Project Report on

Balancing Aspects of Inline and V Engines

Submission by:

Dhruval Javia- 18ME01022

Deepak Senapati-18ME01047

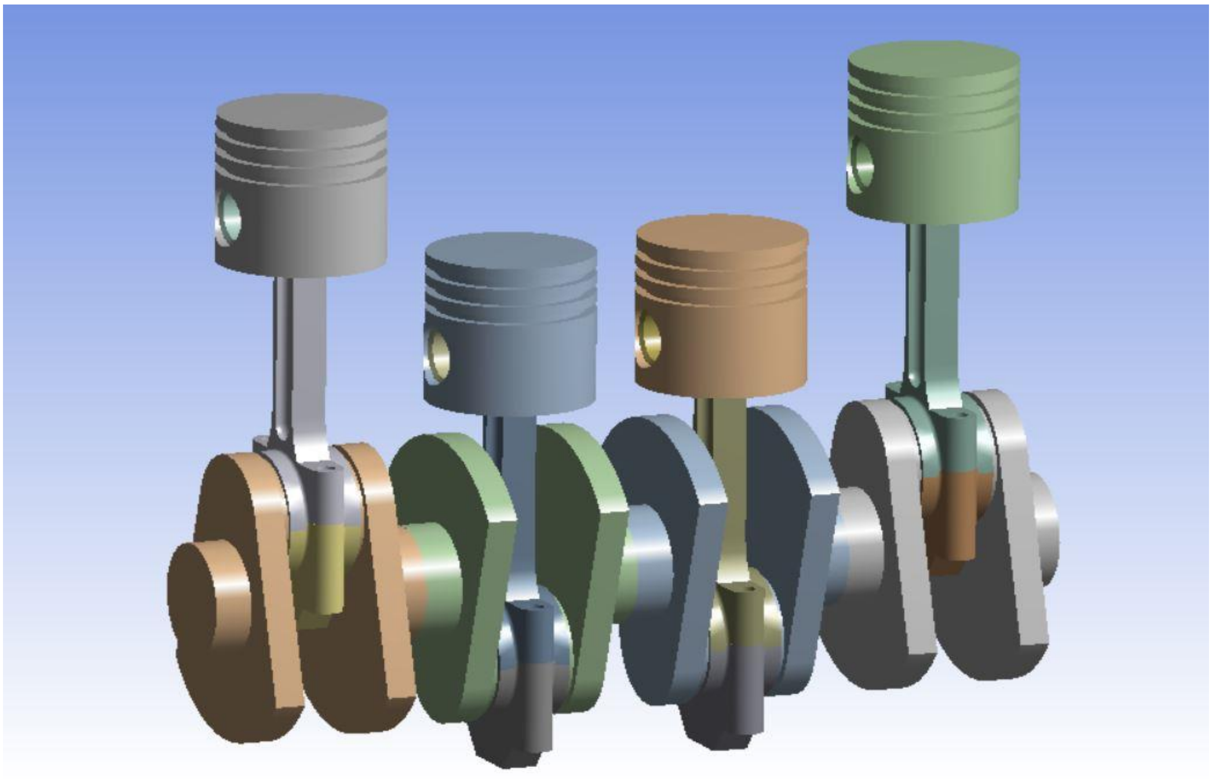
Kartik Tewari-18ME02002

Ruturaj Patil-18ME02005

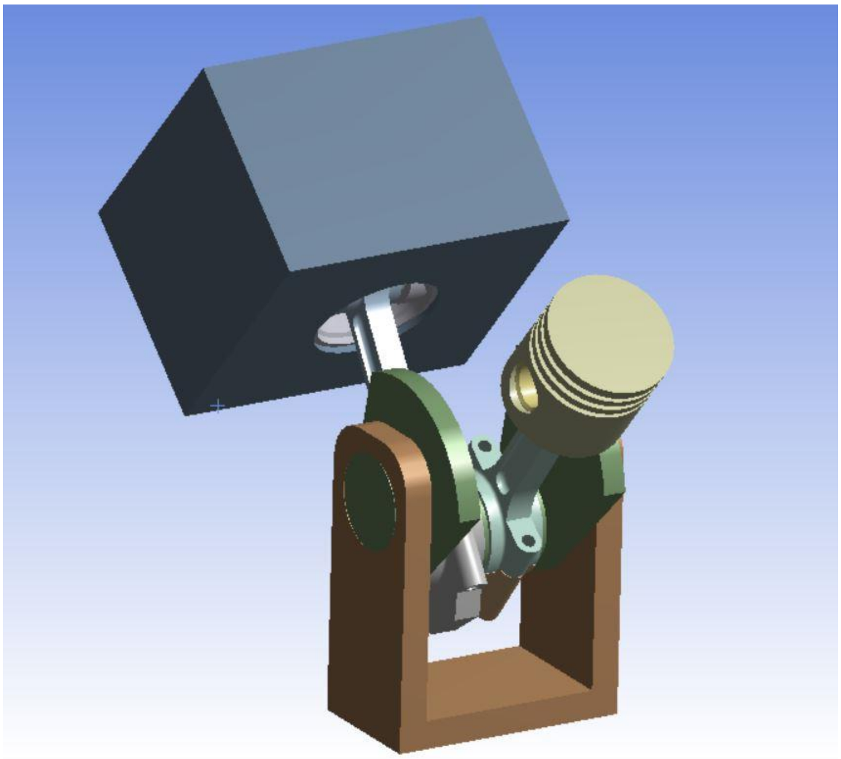
3rd year - B. Tech and B. Tech + M. Tech (MSD) students, School of Mechanical Sciences, IITBBS

Contents of Report:

<u>CAD Models (Solidworks):</u>



Inline 4-cylinder engine



<u>V2 engine</u>

Analysis 1 - Hand Calculations (Expected Results):

General equation of forces: mrw^2 (cos(theta) + cos(2*theta)/n))

where m =effective reciprocating mass,

theta = crank angle,

n = ratio of length of connecting rod to crank radius.

w = angular acceleration given to crank, for this experiment it is kept as 10 rad/s for both Inline and V engine setup.

Assessing Bill of Materials and Mass properties in Solidworks, we obtain the following values: m = 1.726 kg, r = 44mm = 0.044 m, n = 3.89.

<u>In Inline-4 engine</u>:

From vector analysis, primary force resultant = zero, but secondary forces add up in the direction along the piston's motion.

Hence net force in Inline-4 engine = 4*m*r*w^2*cos(2*theta)/n

The equation has been written directly because 2 pistons will have angles as theta, and the other two will be out of phase theta + pi.

Hence maximum net force expected in Inline-4 engine due to unbalance = 4*1.726*0.044*(10^2)/3.89 = 7.81 Newtons.

<u>In V2 engine:</u>

In this case, neither the primary force nor the secondary force turns out to be zero. From, basics of the theory of machines, we understand that the primary force will be directed along the crank and secondary force will be directed along the z-axis. As the CAD design has been made such that the angle between 2 V's is 90 degrees, our equations further simplify.

Net primary force of unbalance = m*r*w^2 along the direction of crank

Thus, x-component of primary force F_{px} = m*r*w^2*cos(theta)

z-component of primary force F_{pz} = m*r*w^2*sin(theta)

Net secondary force of unbalance = sqrt(2) *m*r*w^2/n*sin(2*theta) along z-axis

Thus,

$F_x = F_{px}$ and $F_z = F_{pz} + F_s$

Hence, equation of net force expected in V2 engine due to unbalance

= sqrt(F_x^2 + F_z^2)

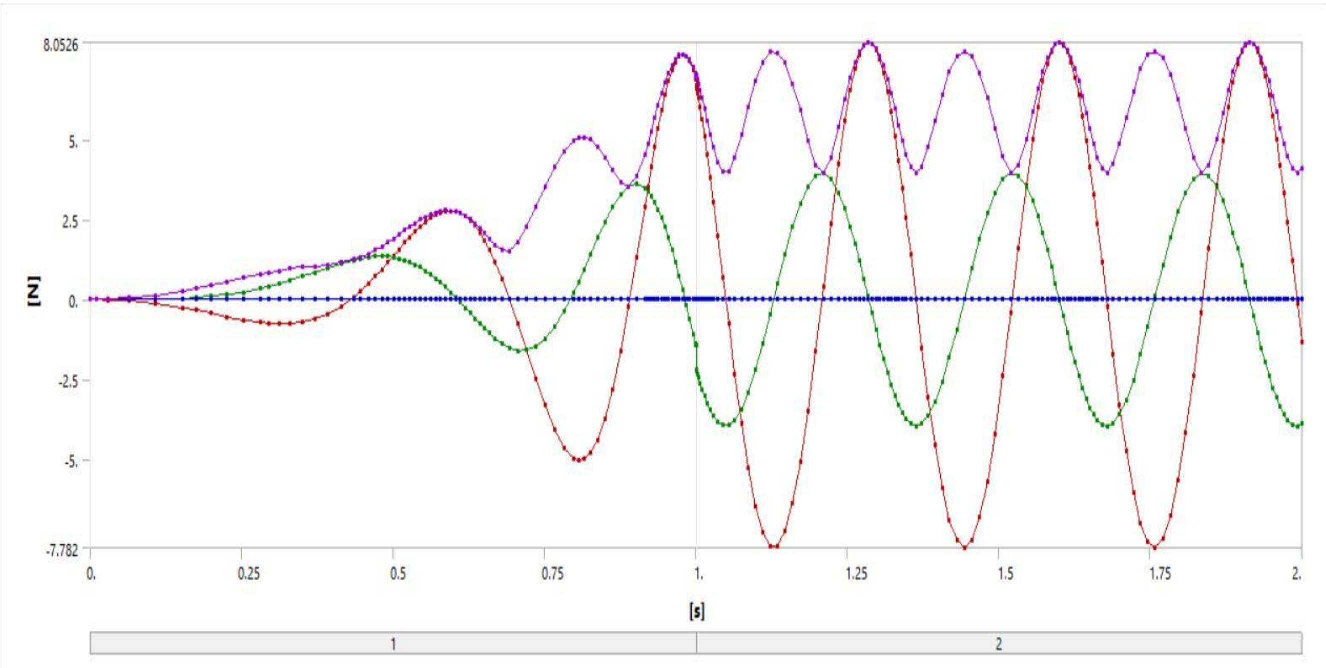
= m*r*w^2*sqrt[cos(theta)^2 + {sin(theta) + sqrt(2) *sin(2*theta)/n}^2]

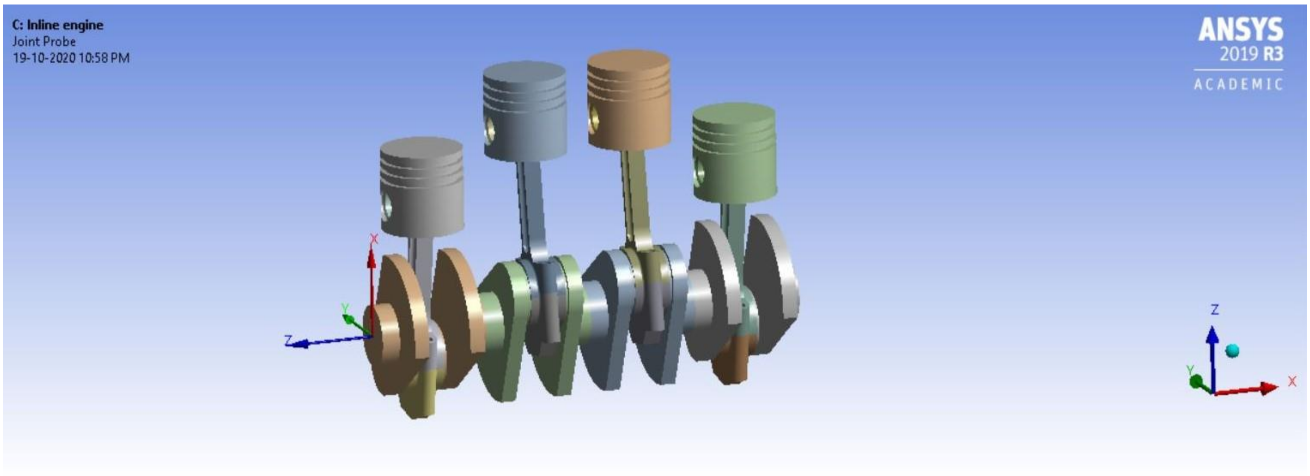
Differentiating and finding maxima, we get: F max. = 9.07 N

Analysis 2 - Simulation Results (ANSYS, Rigid Body Dynamics):

The given graphs show reaction at the revolute joint defined at one of the ends of the crankshaft for inline engine and acceleration of the two piston heads in V2 engine. Red, green and blue colours correspond to positive x, y and z axes and purple indicates resultant magnitudes of reaction force or acceleration.

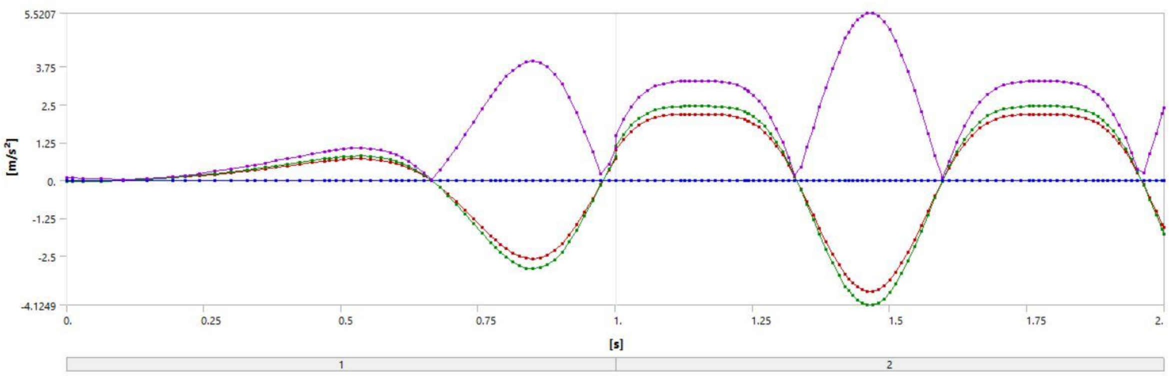
Inline engine revolute joint probe graph



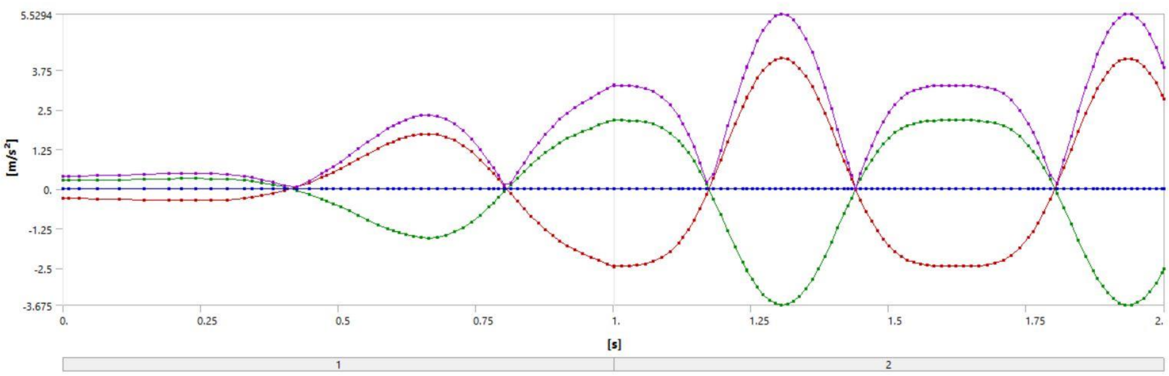


Max. Force for Inline 4 from Simulation = 8.05 N

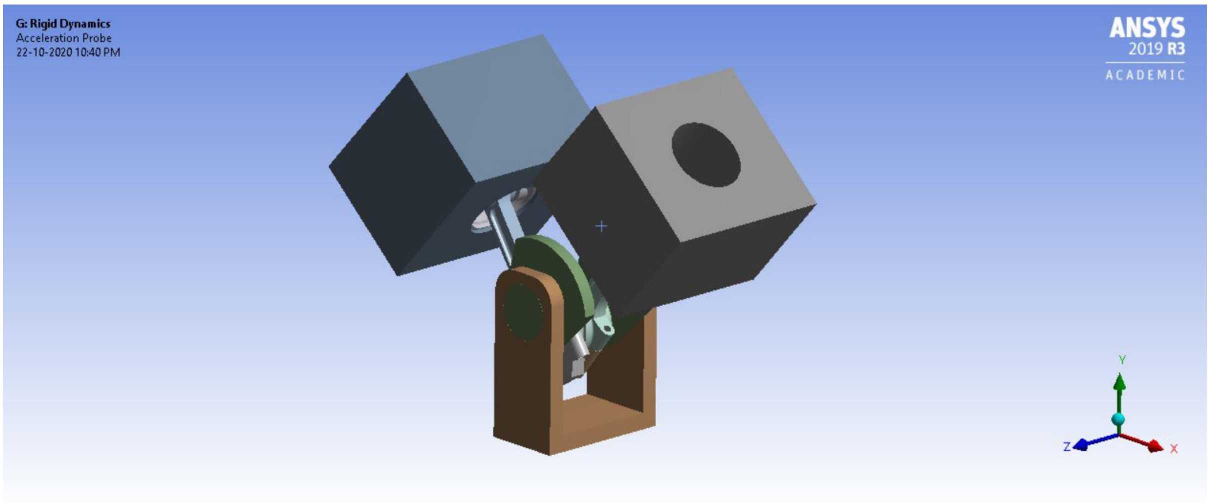
V2 engine piston head acceleration graphs :

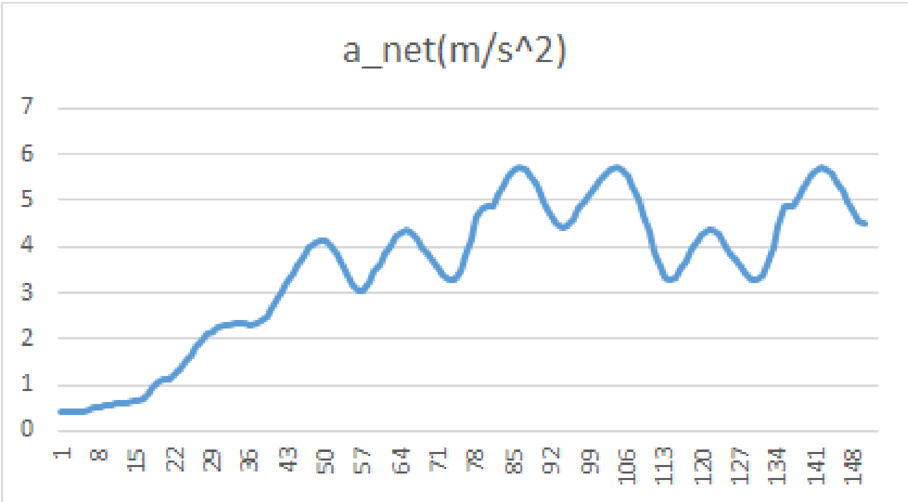


Acceleration plot for piston head on left bank



Acceleration plot for piston head on right bank





Max. force after evaluating accelerations of pistons by transferring real time data in Excel = 9.86 N

<u>Analysis 3 - Mathematical Modelling (MATLAB Codes and graphs)</u>:

<u>Code for Inline-4 engine</u>:

function z = f(m, r, w ,n)

% z is the variable parameterized and dependent on m, r, w.

% Interval of 2*pi is divided in 25 discrete points.

%Only primary unbalance forces are considered, as secondary unbalance cancels out.

%where m = unbalanced mass, r = crank radius and w = angular speed of crankshaft

%n = l/r

theta = linspace(0,2*pi,100);

z = 4*m*r*w^2*cos(2*theta)/n;

plot(theta, z);

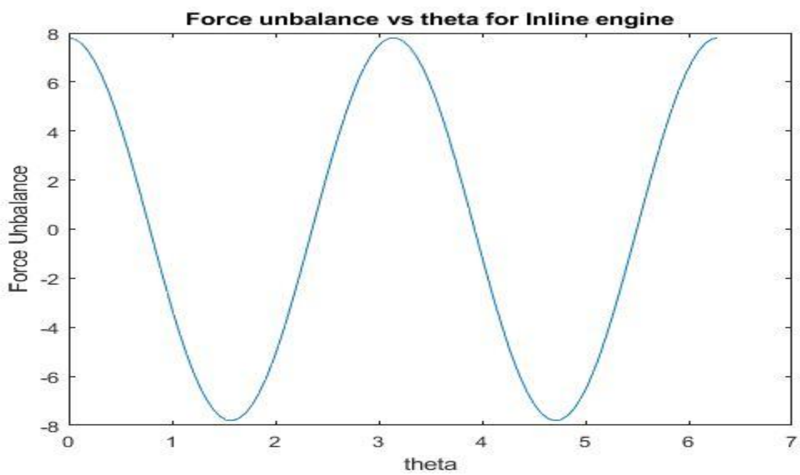
xlabel('theta');

ylabel('Force Unbalance');

title('Force unbalance vs theta for Inline engine');

end

Plot generated for Inline-4 engine:



Max. Force unbalance for the Inline-4 engine was found to be **7.72 Newtons.**

Code for V2 engine:

function FpV2 = forceyv2(m,r,w,n)

% Interval of 2*pi is divided in 50 discrete points.

% primary and secondary unbalanced forces are considered.

% where m = unbalanced mass, r = crank radius and w = angular speed of crankshaft

% n = l/r

% FpV2 - denotes the primary force in the direction of crank for V2 engine,

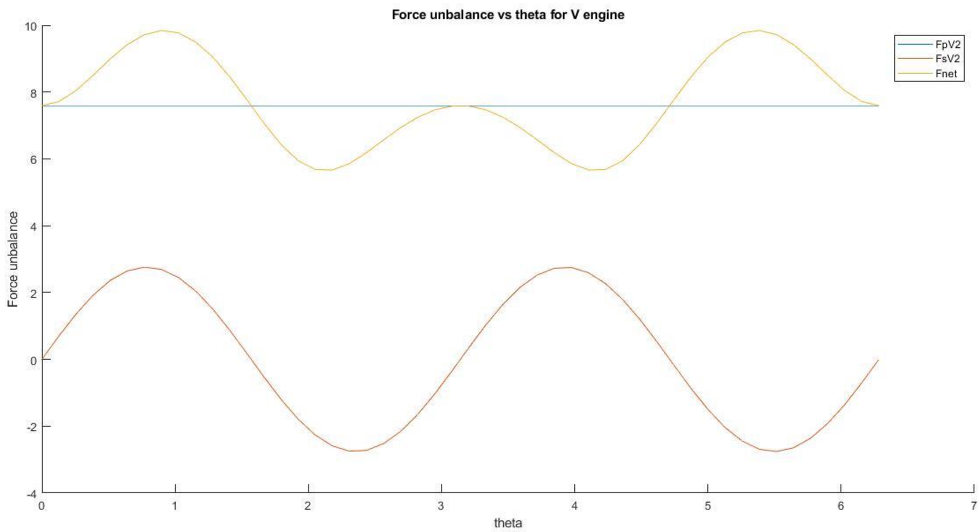
% Fsv2 - denotes the secondary force which will be in z direction.

% tot - resultant force

```
  theta = linspace(0,2*pi,50);
  FsV2 = sqrt(2) *m*r*w*w*sin(2*theta)/n;
  FpV2 = m*r*w*w;
  tot= sqrt((FsV2+ FpV2*sin(theta)).^2+ (FpV2*cos(theta)).^2);
  hold on
  plot(theta, ones(size(theta)) * FpV2);
  plot(theta,FsV2);
  plot(theta,tot);
  legend('FpV2','FsV2','Fnet');
  xlabel('theta');
  ylabel('Force unbalance');
  title('Force unbalance vs theta for V engine');

end
```

<u>Plot generated for V2 engine:</u>



Max. Force unbalance for the V2 engine was found to be **9.84 Newtons.**

Results and Conclusions (Comparison of theoretical, simulation and mathematical modelling results):

Assumptions taken in the mathematical modelling of inline engine*:*

1. Correction couple which is to be added because of inertia effects of connecting rod is neglected.

Assumptions taken in the mathematical modelling of V2 engine:

1. Inertia effects of connecting rod is neglected.
2. Inertia effects of crankshaft is neglected.

Sr. No.	Engine type	Maximum unbalance force as expected from mathematical modelling (in N)	Maximum unbalance force as obtained from analysis done in ANSYS (in N)	% error $(F_{ANSYS} - F_{math\_model})/F_{ANSYS}*100$
1.	Inline engine	7.72	8.05	4.1%
2.	V2 engine	9.84	9.86	0.2 %