ME4435: Dynamics Lab

Experiment 1:

Balancing Of Reciprocating Masses

Group 4

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Aim:

This experiment aims to quantify the free mass forces and mass moments generated by reciprocating engines.

Apparatus:

- Reciprocating piston with crankshaft
- Cylinder
- Additional piston mass
- Plastic piston sleeve
- Chassis and base plate
- Control unit

Theory:

This experiment enables the measurement of unbalanced forces and moments in reciprocating engines. The digital display facilitates the regulation of the rotating speed of the pistons. Strain gauges are strategically placed on the elastic boom of the model mounting bracket to measure both forces and moments. The control unit integrates all electrical functions, allowing for seamless operation.

Markers at $\pi/2$, π, and $3\pi/2$ radians provide reference points, enabling continuous modification of the crank offset for each measurement.

It's important to note that even in the presence of an unbalanced force, an unbalanced couple may persist. This couple arises from the sum of all forces acting on the engine body due to inertia forces. In balanced mechanisms, these inertia couples and forces are counterbalanced. Under specific conditions, the effects of these forces and couples can be virtually eliminated.

Fig: Balance of Reciprocating Masses setup

Force Analysis:

A single IC Engine is dynamically like a slider crank mechanism. The expression which gives the force on the piston in slider crank mechanism is:

$$F = m\omega^2 r(\cos(\theta) + \lambda\cos(2\theta))$$

Where:

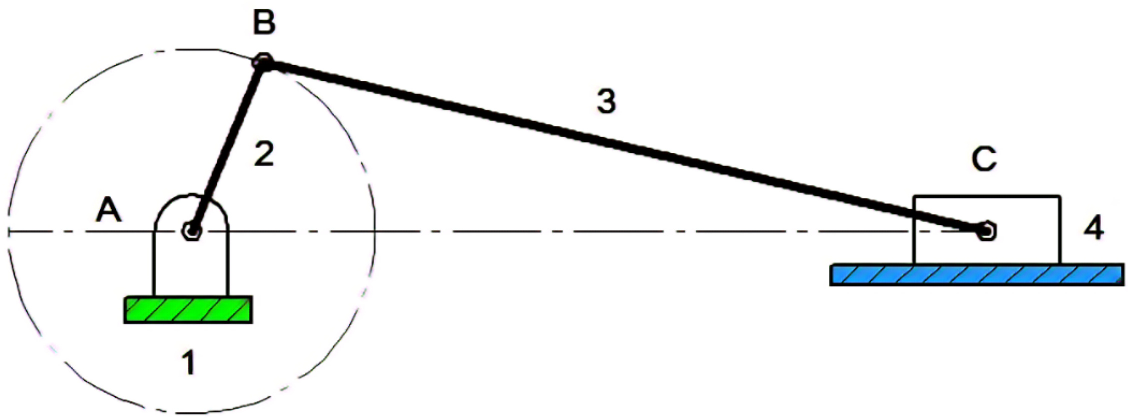
- $m\ is\ the\ reciprocating\ mass$
- $\omega\ is\ the\ angular\ velocity\ of\ the\ system,,$
- $r\ is\ the\ crank\ radius,$
- $\theta\ is\ the\ angle\ between\ the\ crankshaft\ and\ the\ slider's\ axis,$
- $\lambda = \frac{r}{l}\ ,where\ l\ is\ lenght\ of\ connecting\ rod$

The force expression can be reduced to two components:

Primary Force: $F_P = m\omega^2 r\cos(\theta)$

Secondary Force: $F_S = \lambda m\omega^2 r\cos(2\theta)$

For inline engines, if the initial angles of the different cylinders are known with respect to the crankshaft angle, their individual forces can be added to find the overall unbalanced force of the assembly. If the first cylinder is considered to be aligned to the crankshaft & the other cylinders are at α, β & γ then,



Slider-Crank Mechanism

Overall Primary Force:

$$F_P = m\omega^2 r(\cos(\theta) + \cos(\theta + \alpha) + \cos(\theta + \beta) + \cos(\theta + \gamma))$$

Overall Secondary Force:

$$F_S = \lambda m\omega^2 r(\cos(2\theta) + \cos 2(\theta + \alpha) + \cos 2(\theta + \beta) + \cos 2(\theta + \gamma))$$

Moment Analysis:

The forces in the slider crank mechanism give rise to moments in the systems. The overall moment of the slider crank mechanism is:

$$M = xm\omega^2 r(\cos(\theta) + \lambda\cos(2\theta))$$

Where: $x\ is\ the\ distance\ between\ the\ two\ cylinders$

The moment components can be reduced into two components:

Primary Moment: $M_P = xm\omega^2 r\cos(\theta)$

Secondary Moment: $M_S = x\lambda m\omega^2 r\cos(2\theta)$

Similar to our analysis for forces in an inline engine, we will find the total moment in four-cylinder engine by:

Overall Primary Moment:

$$M_P = m\omega^2 r(x_1\cos(\theta) + x_2\cos(\theta+\alpha) + x_3\cos(\theta+\beta) + x_4\cos(\theta+\gamma))$$

Overall Secondary Moment:

$$M_S = \lambda m\omega^2 r(x_1\cos(2\theta) + x_2\cos 2(\theta+\alpha) + x_3\cos 2(\theta+\beta) + x_4\cos 2(\theta+\gamma))$$

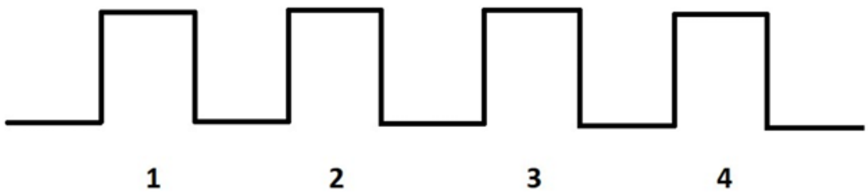
Where x_1, x_2, $x_3$and x_4 are the respective distances from the reference plane.

Procedure:

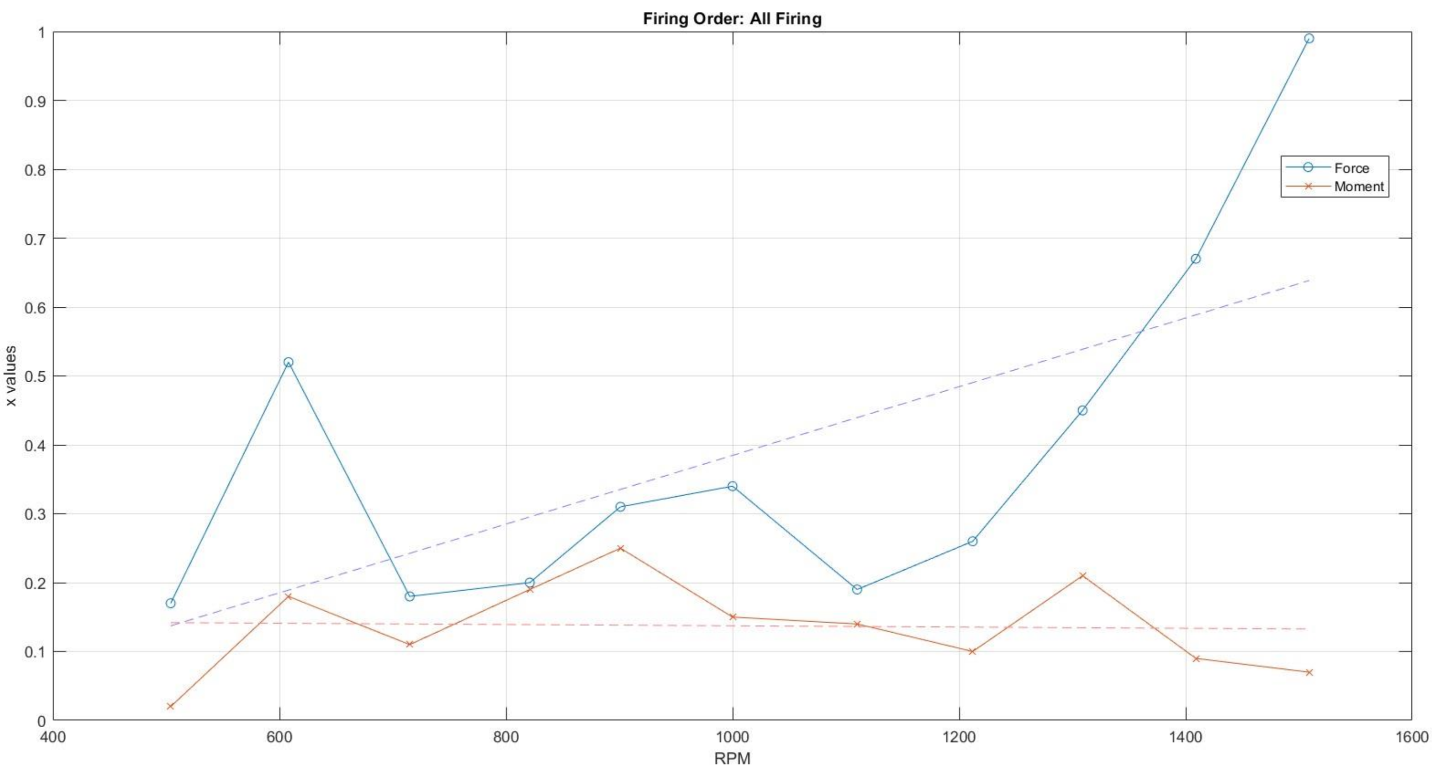
- Adjust the crank offset to the desired configuration.
- Securely tighten the screws and install the clear protective cover.
- Gradually start the apparatus, starting at a speed of 500 and progressing up to the resonance speed, ensuring not to exceed this limit.
- Increment the speed in 100-unit intervals, recording force and moment values till the maximum allowable speed is reached. Avoid prolonged operation at high speeds to avoid damage to the setup.
- Observe any strong sympathetic vibrations indicative of free forces and moments.
- Record observations and calculate the corresponding theoretical values.
- Generate a run-up curve by plotting rotational speed on the x-axis (measured in revolutions per minute) and force and moment on the y-axis (measured in voltage).
- Repeat the entire procedure for different starting configurations of the cylinders.

Tables & Plots:

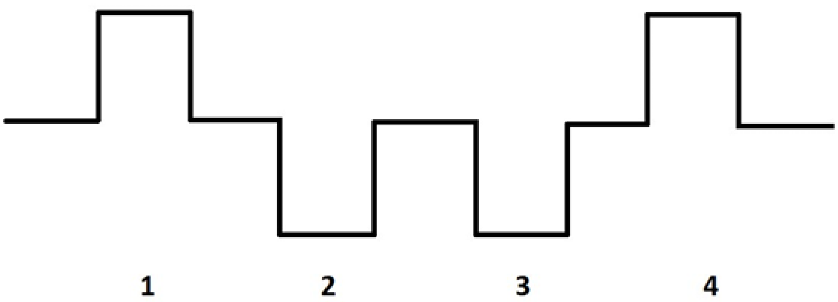
Firing Order: Single Cylinder (All Firing)



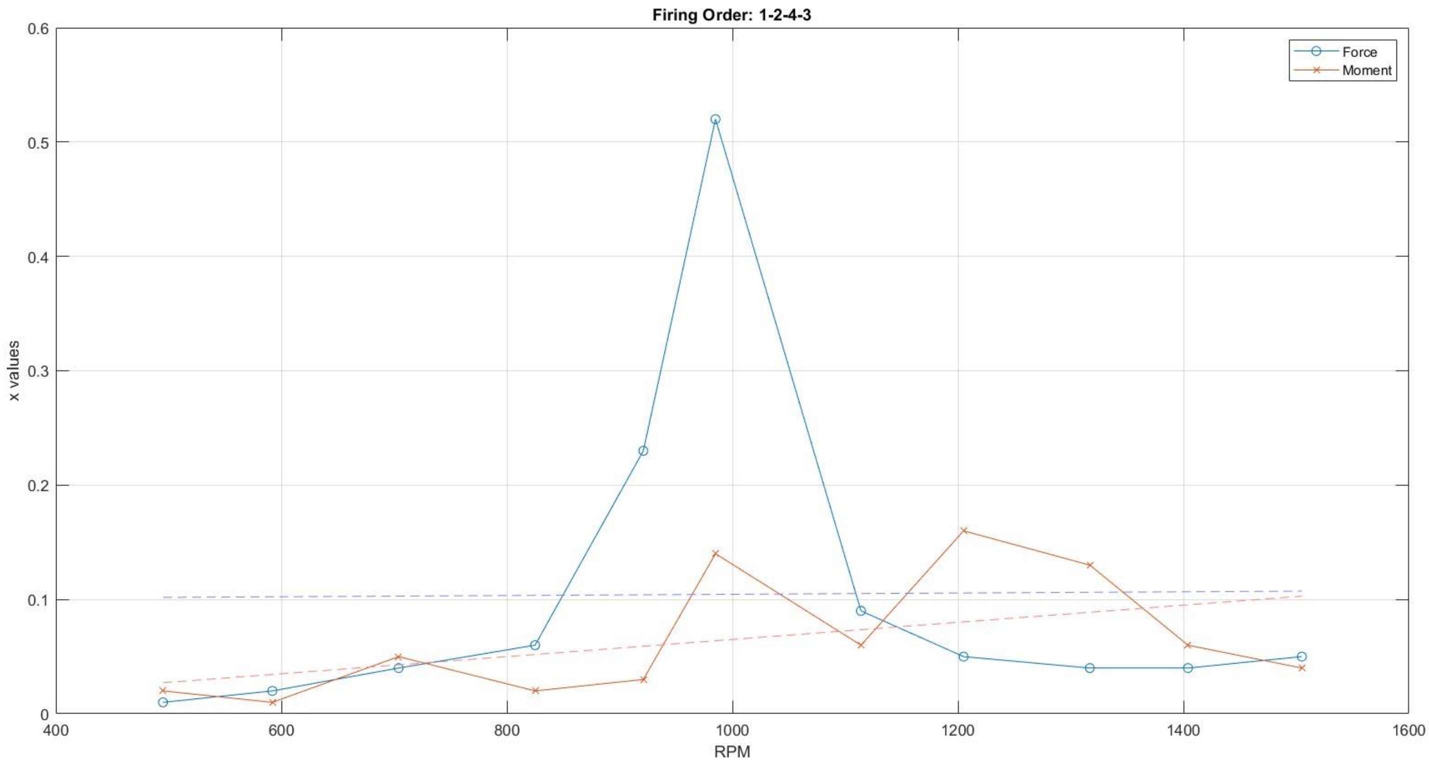
RPM	Force	Moment
504	0.1700	0.0200
608	0.5200	0.1800
715	0.1800	0.1100
821	0.2000	0.1900
901	0.3100	0.2500
1000	0.3400	0.1500
1110	0.1900	0.1400
1212	0.2600	0.1000
1309	0.4500	0.2100
1409	0.6700	0.0900
1509	0.9900	0.0700



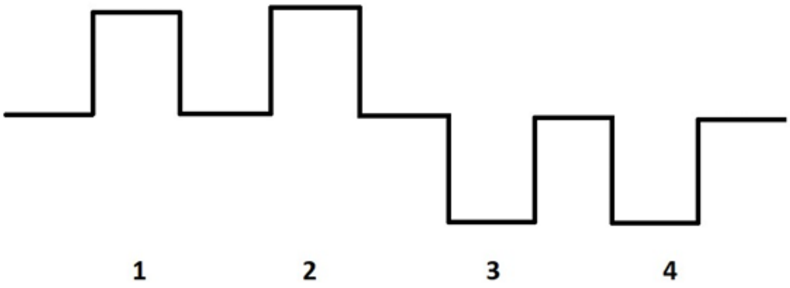
Firing Order: 1-2-3-4



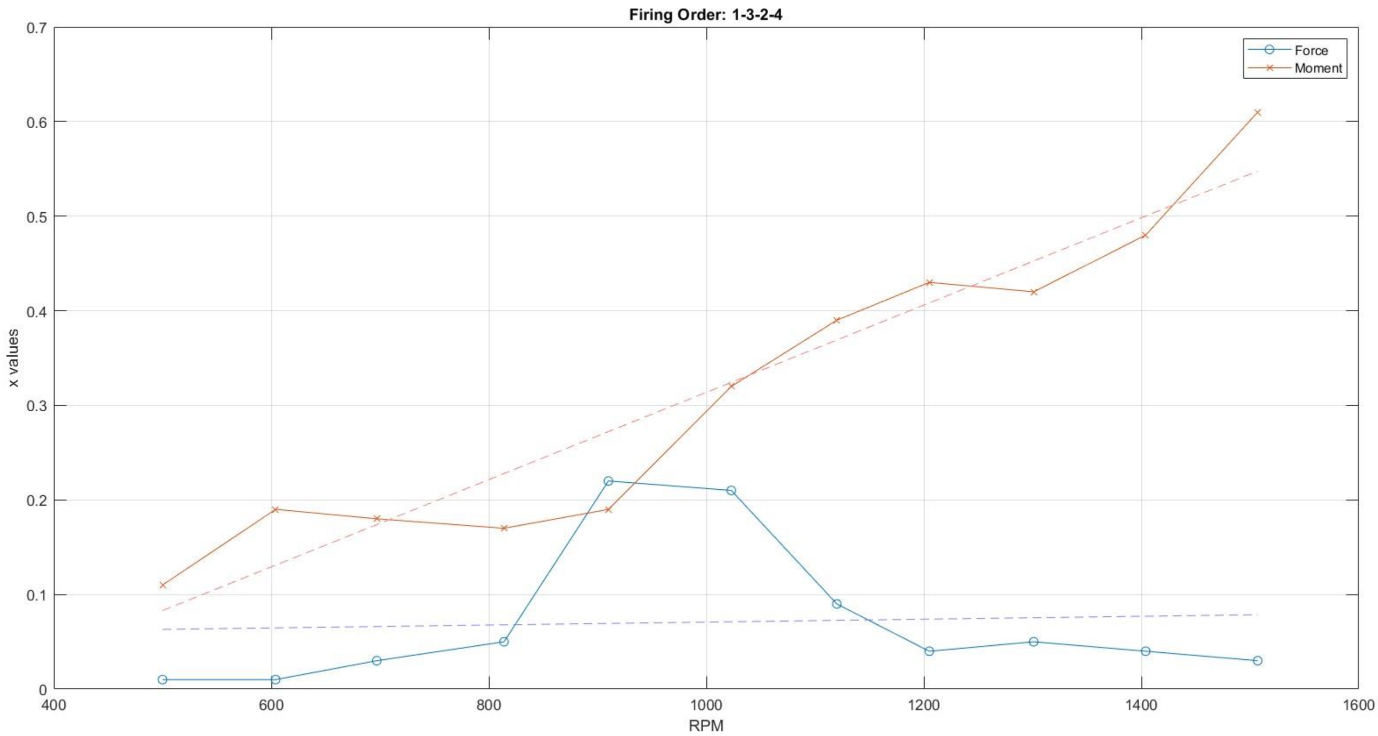
RPM	Force	Moment
495	0.0100	0.0200
592	0.0200	0.0100
704	0.0400	0.0500
825	0.0600	0.0200
921	0.2300	0.0300
985	0.5200	0.1400
1114	0.0900	0.0600
1205	0.0500	0.1600
1317	0.0400	0.1300
1404	0.0400	0.0600
1505	0.0500	0.0400



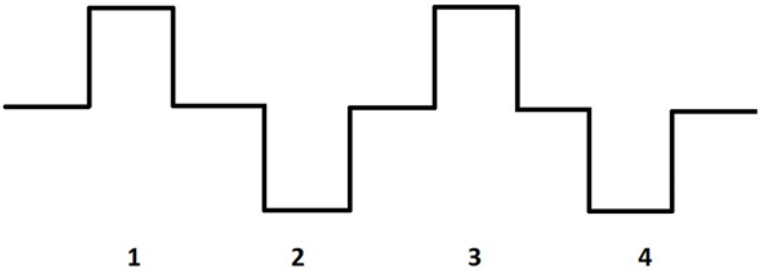
Firing Order: 1-3-2-4



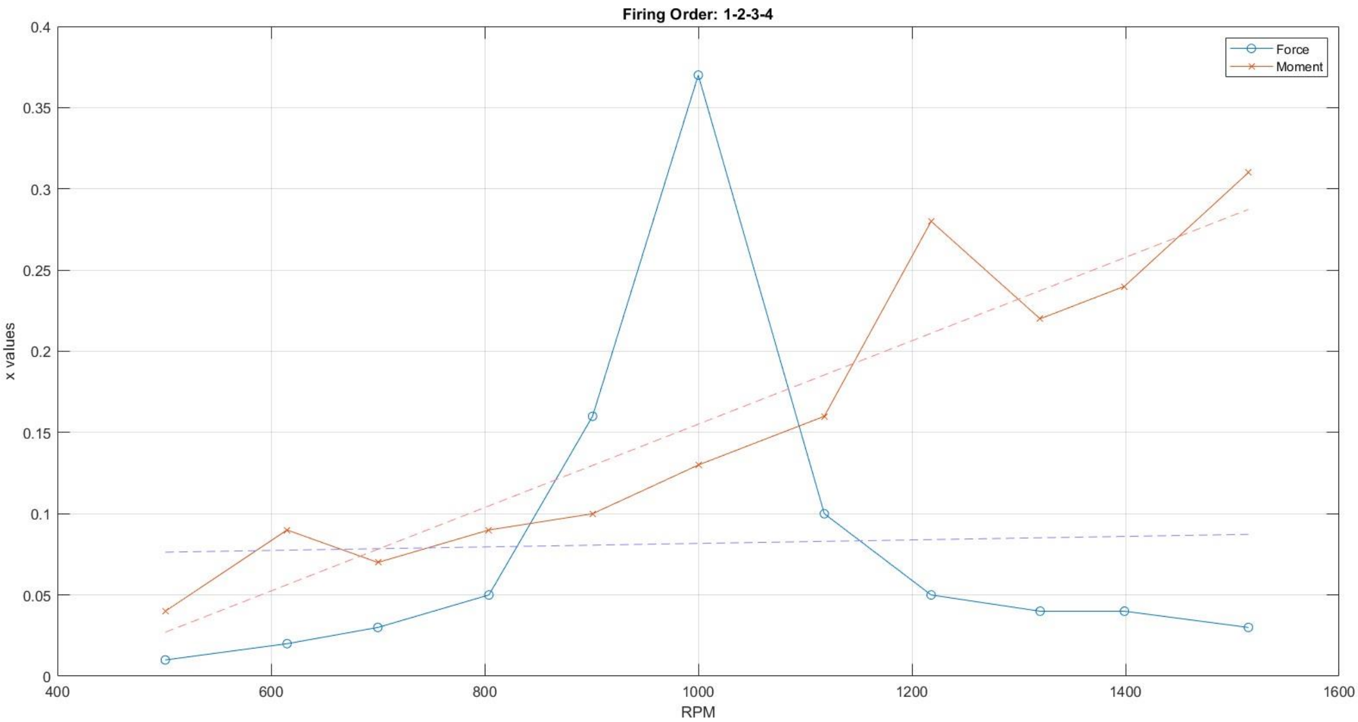
RPM	Force	Moment
500	0.0100	0.1100
604	0.0100	0.1900
697	0.0300	0.1800
814	0.0500	0.1700
910	0.2200	0.1900
1023	0.2100	0.3200
1120	0.0900	0.3900
1205	0.0400	0.4300
1301	0.0500	0.4200
1404	0.0400	0.4800
1507	0.0300	0.6100



Firing Order: 1-2-3-4



RPM	Force	Moment
501	0.0100	0.0400
615	0.0200	0.0900
700	0.0300	0.0700
804	0.0500	0.0900
901	0.1600	0.1000
1000	0.3700	0.1300
1118	0.1000	0.1600
1218	0.0500	0.2800
1320	0.0400	0.2200
1399	0.0400	0.2400
1515	0.0300	0.3100



Sample Calculations:

Connecting rod ratio (λ) = 0.214, distance between cylinders x = 0.035m

$$x_1 = -\frac{3x}{2}, x_2 = -\frac{x}{2}$$

$$x_3 = \frac{x}{2}, x_4 = \frac{3x}{2}$$

Configuration	F_P	F_S	M_P	M_S
$\theta = 0, \alpha = 180,$ $\beta = 0, \gamma = 180$	0	$0.856mr\omega^2$	$-0.07mr\omega^2$	0
$\theta = 0, \alpha = 0,$ $\beta = 180, \gamma = 180$	0	$0.856mr\omega^2$	$-0.14mr\omega^2$	0
$\theta = 0, \alpha = 180,$ $\beta = 180, \gamma = 0$	0	$0.856mr\omega^2$	0	0
$\theta = 0, \alpha = 0,$ $\beta = 0, \gamma = 0$	$4mr\omega^2$	$0.856mr\omega^2$	0	0

Sample calculation for first configuration

$$\theta = 0^o, \alpha = 180^0, \beta = 0^0, \gamma = 180^0$$

$$F_P = m\omega^2 r(\cos(0) + \cos(0+180) + \cos(0+0) + \cos(0+180))$$

$$\boldsymbol{F_P = m\omega^2 r(0) = 0}$$

$$F_S = \lambda m\omega^2 r(\cos(0) + \cos 2(0+180) + \cos 2(0+0) + \cos 2(0+180))$$

$$\boldsymbol{F_S = 0.214m\omega^2 r(4) = 0.856m\omega^2 r}$$

$$M_P = m\omega^2 r(x_1\cos(0) + x_2\cos(0+180) + x_3\cos(0+0) + x_4\cos(0+180))$$

$$\boldsymbol{M_P = -2xm\omega^2 r = -0.07m\omega^2 r}$$

$$M_S = \lambda m\omega^2 r(x_1\cos(0) + x_2\cos 2(0+180) + x_3\cos 2(0+0) + x_4\cos 2(0+180))$$

$$\boldsymbol{M_S = 0}$$

Performing similar calculations to all the four configurations, we obtain the values mentioned in the above table for forces and moments.

Conclusion:

The experiment successfully demonstrated the balancing of reciprocating masses by analysing the unbalanced forces and moments in various engine configurations and firing orders. The results showed that as the RPM increased, the forces and moments also increased, highlighting the dynamic behaviour of the engine. The experiment also reinforced the theoretical principles of primary and secondary forces and moments. Achieving an optimal balance is crucial for minimizing vibrations and improving the engine's operational efficiency