres on  $CA$  as a radius cut arcs at  $A_1, A_2 \dots A_{12}$ .
3. Draw a line  $AD$  conveniently at any angle from  $A$ , such that  $AB$  is the base length of the PV diagram. Now join  $A_{12}$  with  $D$ .
4. Draw lines parallel to  $A_{12}D$  through  $A_{11}, A_{10} \dots$
5. Now we have points  $D_{11}, D_{10}$  etc on  $AD$ .
6. Transforms these point in PV diagram.
7. corresponding to these points gas pressure can be determined from PV-diagram in both power and compression stroke.

## RESULTANT FORCE:

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

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

## CALCULATION:

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

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

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

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

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

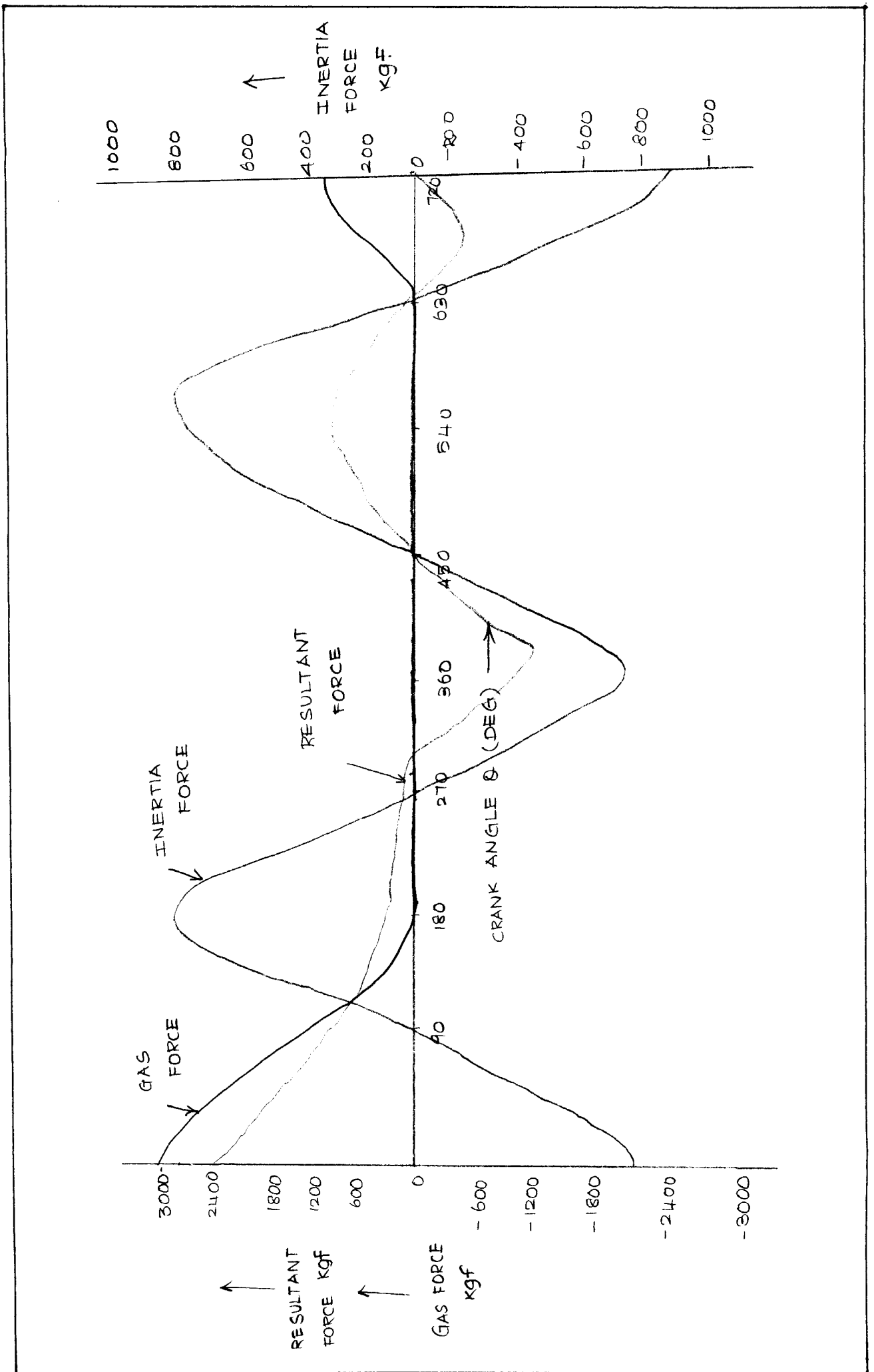
$$W = 0.68 \text{ kgf}$$

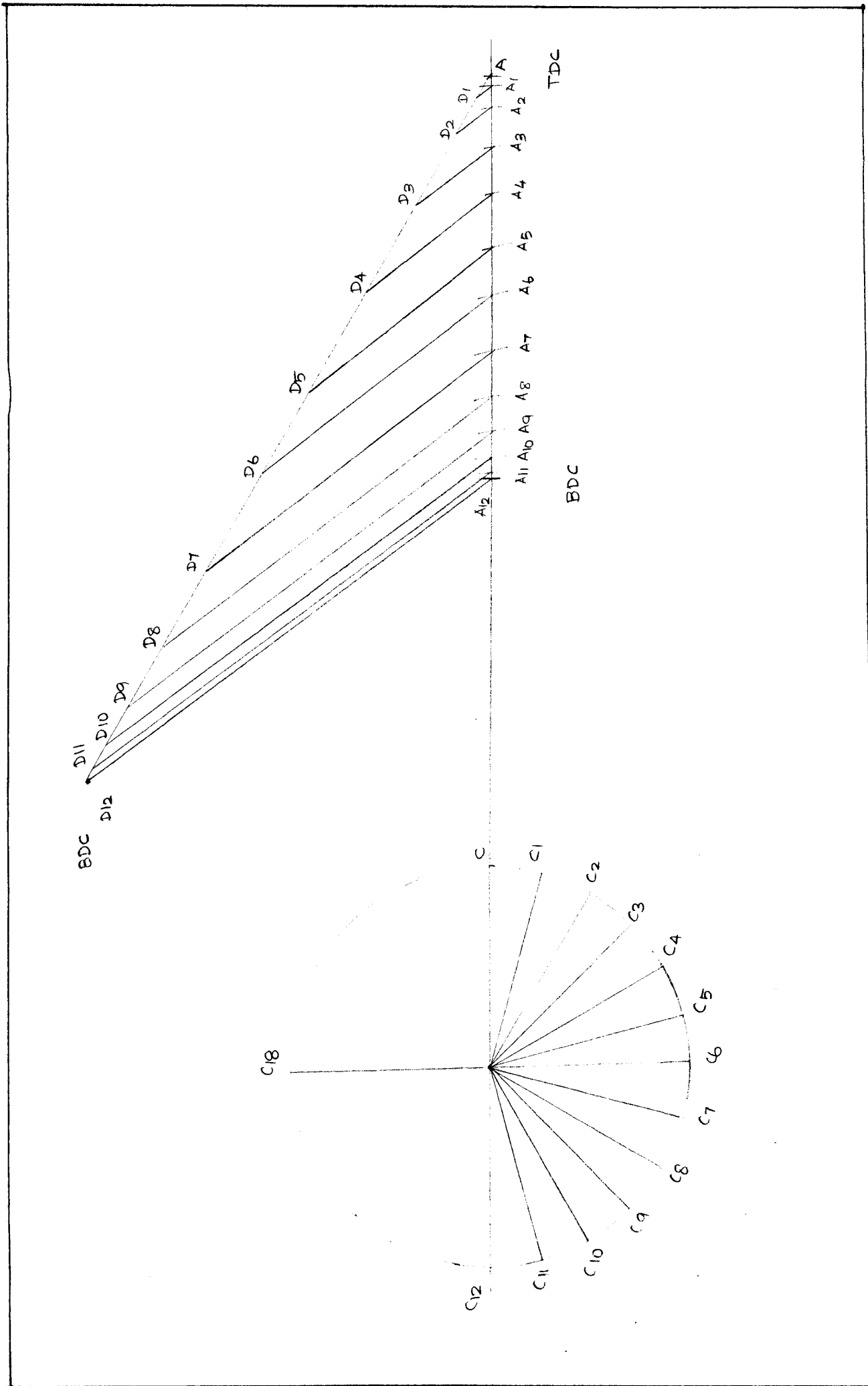
$$G.F = \text{cylinder pr} \times \text{Boye Area}$$

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

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

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





| STROKE | crankangle<br>θ deg | Gas pr.<br>kg/cm <sup>2</sup> | Back pr.<br>kg/cm <sup>2</sup> | Gas Force<br>kgf | Inertia force<br>kgf | Resultant<br>Force<br>kgf | Turning<br>Moment<br>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                     |
|        | 60                  | 15.0                          | 1.03                           | 679.4            | -163.32              | 516.08                    | 1978.33                     |
|        | 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<br>$\theta$ (deg) | Gas pr.<br>kg/cm <sup>2</sup> | Back pr.<br>kg/cm <sup>2</sup> | Gas Force<br>kgf | Inertia<br>Force<br>kgf | Resultant<br>Force<br>kgf | Turning<br>Moment<br>kg-cm |
|-------------------|-------------------------------|-------------------------------|--------------------------------|------------------|-------------------------|---------------------------|----------------------------|
| Exhaust<br>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                    | -755.1                     |
|                   | 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                       |

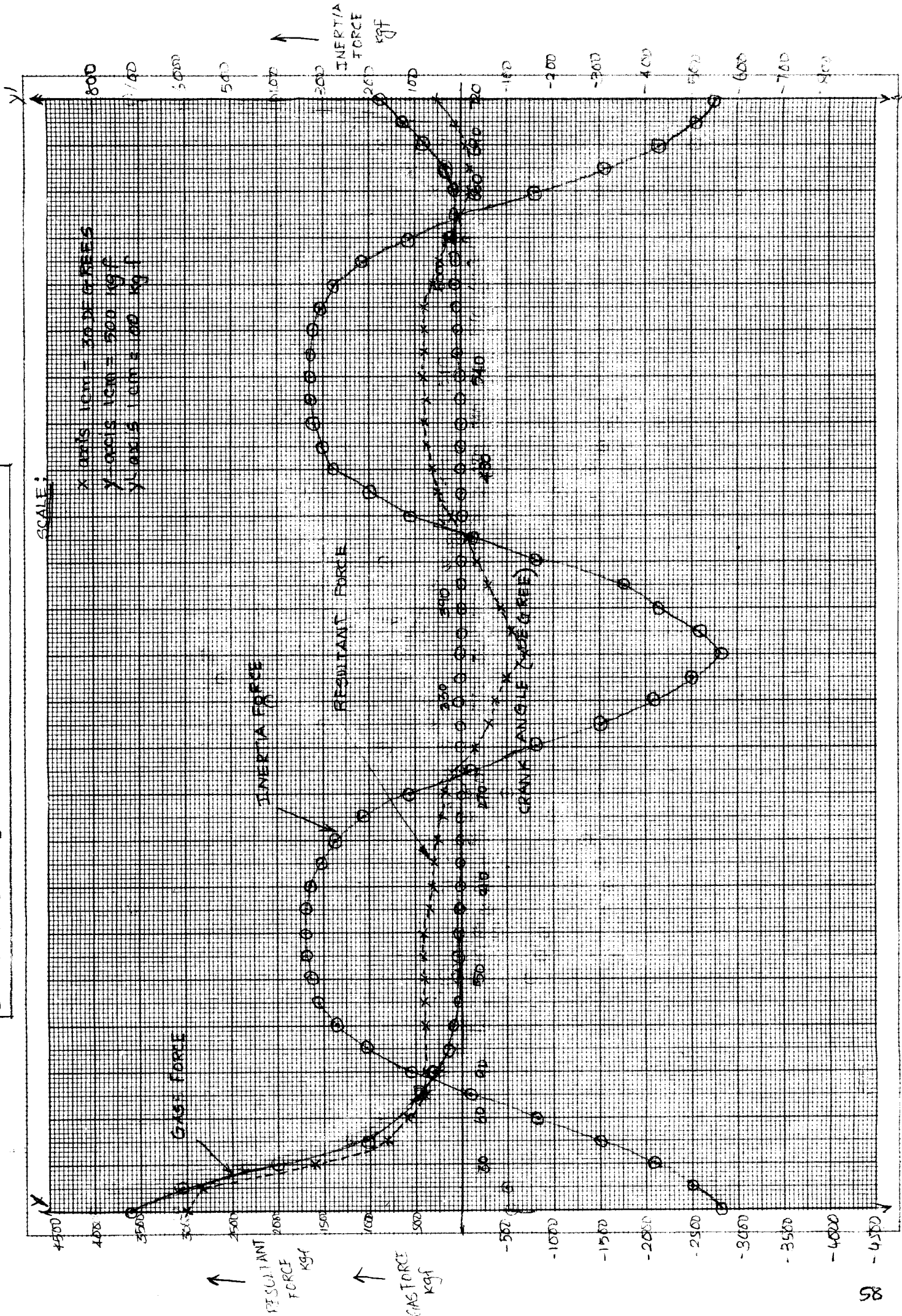
| STROKE  | crank angle<br>$\theta$ (deg) | Gas pr.<br>kg/cm <sup>2</sup> | Back pr.<br>kg/cm <sup>2</sup> | Gas Force<br>kgf | Resultant<br>Force<br>kgf | Resultant<br>Force<br>kgf | Turning<br>Moment<br>kgf-m. |
|---------|-------------------------------|-------------------------------|--------------------------------|------------------|---------------------------|---------------------------|-----------------------------|
|         | 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                      |
| SUCTION | 435                           | 0.96                          | 1.03                           | -3.4043          | -18.509                   | -21.9133                  | -88.7                       |
| STROKE  | 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<br>$\theta$ (deg) | Gas Pr.<br>kg/cm <sup>2</sup> | Back Pr<br>kg/cm <sup>2</sup> | Gas FORCE<br>kgf | Inertia<br>Force<br>kgf | Resultant<br>Force<br>kgf | Turning<br>Moment<br>kgf-cm |
|--------|-------------------------------|-------------------------------|-------------------------------|------------------|-------------------------|---------------------------|-----------------------------|
|        | 555                           | 1.20                          | 1.03                          | 8.268            | 326.42                  | 334.7                     | -258.5                      |
|        | 670                           | 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                  | 273.763                   | -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                          | 82.676           | -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                        |

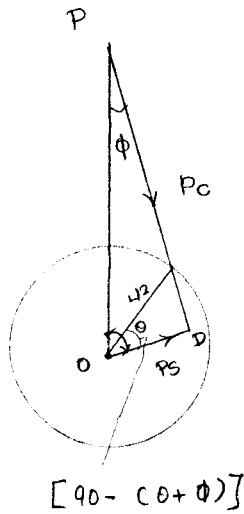
COMPRESSION

STROKE

**CRANK ANGLE VS RESULTANT, GAS, INERTIA FORCES**



## TURNING MOMENT:



R- Resultant Force

$P_c$  - force acting on connecting rod

$P_s$  - side force or side thrust.

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

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

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

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.

$$\text{Turning Moment} = P_c \times OD$$

We can determine turning moment & side thrust Now.

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

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

$$\text{Turning Moment} = P_c \times OD$$

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

$$\begin{aligned} \text{Turning Moment} &= \frac{PL}{2} \left[ \frac{\sin\theta \cos\phi + \cos\theta \sin\phi}{\cos\phi} \right] \\ &= \frac{PL}{2} \left[ \sin\theta + \cos\theta \cdot \tan\phi \right] \because \tan\phi \approx \frac{\sin\theta}{2h} \\ &= \frac{PL}{2} \left[ \sin\theta + \cos\theta \frac{\sin\theta}{2h} \right] \\ & \qquad \qquad \qquad \cos\theta \sin\theta = \frac{\sin 2\theta}{2} \\ &= \frac{PL}{2} \left[ \sin\theta + \frac{\sin 2\theta}{4h} \right] \end{aligned}$$

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

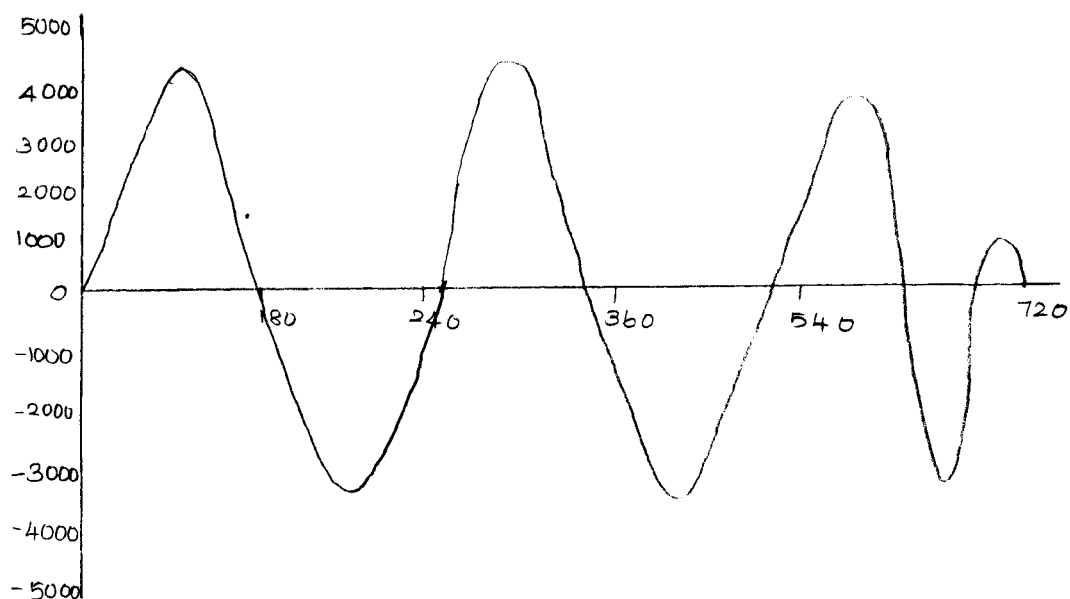
$$\begin{aligned} \text{T.M} &= \frac{Pr \cdot AL}{200} \left[ \sin\theta + \frac{\sin 2\theta}{4h} \right] \\ &= \frac{Pr \cdot D}{200} \left[ \sin\theta + \frac{\sin 2\theta}{4h} \right] \dots \text{kgf m} \end{aligned}$$

where,

$P_r$  = Resultant pressure kgf/cm<sup>2</sup>

$D$  = Engine displacement in cc.

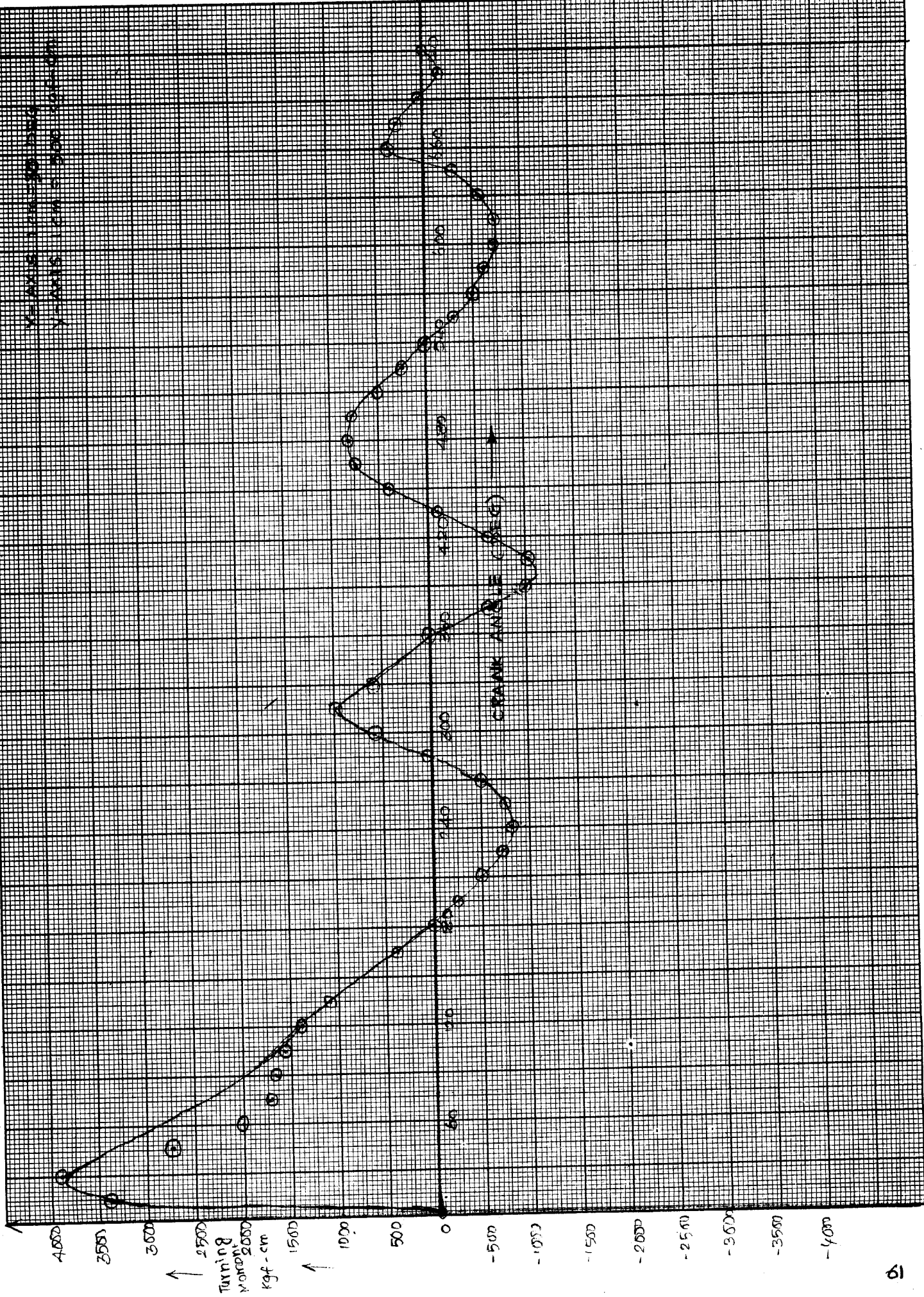
T- $\theta$  GRAPH:



# TURNING MOMENT VS CRANK ANGLE

SCALE

Y-AXIS TURNING MOMENT  
Y-SCALE 1 CM = 500 KG-CM



COMBINED TURNING MOMENT :

For six cylinder engines,

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

$$\text{firing interval} = \frac{720^\circ}{6} = 120^\circ$$

Four cylinder engines,

firing order is 1, 3, 4, 2.

$$\text{firing interval} = \frac{720^\circ}{4} = 180^\circ$$

Four cylinder Engines:

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

SIX CYLINDER ENGINES:

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

| I <sup>st</sup> cylinder |         | II <sup>nd</sup> cylinder |         | III <sup>rd</sup> cylinder |          | IV <sup>th</sup> cylinder |         | Combined T.M |
|--------------------------|---------|---------------------------|---------|----------------------------|----------|---------------------------|---------|--------------|
| $\theta$                 | T.M     | $\theta$                  | T.M     | $\theta$                   | T.M      | $\theta$                  | T.M     | Kgf-cm       |
| deg                      | Kgf cm  | deg                       | Kgf cm  | deg                        | Kgf cm   | deg                       | 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                       | -685.4  | 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  | 5103.96      |
| 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.  $\omega$ , between  $0^\circ$  to  $180^\circ$

$$\text{side thrust} = P_s = P \tan \phi$$

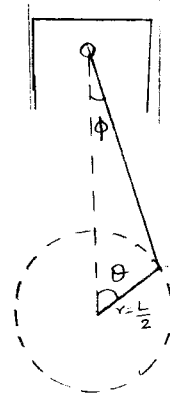
$P =$  Resultant Force.

on resolving force,

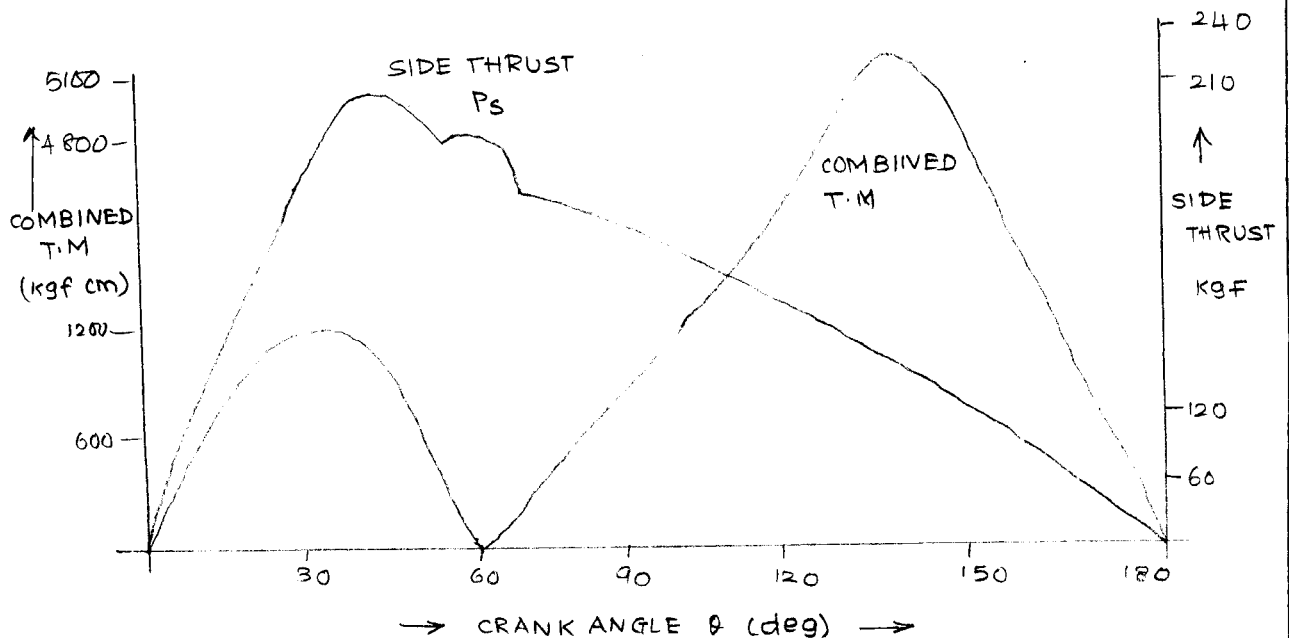
$$nL \sin \phi = \frac{L}{2} \sin \theta$$

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

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



**GRAPH:**

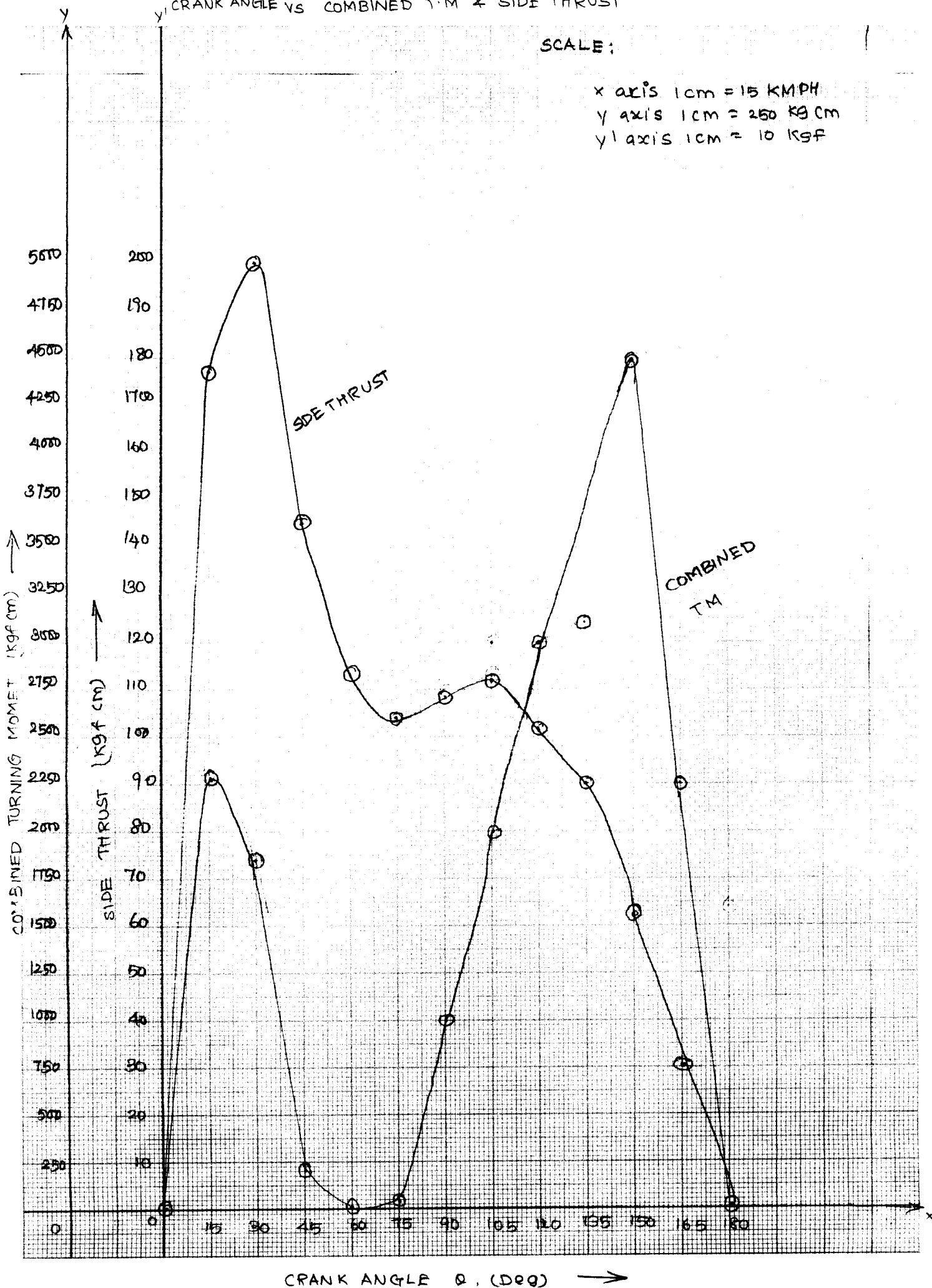


| crank angle<br>$\theta$ (deg) | $\frac{\sin \theta}{2r}$ | $\theta = \sin^{-1} \left( \frac{\sin \theta}{2r} \right)$ | $\tan \phi$ | side Thrust<br>$P_s = P \tan \phi$<br>kgf |
|-------------------------------|--------------------------|--|-------------|---|
| 0                             | 0                        | 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

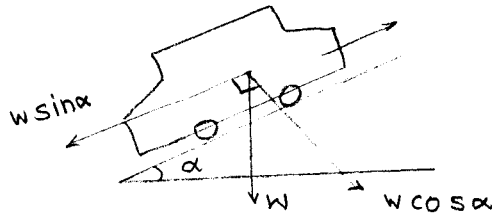
SCALE:

x axis 1cm = 15 KMPH  
 y axis 1cm = 250 KG CM  
 y' axis 1cm = 10 KGF



CRANK ANGLE  $\theta$  (DEG) →

DETERMINATION OF GRADIABILITY, ACCELERATION, GEAR RATIO:



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

$$\text{Gradiability} = 100 \tan \alpha$$

$$\text{Gradient resistance, } R_g = W \sin \alpha$$

Assume first gear ratio as 3:1

From the graph  $T$  vs  $v$ ,

Find  $v$  corresponding to the  $T_{max}$  also find  $T_{max}$

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.

$$R_{T1} = R_a + R_r = k_d A v_1^2 + (7.6 + 0.056 v_1) W$$

$$\text{Now, } 100 \tan \alpha = 38 \Rightarrow \alpha = ?$$

$$R_g = W \sin \alpha \dots K_g F$$

$$\text{Driving Force, } DF = R_{T1} + R_g \dots K_g F$$

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

$T_e$  = Engine Torque

$G$  = Gear ratio

$r_a$  = Axle reduction

$\eta_t$  = 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   | $G_2$      | $(G_1)^{2/3}$ | $(G_1)^{2/3}$     | (.9P) |
| 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:

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

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

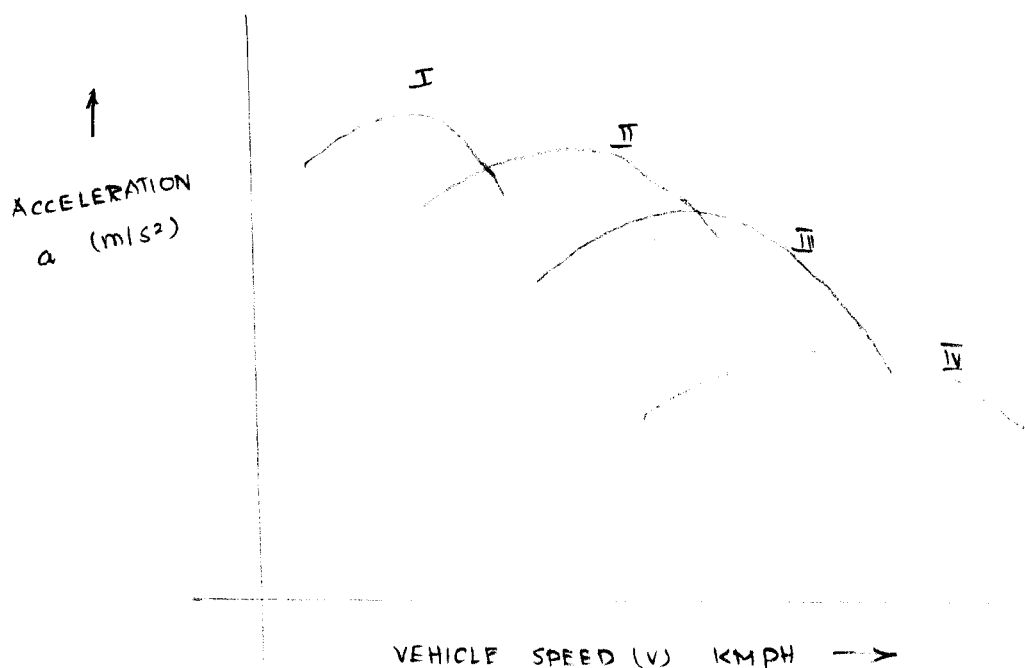
$$a = \frac{K g EDF}{W} \dots \dots m/s^2$$

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

and,  $EDF = DF - R_e$

$$\checkmark R_e = R_a + R_r + R_g$$

W - GVW in kgf.



FIRST GEAR:

| V<br>KMPH | N<br>rpm | T<br>kgf m | RE<br>kgf | DF<br>kgf | EDF<br>kgf | $\alpha$<br>m/s <sup>2</sup> | $\sin \alpha$<br>$\left(\frac{EDF}{W}\right)$ | $\alpha$ | Gradability<br>100 Tan $\alpha$ |
|-----------|----------|------------|-----------|-----------|------------|------------------------------|---|----------|---------------------------------|
| 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        | 528.0    | 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      | 2.43                         | 0.333   | 19.451   | 35.32                           |
| 40 (N)    | 1413.3   | 12.78      | 20.35     | 400.00    | 379.65     | 2.472                        | 0.336   | 19.63    | 35.67                           |

SECOND GEAR:

| V<br>KMPH | N<br>rpm | T<br>kgf-cm | R <sub>F</sub><br>kgf | DF<br>kgf | EDF<br>kgf | a<br>m/s <sup>2</sup> | sin α<br>( $\frac{EDF}{W}$ ) | α     | Gradability<br>100 tan α |
|-----------|----------|-------------|-----------------------|-----------|------------|-----------------------|------------------------------|-------|--------------------------|
| 10        | 353.23   | 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<br>KMPH | N<br>rpm | T<br>kgfcm | Rt<br>kgf | DF<br>kgf | EDF<br>kgf | $\omega$<br>m/s <sup>2</sup> | $\sin \alpha$<br>( $\frac{EDF}{W}$ ) | $\alpha$ | Gradability<br>100 tan $\alpha$ |
|-----------|----------|------------|-----------|-----------|------------|------------------------------|--------------------------------------|----------|---------------------------------|
| 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     | 126.32    | 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

SCALE

X-AXIS 1CM = 0.25 m/s<sup>2</sup>

Y-AXIS 1CM = 5 KMPH

