ME-291: COMPUTER AIDED ENGINEERING
PROJECT REPORT

MODELLING AN INTERNAL COMBUSTION ENGINE

Yousuf Moiz (ya03482)
Arsalan Ahmed (aa03980)
Mohammad Diyyan khokhar (md04112)

Dhanani School of Science and Engineering
Habib University

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INTRODUCTION

One of the most important components of any automobile is the internal combustion engine. An internal combustion engine converts the stored chemical energy into mechanical power needed to drive a vehicle (or to rotate the connected shaft in general). This is done by the release of fuel's chemical energy inside the engine.

The most common type of internal combustion engine are the reciprocating piston-type engines where the fuel-air mixture is ignited through a spark. Figure 1 represents the working of a four stroke internal combustion engine [1].

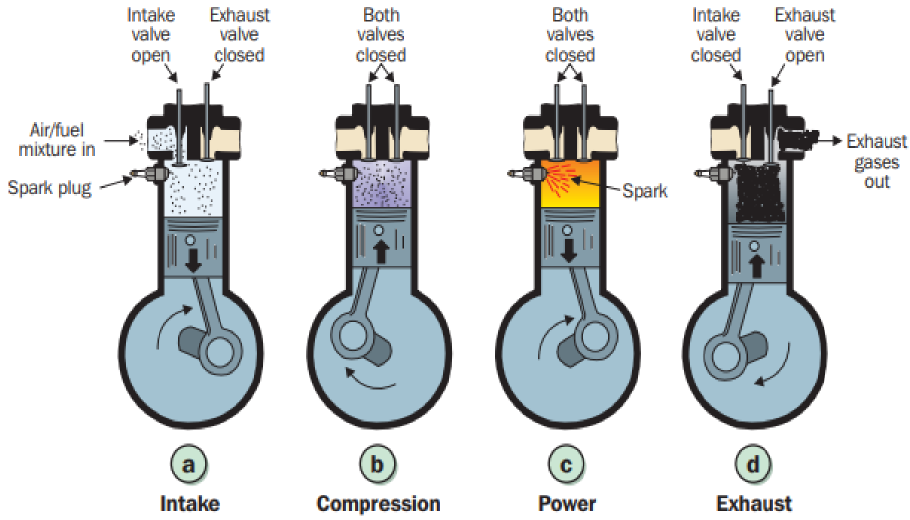

Figure 1: A four-stroke internal combustion engine

As shown in the above figure, a four-stroke internal combustion engine undergoes four distinct events in order to complete each power cycle. These events include intake, compression, power and exhaust. In the intake stage, the piston moves in the downward direction in order to increase the volume of the chamber allowing fuel-air mixture to enter. Next, in the compression event, the compression of fuel-air mixture takes place as the piston moves up. At the end of this event, ignition of the fuel-air mixture happens with the help of a spark plug starting the combustion process. When the combustion completes, the heat released in the chamber increases the pressure in the downward direction pushing the piston down and creating the power output. Lastly, in the exhaust event, the exhaust valve opens to allow the exhaust gas to be pushed out by the upwards moving piston.

The design and working of this type of internal combustion engine will become more evident and clear at the end of this report.

GOALS AND OBJECTIVES

The aim of this project is to design/model a single cylinder with a single piston of a four-stroke internal combustion engine on a software called Creo. The design should conform to all the requirements given by the client which in this case is our instructor Dr. Bajwa. The requirements given to us are discussed in the next section. Furthermore, the developed 3D model of the engine is to be actuated and adequate motion analysis is to be performed.

The following are the major components that have been studied and then designed in Creo 6.0:

1. Two intake valves with ports
2. Two exhaust valves with ports
3. One direct fuel injector
4. One spark plug
5. Piston bowl and cylinder head with appropriate combustion chamber geometry
6. Connecting rod with wrist pin
7. Crankshaft with bearings

CONSTRAINTS

The major design constraints given for this project are listed below.

1. The diameter of the intake valve/port should be at least 5% larger than the exhaust valve/port diameter.
2. The valves should be loaded with appropriately sized springs with squared and ground ends.
3. Valve recesses for each valve are need to be made in the piston crown with depth equal to or up to 50% larger than the valve head margins.
4. Valve ports in the cylinder head need to have appropriate chamfers.
5. Compression ratio of the engine should be equal to 12.

6. The spark plug should be sized proportionately with regards to the overall engine assembly with its widest part being less than 25 mm. The plug should be axially mounted on top of the cylinder at the center of the valves with its electrodes exposed to the fuel-air mixture. Standard threads should be made both in the spark plug as well as in the cylinder head so that they can be fastened together.

7. The fuel injector should have 1-6 holes for spraying fuel with its widest part less than 30 mm.

8. The radial distance from the outer edge of the intake valves to the inside cylinder wall should not be greater than 3% of the cylinder bore.

9. The cylinder wall should be designed such that it should be able to withstand a maximum pressure of 2500 kPa and a temperature of 1250 K. Internal cooling channels are to be designed within the cylinder wall.

10. The piston should have 3-6 piston rings assembled in the appropriate sized grooves in the piston wall.

11. A bowl is to be made into the piston crown with its outer diameter not greater than 60% of the piston diameter.

12. The connecting rod should be made up of smaller sub-parts assembled together. These parts include connecting rod (upper part), cap, journal bearings and bolt with nut having standard threads.

Some of the terms used in this section will become clearer through the discussion in the upcoming sections.

MODELLING OF INDIVIDUAL PARTS

In this section, each of the modelled individual parts of the engine will be discussed in detail. Specifically, the following things about each part will be mentioned:

1. A brief overview about the working principle and functionality of the part in the context of the overall engine assembly.

2. Approaches and assumptions taken to arrive at the final design of the part along with their corresponding calculations. Here, all the design choices will also be justified.

3. Relevant images of the modelled part.

4. Engineering drawing of the part mentioning all the important dimensions.

1. Engine cylinder

The cylinder is the main part of the engine where the working fluid is retained and the process of combustion takes place. The piston reciprocates inside the cylinder using the cylinder wall as a guide converting thermal energy from the combustion process into mechanical work. Therefore, it is said that the cylinder holds the combustion chamber.

The following points explain our design approaches and assumptions in order to meet the given constraints.

(a) The first thing we did was to select the size of the cylinder bore which is the inner diameter of the cylinder. We selected a bore size of 120 mm based on our internet search about some standard bore sizes.

(b) Next, we had to select a suitable material for the cylinder wall. For this, we first finalized the thickness of our cylinder wall which was again based on a quick internet search. The thickness was set at 10 mm. Since the dominant stresses in the cylinder are the tangential hoop stresses, we calculated our design stress as shown below:

$$Hoop\,stress = \frac{Pressure\,inside\,cylinder}{Wall\,thickness} \times Mean\,radius\,of\,cylinder \tag{1}$$

The pressure inside the cylinder was provided to us while the mean radius of the cylinder was 65 mm based on the wall thickness and the cylinder bore size.

$$Design\,stress = Hoop\,stress = \frac{2500}{10} \times 65 = 16250\,kPa \tag{2}$$

The calculated value of the design stress was used to calculate the required yield strength using a factor of safety of 2.5 as shown below:

$$Factor\,of\,safety = \frac{Yield\,stress}{Design\,stress} \tag{3}$$

$$Yield\,stress = 2.5 \times 16250 = 40625\,kPa\;\;or\;\;40.625\,MPa \tag{4}$$

Using this value of minimum yield stress along with the requirement that the cylinder should withstand a peak temperature of 1250 K, a suitable material was selected for the cylinder wall using the MatMatch database. This material was **wrought copper high**

copper alloy named **UNS C16200 OS050**. Some properties of this material are shown in table 1.

Table 1: Properties of cylinder wall material

Parameter	***Value***
Elastic modulus	120 GPa at 20 °C
Elongation	56 % at 20 °C
Tensile strength	240 MPa at 20 °C
Yield strength	48 MPa at 20 °C
Coefficient of thermal expansion	0.000017 $\frac{1}{K}$ at 20 °C
Melting point	1030 °C or 1303.15 K

(c) The total length of the cylinder was set at 270 mm. This was adjusted based on the calculations of the compression ratio which is discussed later in this report.

(d) Since there was no restrictions regarding the size and cross sectional profile of the cooling channel, we made a narrow rectangular one having a height of 240 mm and a thickness of 5 mm.

(e) The cylinder head profile was chosen to be flat in order to ease out the process of making valve ports and holes for the spark plug and the fuel injector. There were four ports made for the valves with appropriate 45 ° chamfers so that the valves could sit in them providing an intimate contact required for a good seal. The valve ports were placed such that the radial distance from the outer edge of the intake valves to the inside cylinder wall was not greater than 3% of the cylinder bore. We used this constraint for all the four valve ports. For this, we just calculated a the 3% value of the bore and set this the distance between the inner surface of the cylinder and the ports' edge. The hole for the spark plug was made at the center with threads of type M14 x 2. The hole for the fuel injector was made such that the injector could be placed axially similar to the orientation of the spark plug but this hole was near the edge of the cylinder head.

Some views of the designed cylinder along with its engineering drawing are shown in the following figures.

Figure 2: Angled view of the cylinder

Figure 3: Cross-sectional view of the cylinder

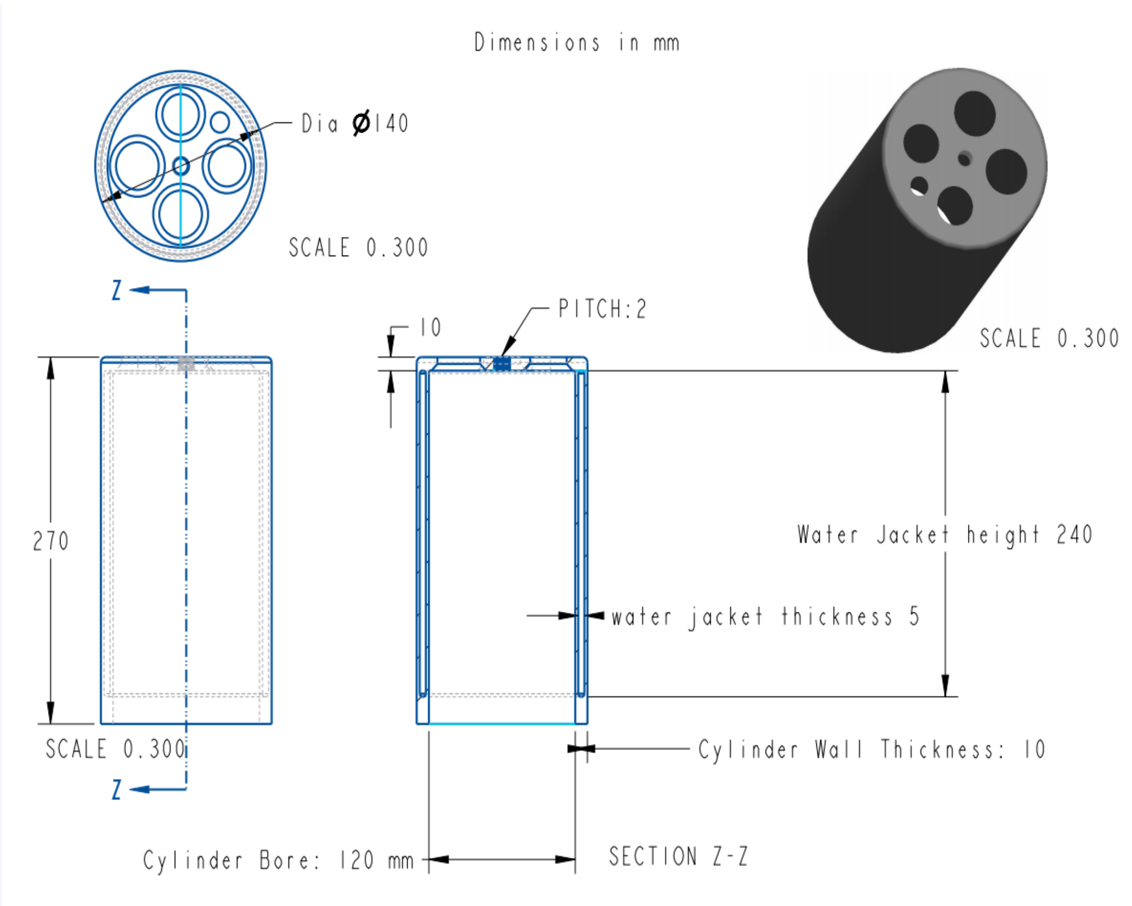

Figure 4: Engineering drawing of the engine cylinder

2. Piston

The piston is the disc which reciprocates inside the cylinder. The main function of the piston is to transmit the energy from the impulse of the expanding gas to the crankshaft through the connecting rod.

The following points explain our design approaches and assumptions in order to meet the given constraints.

(a) The dimensions of the piston were chosen such that it looked proportionate in comparison to the cylinder and fitted well inside it. However, the piston diameter was set slightly lesser than the cylinder diameter since piston rings were to be there to provide a good seal.

(b) We made three groves on the piston where piston rings were to be installed and made them in such a way that the ring cross-section were to be a square.

(c) There were two handles made on the bottom surface of the piston for placing the connecting rod in between them with the wrist pin through them.

(d) On the piston crown which is the top most surface of the piston, we made four valve recesses and a piston bowl while making sure that the given constraints related to them are met. Valve recesses are there to avoid collision of the piston with the valves while the piston bowl allows are more efficient mixing of the fuel-air mixture leading to ideal combustion.

(e) Next, in order to define the end limits of the piston reciprocation, we did some calculations based on the compression ratio (CR) of the engine. Compression ratio is the ratio of the maximum to the minimum volume of the space enclosed by the piston and the cylinder during one full stroke. The relevant calculations are shown below:

$$CR = \frac{\frac{\pi}{4}B^2(H+S) + V_{pistonrecess}}{\frac{\pi}{4}B^2(H) + V_{pistonrecess}} \tag{5}$$

Where B is the cylinder bore, H is the position of the Top Dead Center (TDC), S is called the stroke which is the position of the Bottom Dead Center (BDC) from the TDC and $V_{pistonrecess}$ is the empty volume of the recess plus bowl cavity. We knew the cylinder bore size and assumed the position of TDC to be 9 mm. We were not able to measure the empty volume directly from Creo so what we did was to measure the total volume of the part before and after filling the empty volume and subtract the two to get the recess volume whose value was 111599.19 mm^3. It was requirement that we had to set the CR at 12. Hence, our goal now was to find the value of S.

$$12 = \frac{\frac{\pi}{4}120^2(9+S)+111599.19}{\frac{\pi}{4}120^2(9)+111599.19} \tag{6}$$

Solved the above equation to get:

$$S = 207.54mm \tag{7}$$

We can say that S is the value the piston moves in one direction during its operation.

Some views of the designed piston along with its engineering drawing are shown in the following figures.

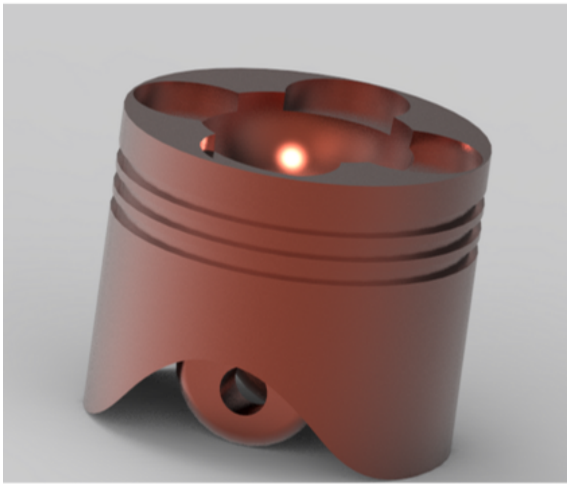

Figure 5: Angled view of the piston head

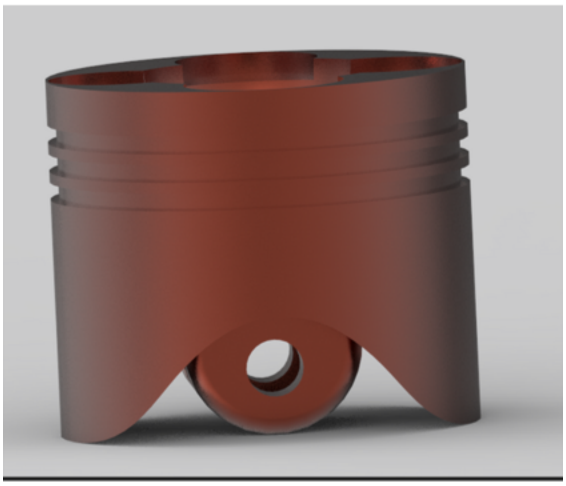

Figure 6: Angled view of the piston head

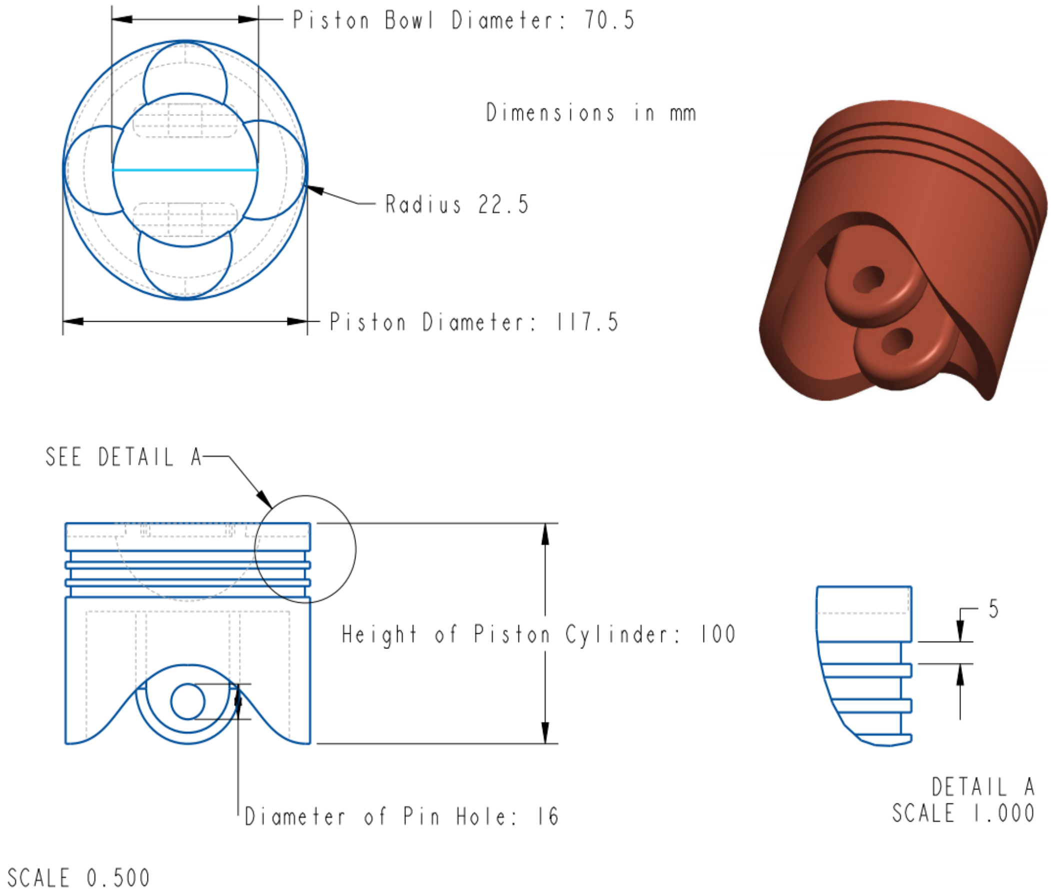

Figure 7: Engineering drawing of the engine piston head

3. Piston rings

Piston rings are metallic rings attached to the outer diameter of a piston making sure that no gases from the combustion process leak out. As discussed earlier we designed are piston rings with square cross section with its outer diameter exactly equal to that of the cylinder bore.

A view of the designed piston ring along with its engineering drawing are shown in the following figures.

Figure 8: Engineering drawing of the engine piston ring

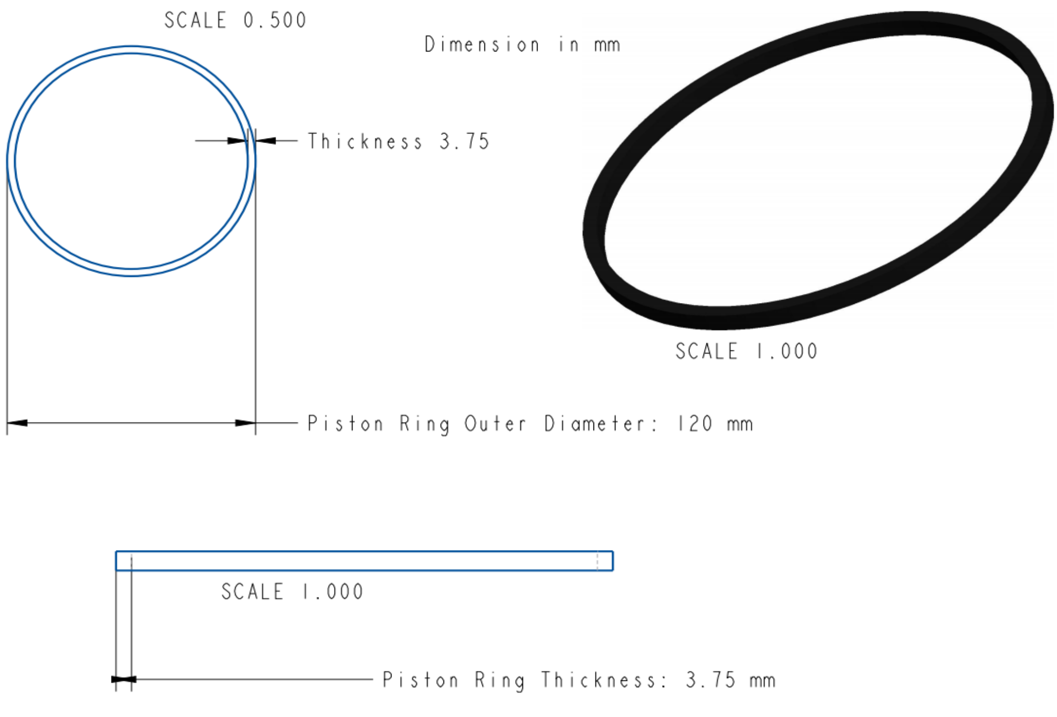

Figure 9: Engineering drawing of the engine piston Ring

4. Valves

The valves are the parts of the engine that are designed to open and close at precise moments aiding to the smooth and efficient working of the engine. The intake valves allow the fuel-air mixture into the cylinder while the exhaust valves emit the exhaust gases to the outside of the combustion chamber.

We have also modelled both the intake as well as the exhaust valves based on the standard dimensions that we found on the internet along with the general carefulness that the valves size should be appropriate in relation to the previously modelled parts. One key point which was also a requirement is that the diameter of the intake valve should be at least 5% larger than the exhaust valve diameter which was to allow more air to enter the combustion chamber.

The modelled intake and exhaust valves are shown in the following figures along with their engineering drawings.

Figure 10: Angled view of the exhaust Valve

Figure 11: Angled view of the intake valve

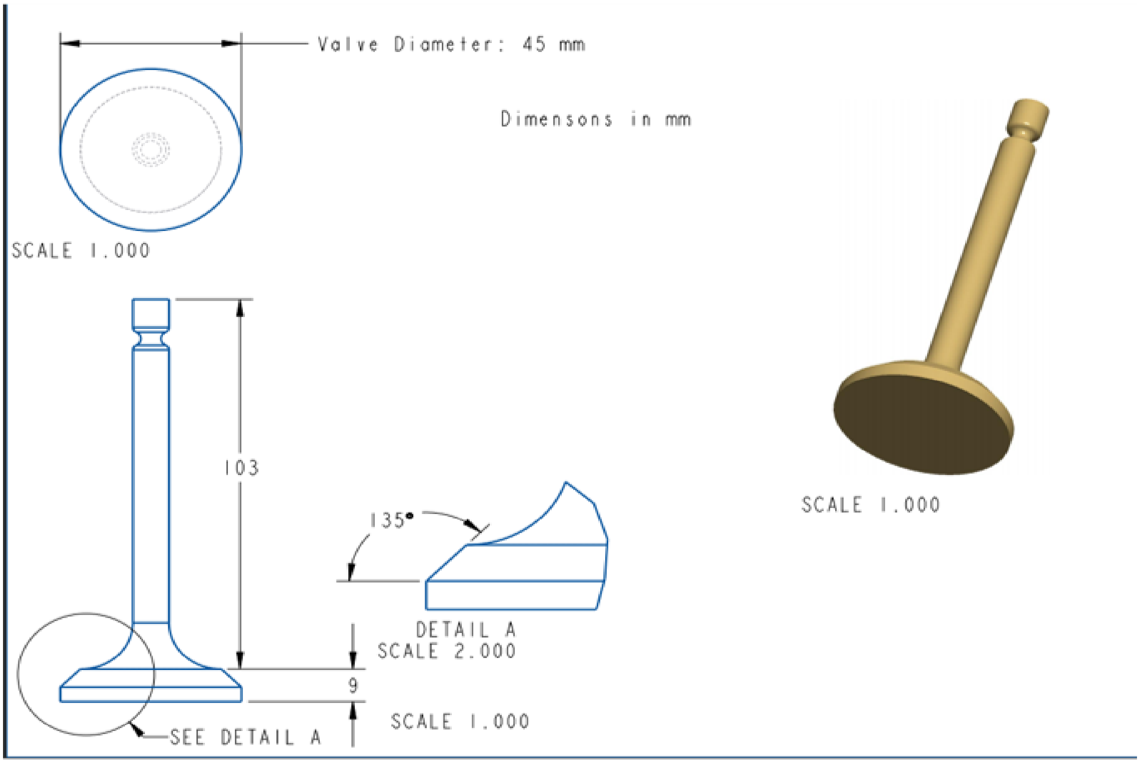

Figure 12: Engineering drawing of the engine intake valve

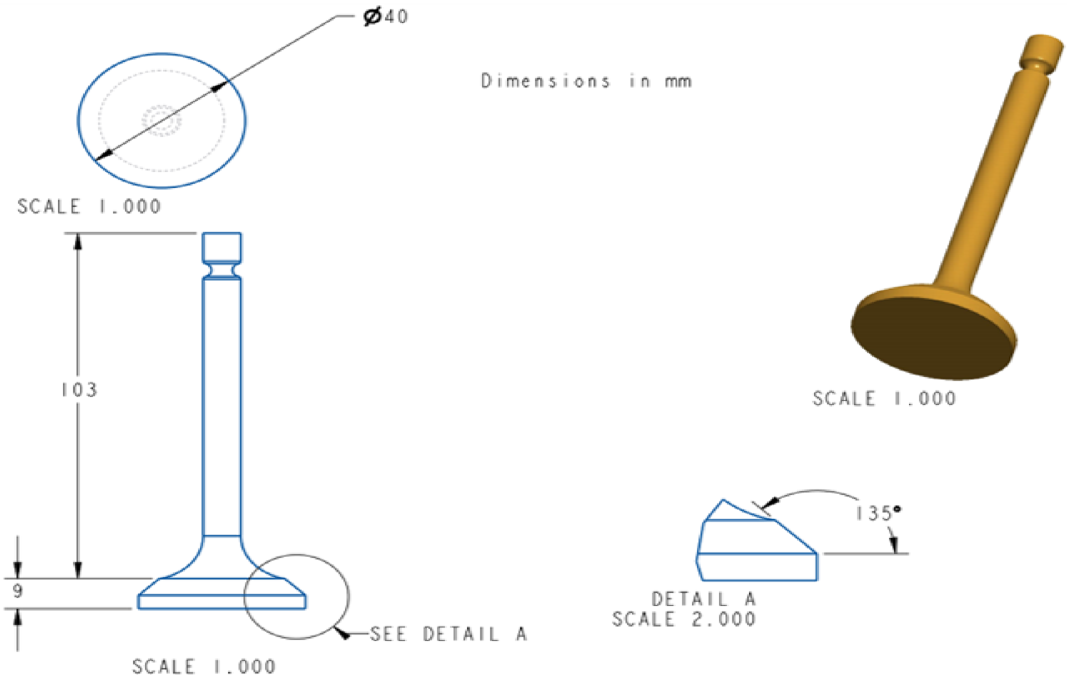

Figure 13: Engineering drawing of the engine exhaust valve

5. Valve spring

A valve spring is placed around the stem of the valve and its main function is to close the valves when they have been opened by the flow pressure or either mechanically.

The following table summarizes the properties of the spring that we have designed.

Table 2: Valve spring properties

Type	Compression spring
Spring index	4.375
Helix pitch	12 mm
Helix angle	9.6 °

Compression springs are open-coiled helical springs designed to resist a force applied in the axial direction. The rational behind choosing the spring as a compression spring is that in engines the valve spring is packaged around the valves such that if the spring compression opens the valve while the relaxed springs keep the valves closed. The spring index is the ratio of the mean diameter of the spring with the thickness of the spring wire. The reason for choosing a index value between 4-5 was that it ensured good manufacturability as well as strength. Lastly, the pitch of the spring was selected by keeping in mind the lift distance or the length of the valve movement.

The modelled valve compression spring is shown in the following figure along with its engineering drawing.

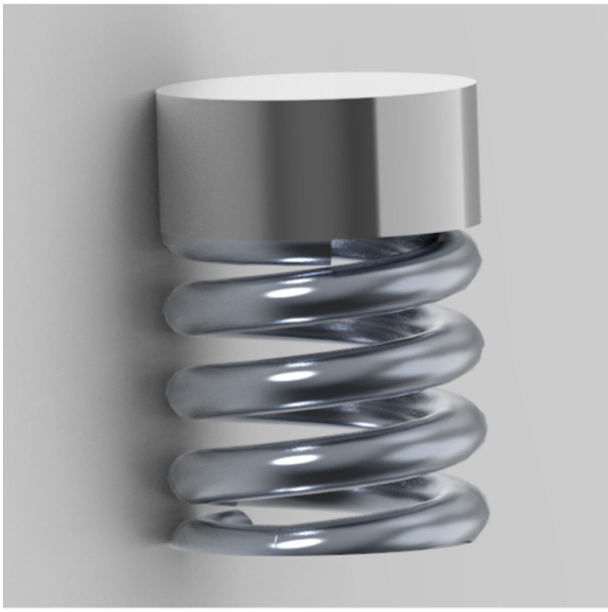

Figure 14: Angled view of the valve spring

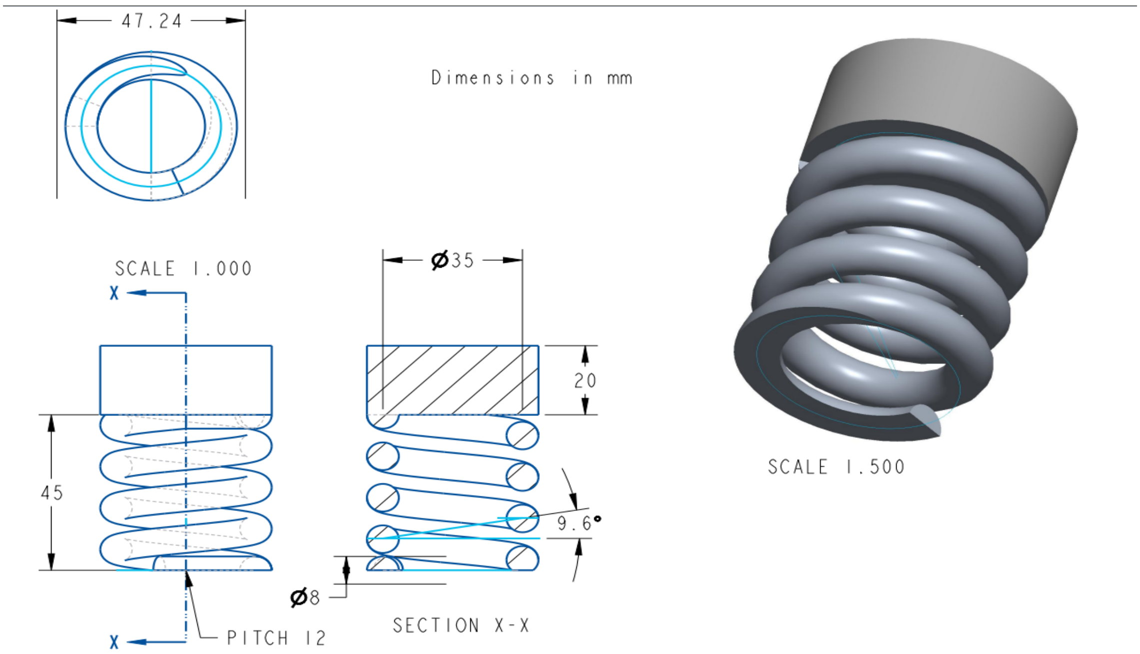

Figure 15: Engineering drawing of the engine valve spring

6. Spark plug

Spark plug is the device which is fitted into the cylinder head carrying current fro high voltage source in order to create a spark for fuel ignition.

The following images shows the spark plug that we have designed along with its engineering drawing. The design and most of the dimensions of the spark plug was based on some standard documents found on the internet. Two important points to note here includes that the threads made on the plug are of type M14 x 2 and the widest part of the plug has a diameter of 20 mm complying to a constraint.

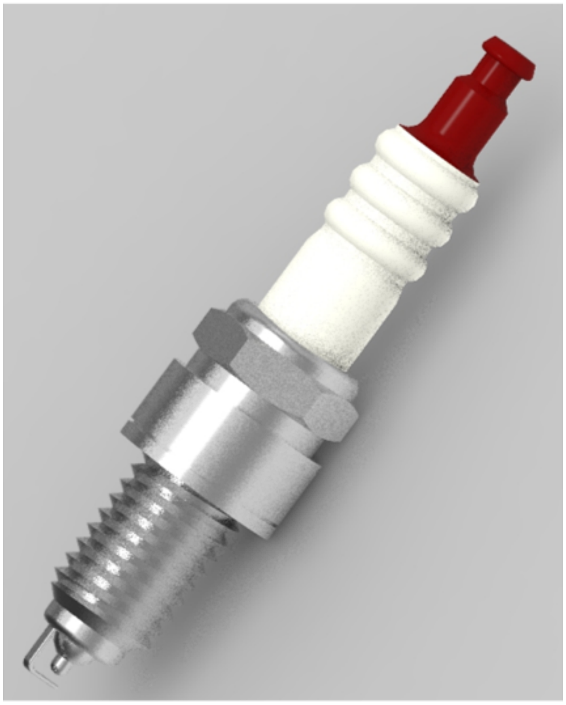

Figure 16: Angled view of the spark plug

Figure 17: Angled view of the spark plug

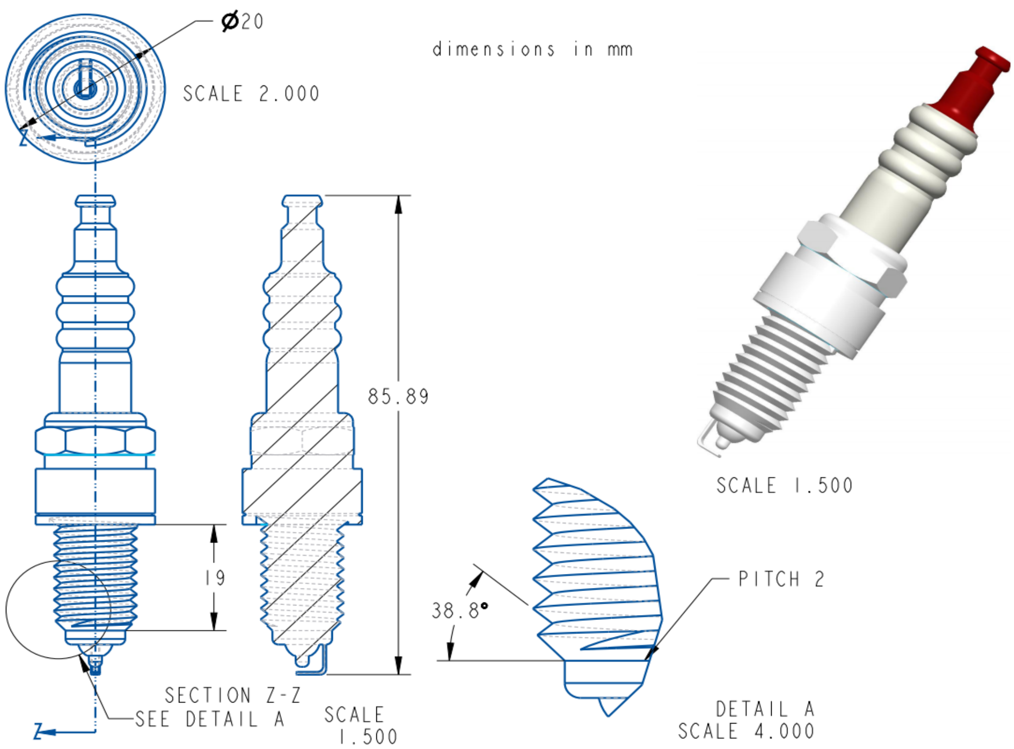

Figure 18: Engineering drawing of the engine spark plug

7. Fuel injector

A fuel injector is also assembled on top of an engine cylinder and is used to spray fuel into the combustion chamber.

The following images shows the fuel injector that we have designed along with its engineering drawing. The design and most of the dimensions of the spark plug was based on some standard documents found on the internet. We have made four holes on the nozzle of the fuel injector for the purpose of spraying fuel. Furthermore, the widest diameter on the injector is 22 mm which satisfies one of the constraints regarding the injector diameter limit.

Figure 19: Angled view of the fuel injector

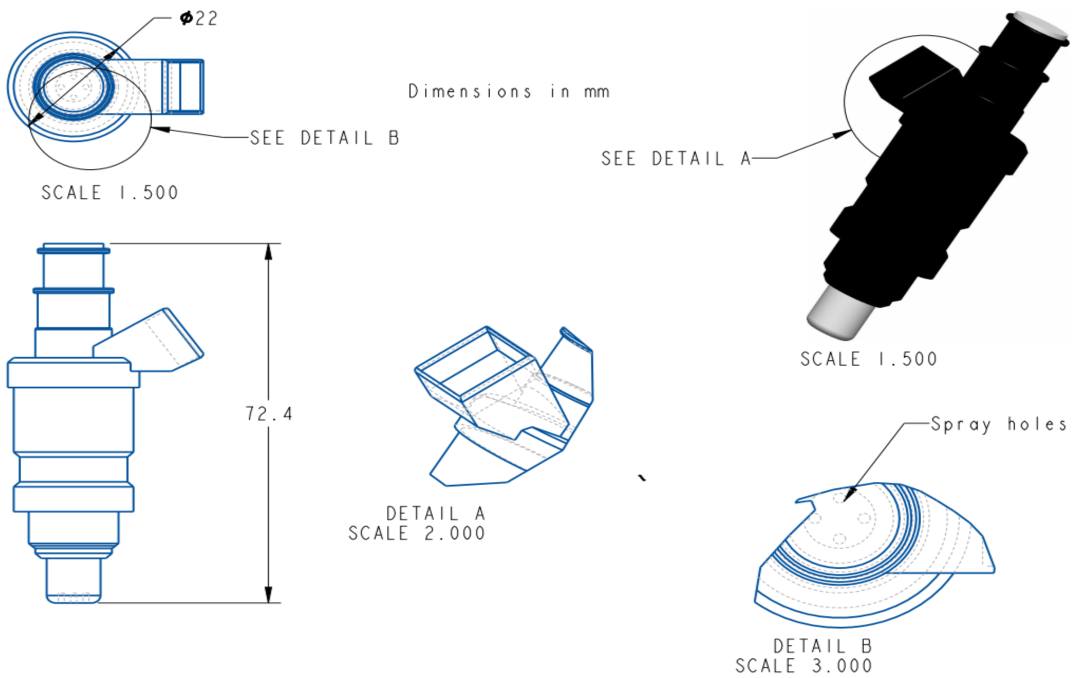

Figure 20: Engineering drawing of the engine fuel injector

8. Wrist pin

The wrist pin or the gudgeon pin is used to connect the piston with the connecting rod providing a bearing for the connecting rod to pivot upon as the piston moves.

The following images shows the wrist pin that we have designed along with its engineering drawing. The wrist pin had been designed to perfectly fit between the holes of the piston handles and the hole of the connecting rod. The image below shows the surface of the pin that rests on the piston skirt acting as the journal.

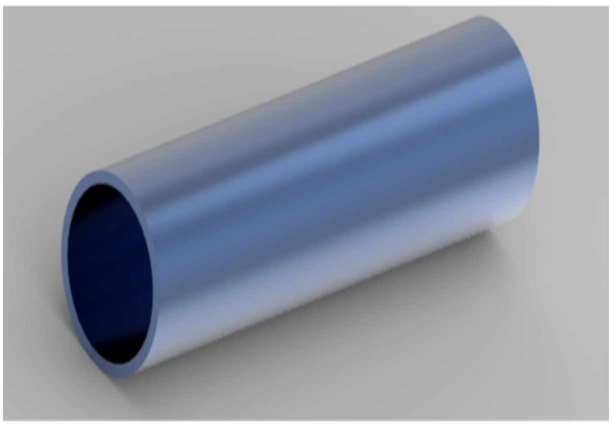

Figure 21: Angled view of the wrist pin

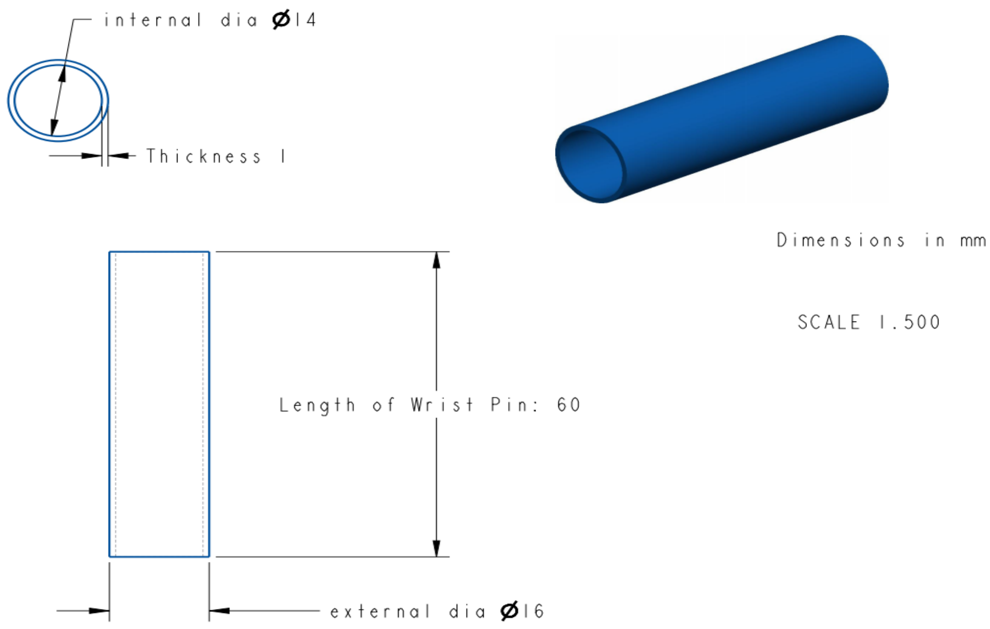

Figure 22: Engineering drawing of the engine wrist pin

9. Con-rod with cap

The connecting rod also known as the con-rod is the part of the engine which connects the piston to the crankshaft transforming the reciprocal motion of the piston into rotational motion of the crankshaft. The connecting rod also accompanies a removable section called the rod cap which provides a bearing surface for the crankpin journal. This part is usually connected to the rod through bolts or screws.

The following images shows the con-rod with its cap that we have designed along with their engineering drawings. These parts have been designed to look proportional in the overall assembly. Two through hole had been made on either side extending from the rod to the cap for bolts and nuts.

Figure 23: Angled view of the con-rod

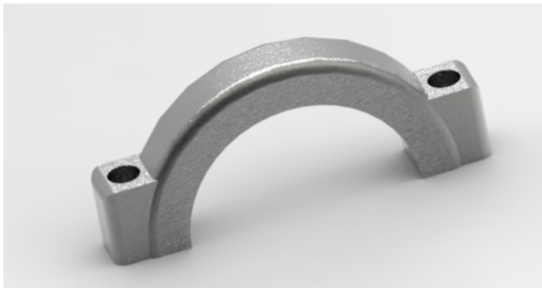

Figure 24: Angled view of the con-rod cap

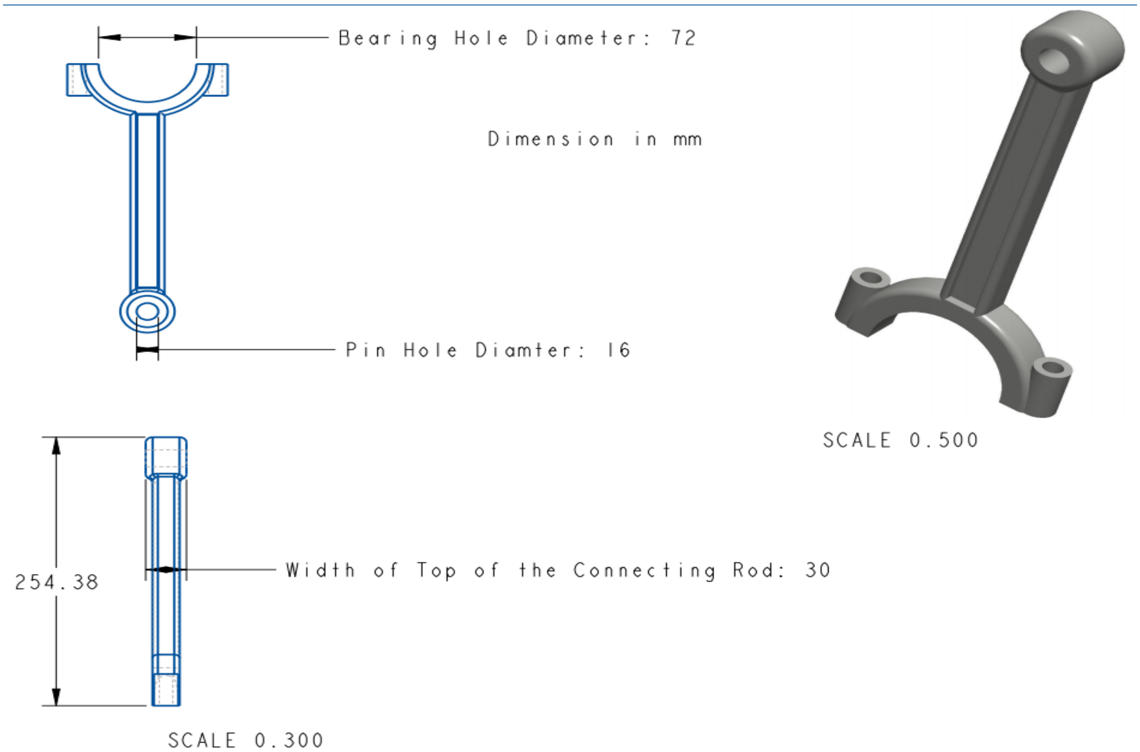

Figure 25: Engineering drawing of the con-rod

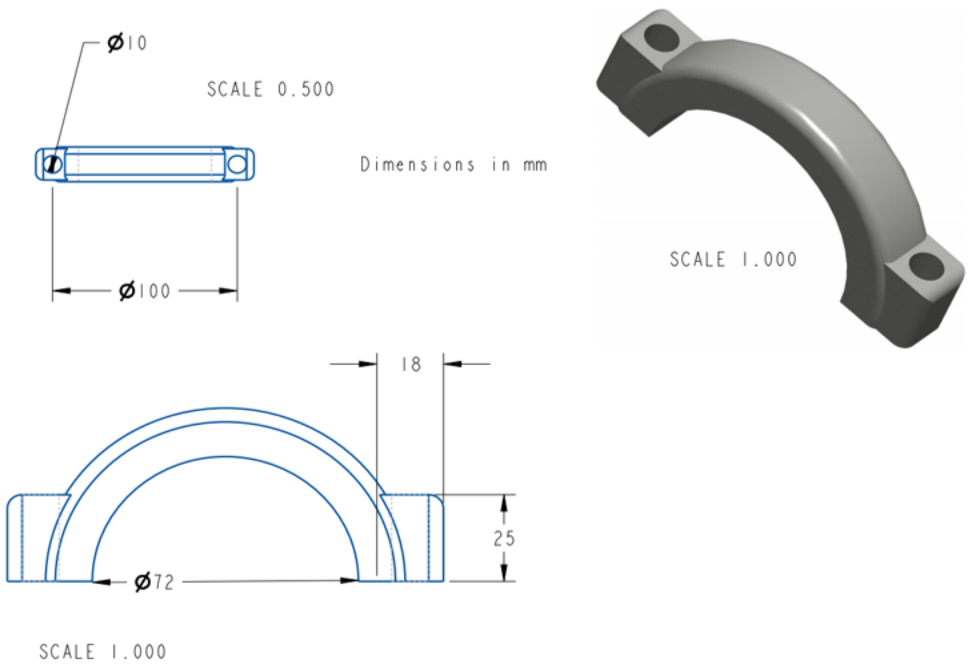

Figure 26: Engineering drawing of the con-rod cap

10. Con-rod bearing

Connecting rod bearings provide rotating motion of the crank pin within the connecting rod, which transmits cycling loads applied to the piston.

The following images shows the con-rod bearing that we have designed along with its engineering drawing.

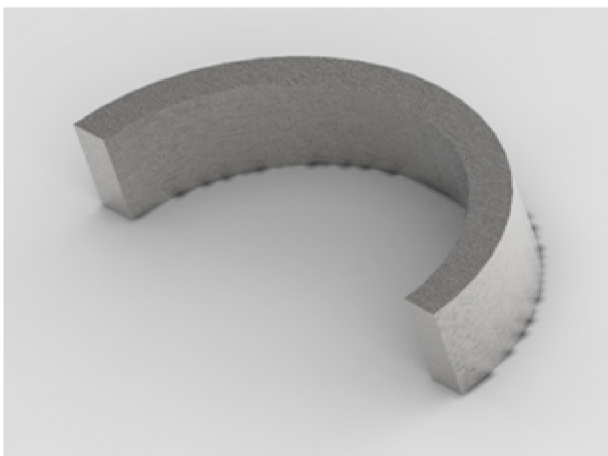

Figure 27: Angled view of the connecting rod bearing

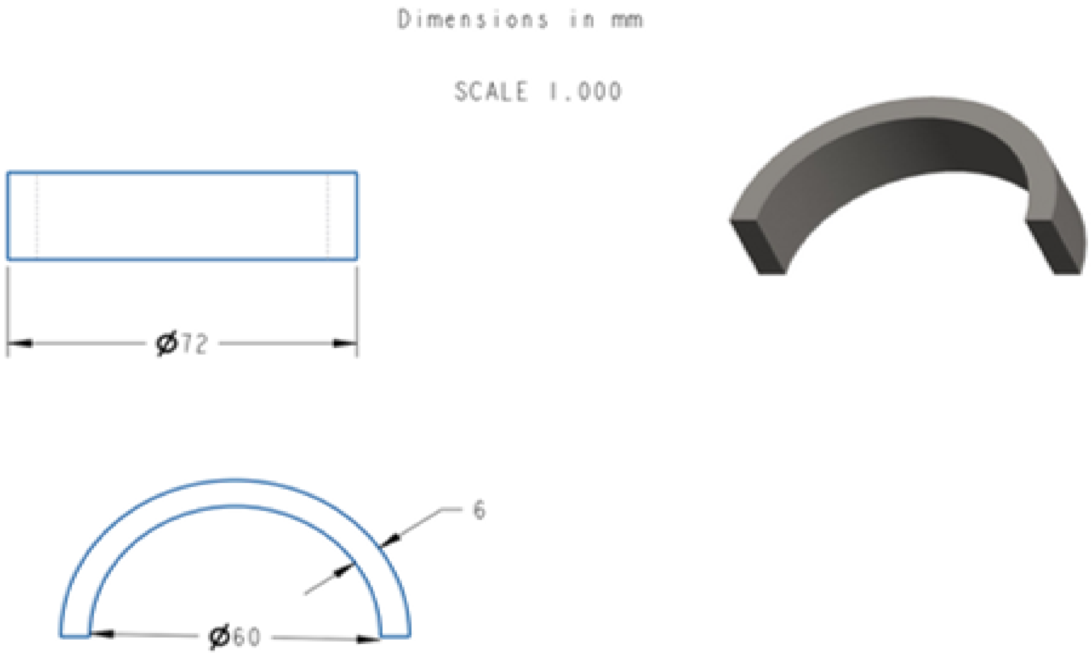

Figure 28: Engineering drawing of the Connecting rod bearing

11. Con-rod bolt and nut

Nuts are almost always used in conjunction with a mating bolt to fasten multiple parts together. The two partners are kept together by a combination of their threads. In an engine, two bolts along with their nuts are used to connect the con-rod with its rod cap.

The following images shows the bolt and nut that we have designed along with their engineering drawings. The threads used in these parts are of the type M10 x 1.5. We can also see that the significant length of the bolt is un-threaded. This is because of the presence of the through holes in the con-rod as well as its cap such that the nut is fastened on the lower threaded region of the bolt.

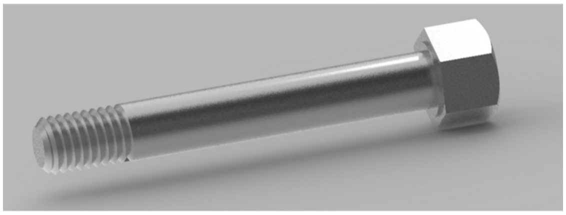

Figure 29: Angled view of the bolt

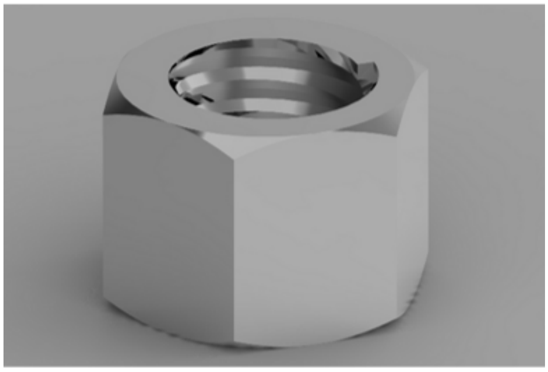

Figure 30: Angled view of the nut

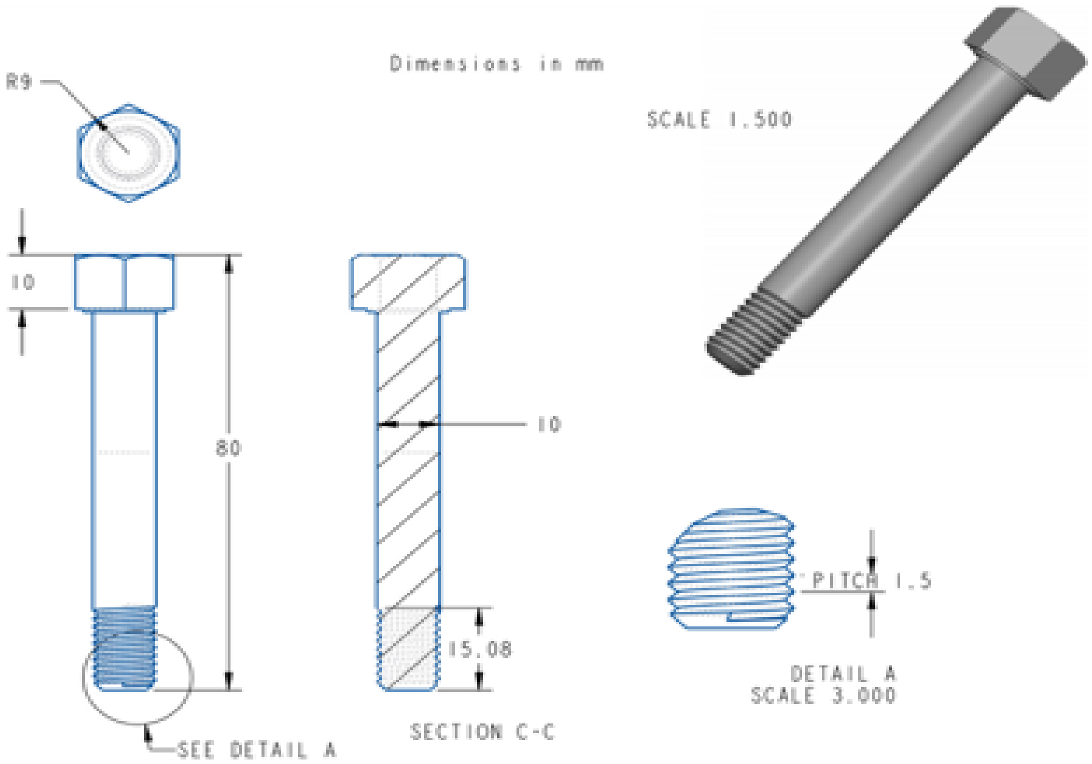

Figure 31: Engineering drawing of the bolt

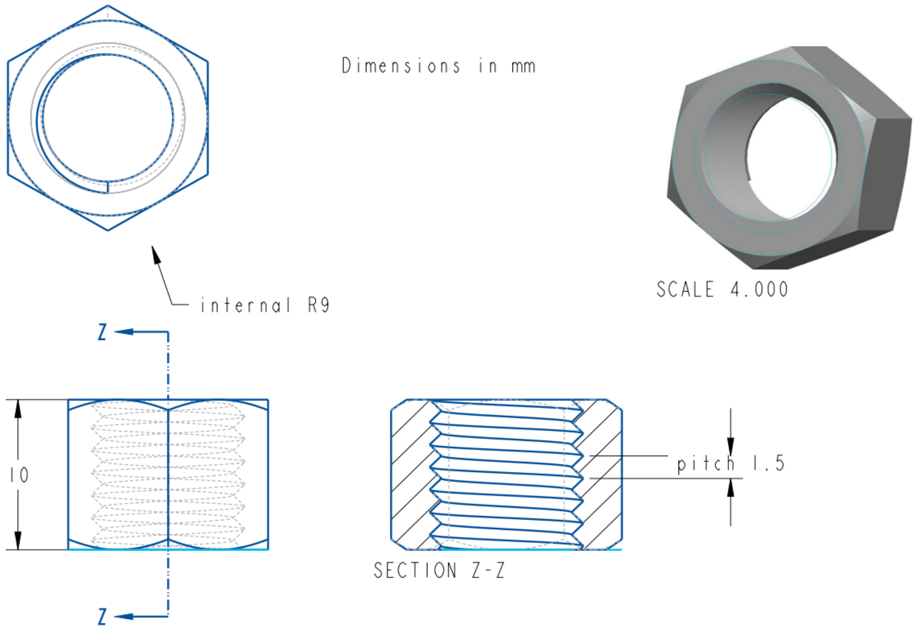

Figure 32: Engineering drawing of the nut

12. Crankshaft with bearings

The crankshaft of an engine is the moving part of the engine whose main function is to transform the linear motion of the piston into rotational motion. Ultimately, through a system of gears in the powertrain, this motion drives the vehicle's wheels. There is also a bearing which accompanies the crankshaft. This bearing is responsible for holding the shaft in place while also allowing it to rotate within the engine block.

These parts have been modelled by looking at some of the reference pictures and designs provided to us. The main design consideration that was required here was the selection of the distance between the two rotating axes of the crankshaft. We set this distance at a value of half of the stroke length which was equal to 103.77 mm. Since the movement of the crankshaft is rotatory so this would allow it to move the piston exactly from the BDC to the TDC. The following images shows the crankshaft and its bearing that we have designed along with their engineering drawings.

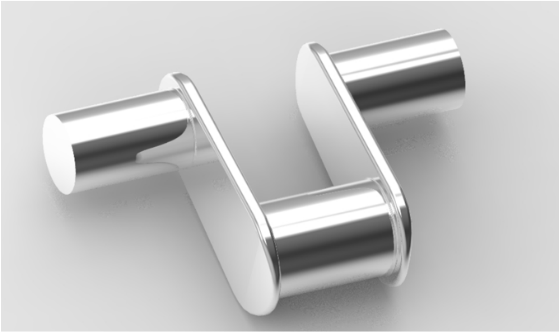

Figure 33: Angled view of the Crankshaft

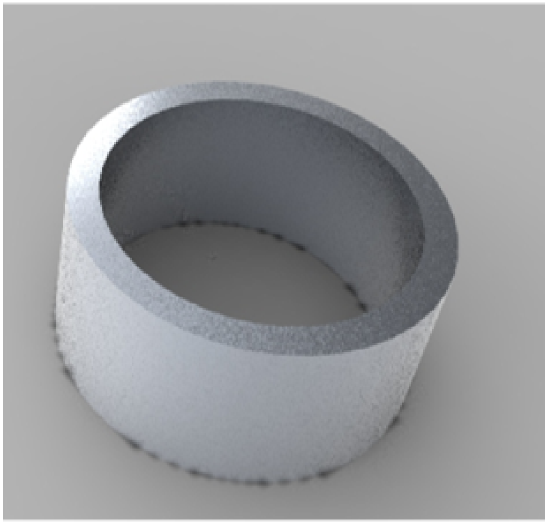

Figure 34: Angled view of the Crankshaft bearing

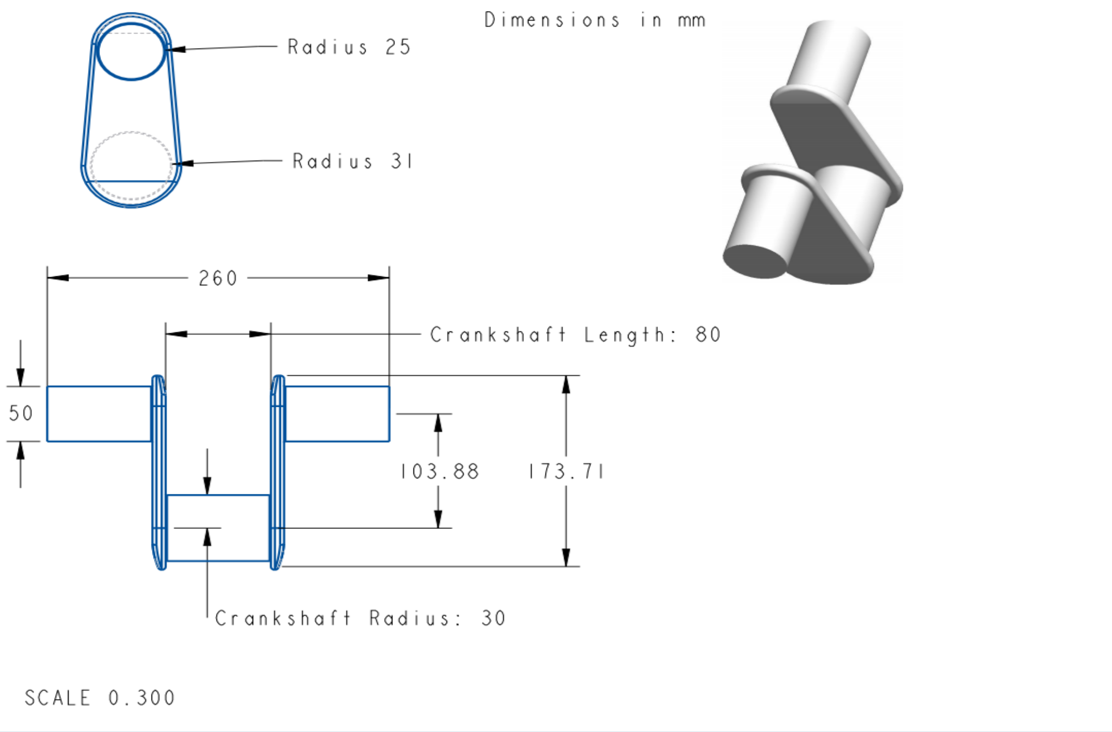

Figure 35: Engineering drawing of the engine Crankshaft

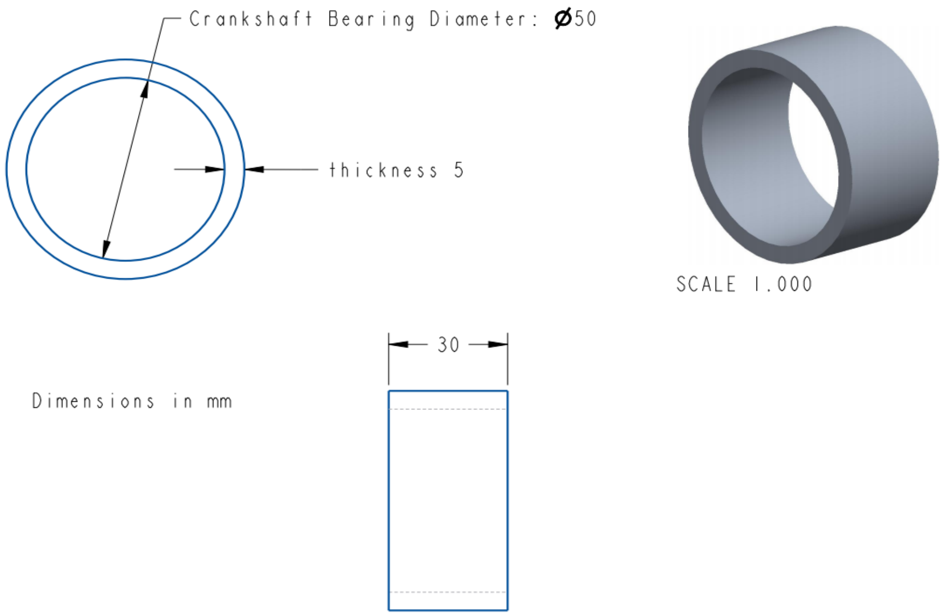

Figure 36: Engineering drawing of the engine Crankshaft bearing

Final Assembly

After modelling all the individual parts of the internal combustion engine, we finally assembled all the parts to form single internal combustion engine. Figure 41 shows the exploded view of the assembly which gives an idea of how many parts were assembled together to form a single cylinder single piston engine. Creo 6.0 has the functionality to assign different joints to the parts assembled and the different types of joints used in our assembly our listed below:

- **Piston:** Slider joint
- **Connecting Rod:** Pin joint
- **Crankshaft:** Connected through two pin joints, one with the crankshaft bearing and the other with the connecting rod bearing.

  Figures 39 and 40 show the engine assembly at the TDC and the BDC respectively.

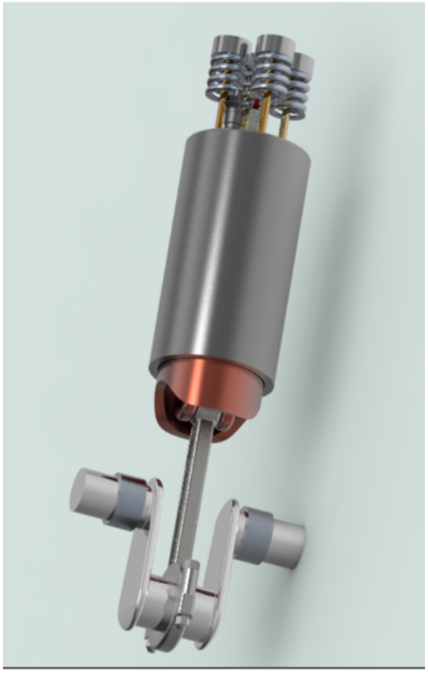

Figure 37: Angled view of the internal combustion engine

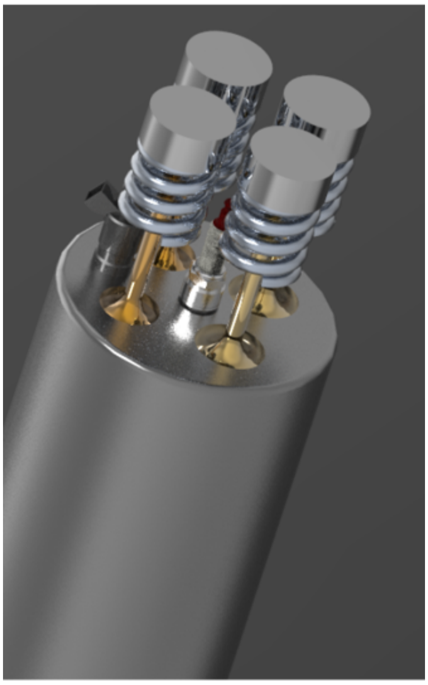

Figure 38: Angled view of the internal combustion engine

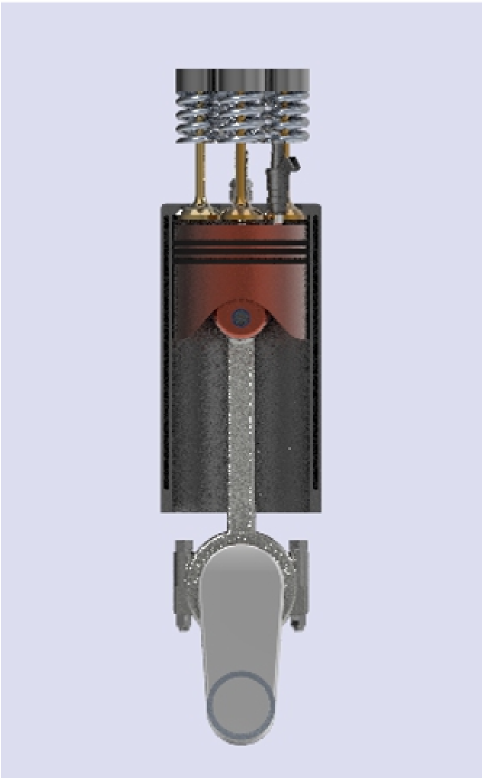

Figure 39: Top dead center position

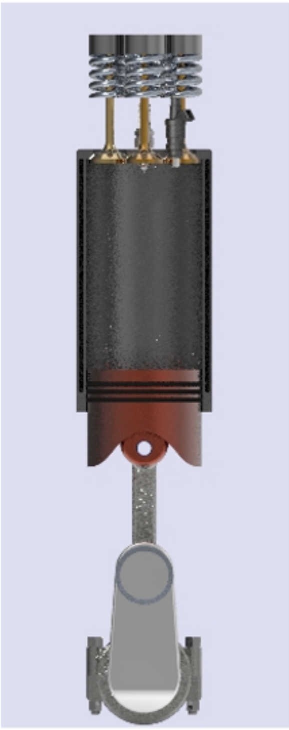

Figure 40: Bottom dead center position

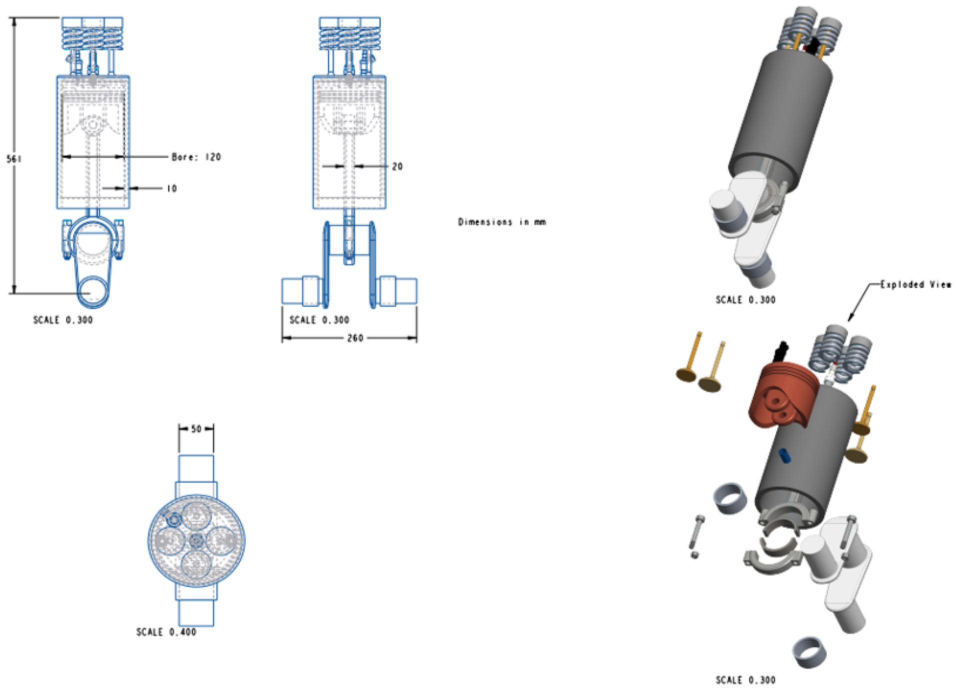

Figure 41: Engineering drawing of the internal combustion engine

Bill of Materials

The Bill of Materials (BOM) provides the complete list of all the items that are required to build a product. This BOM is a complete inventory of raw materials, parts, and assembly of engine.

Bom Report : ENGINE

Assembly ENGINE contains:

Quantity	Type	Name	Actions
1	Part	CYLINDER	
2	Part	INTAKEVALVE	
2	Part	EXHAUSTVALVE	
4	Part	VALVLESPRING	
1	Part	SPARKPLUG	
1	Part	FUELINJECTOR	
1	Part	PISTONHEAD	
3	Part	PISTONRING	
1	Part	CONNECTINGROD	
1	Part	RODCAP	
2	Part	CONNECTINGROD_BOLT	
2	Part	CONNECTINGROD_NUT	
2	Part	RODBEARING	
1	Part	WRISTPIN	
2	Part	CRANKSHAFTBEARING	
1	Part	CRANKSHAFT	

Summary of parts for assembly ENGINE:

Quantity	Type	Name	Actions
1	Part	CYLINDER	
2	Part	INTAKEVALVE	
2	Part	EXHAUSTVALVE	
4	Part	VALVLESPRING	
1	Part	SPARKPLUG	
1	Part	FUELINJECTOR	
1	Part	PISTONHEAD	

Figure 42: Bill of Materials

3	Part	PISTONRING
1	Part	CONNECTINGROD
1	Part	RODCAP
2	Part	CONNECTINGROD_BOLT
2	Part	CONNECTINGROD_NUT
2	Part	RODBEARING
1	Part	WRISTPIN
2	Part	CRANKSHAFTBEARING
1	Part	CRANKSHAFT

Figure 43: Bill of Materials

The following table shows the detailed summary of each of the part used in the assembly.

Table 3: All parts information

Part Name	Material used	Weight	Machine Element
Engine cylinder	Wrought Copper	59.907 N	No
Intake valves	Steel	1.588 N	No
Exhaust valves	Steel	1.362 N	No
Spark plug	Nickel	0.9996 N	No
Fuel injector	Stainless steel	1.147 N	No
Piston	Aluminium wrought	14.205 N	No
Piston ring	Cast iron	0.478 N	No
Connecting rod	Steel	10.316 N	No
Connecting rod cap	Steel	3.266 N	No
Connecting rod bearing	High Carbon steel	0.957 N	Yes
Crankshaft	Cast iron	52.683 N	No
Crankshaft bearing	High carbon steel	1.994 N	Yes
Bolt	High carbon steel	0.572 N	Yes
Nut	High Carbon steel	0.0605 N	Yes
Wrist pin	Steel	0.217 N	No
Valve spring	High carbon steel	3.9 N	Yes

Total weight of the assembly is 172.8416 N. Material selection for each part was finalised using the standard data.

WORKING OF THE ASSEMBLY

We will now demonstrate a single revolution of the internal combustion engine through our assembly.

- **Crankshaft at the bottom dead center:**

Figure 44: Engine at BDC

- **Crankshaft at the midpoint between TDC and BDC:**

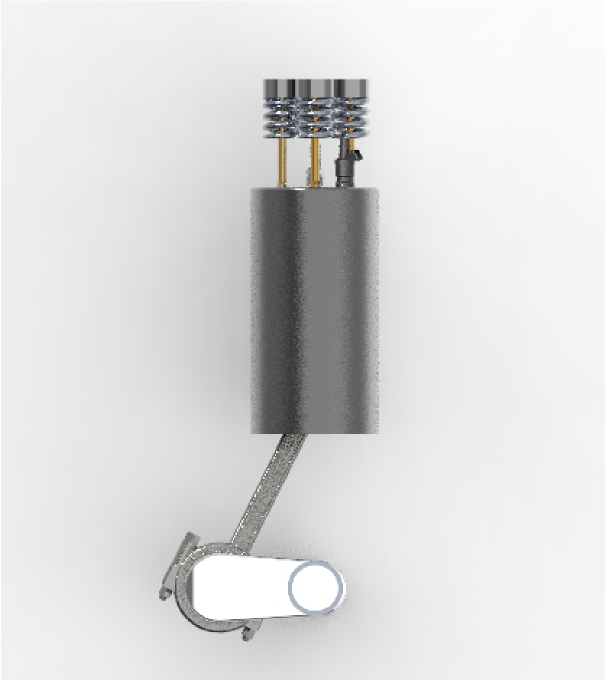

Figure 45: Engine at Midpoint

- **Crankshaft at the TDC:**

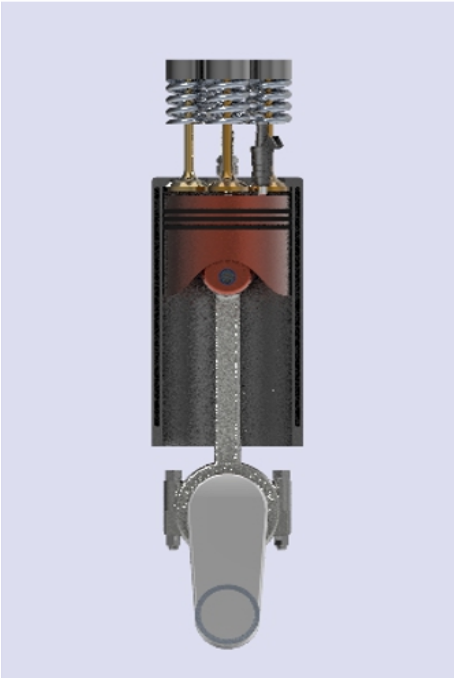

Figure 46: Engine at TDC

- **Crankshaft at the midpoint between TDC and BDC on the return path:**

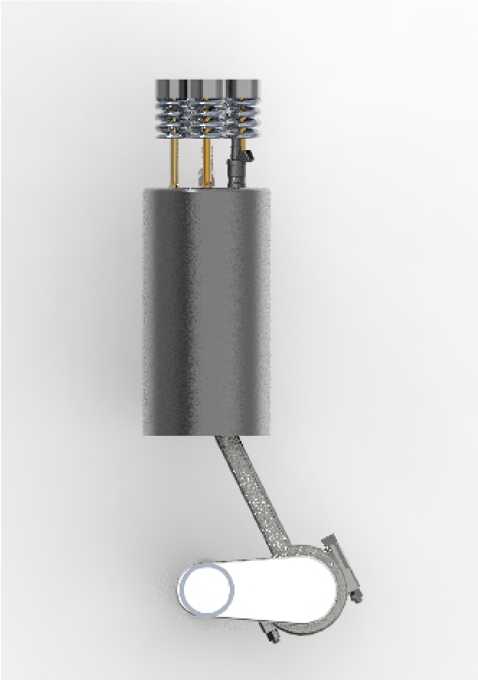

Figure 47: Engine at midpoint

- **Crankshaft at the BDC:**

Figure 48: Engine at BDC

The series of pictures above show a complete revolution of the engine, with the engine finally returning to the position to where it started (the BDC).

MOTION ANALYSIS

To perform the motion analysis of our assembly, the first thing that we needed to do was to choose which type of analysis we want to perform. Since we are not considering the effects of mass and external forces for the time being, therefore, we chose kinematic analysis as our preferred form of analysis. The motion analysis was performed on two angular speeds, 1500 and 3000 RPM. Since we needed to do the motion analysis for two revolutions of the internal combustion engine, therefore, the time that we needed to run the analysis can be found from the following steps:

$$Angular\ Speed = 1500\ RPM \tag{8}$$

Converting from RPM to degrees:

$$Degrees/s = 1500 \times 6 = 9000\ degrees/s \tag{9}$$

There are 720 degrees in two revolutions, therefore, time required for two revolutions:

$$t = \frac{720}{9000} = 0.08s \tag{10}$$

To understand the motion analysis, it is important that we define an axis, which will be uniform for every point that we intend to do the analysis on. The figure below gives a pictorial representation of the axis that was used for our analysis, and it can be clearly seen that the positive x-axis is pointing towards the right hand side and the positive z-axis is pointing downwards. The y-axis is pointing into the page, and it is clear from the figure that there will be no motion in the y-axis for the engine assembly.

The analysis was performed on three points on the engine assembly:

- **Center of the Piston:** A point selected at the center of the piston. From the axis shown in the figure above, this point will experience motion in the positive z-direction only.
- **Center of the wrist pin:** A point selected at the center of the wrist pin. From the axis shown in the figure above, this point will also experience motion in the positive z-direction only.

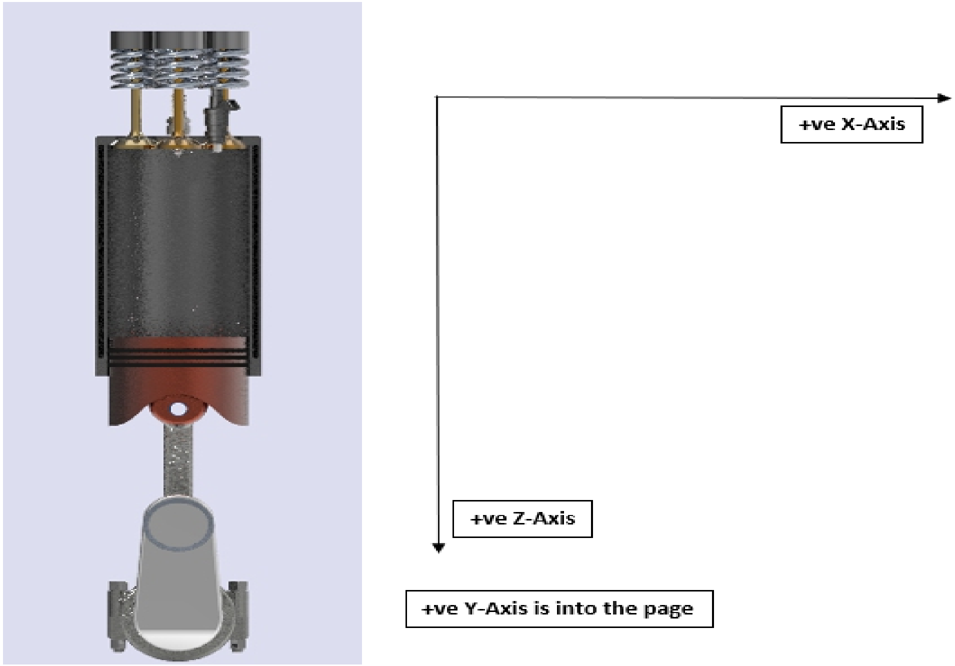

Figure 49: Axis representation for motion analysis

- **Center of the Connecting Rod:** A point selected at the center of the wrist pin. From the axis shown in the figure above, this point will experience motion in the positive z-direction as well as the positive x-direction.

The starting point or the initial point of the simulation was selected to be the bottom dead center (BDC) of the engine. The engine in the figure on the previous page shows the assembly at the bottom dead position. In the two revolutions, the piston will reach the top dead center (TDC) from the BDC, and return again to the BDC to complete one revolution. This cycle will be repeated to complete two revolutions. The graphs for the x, y and z components and the magnitudes for the position, velocity and acceleration of all the three points are shown in the series of figures next followed by brief explanations of each.

Piston point analysis at 1500 RPM:

Z-Component:

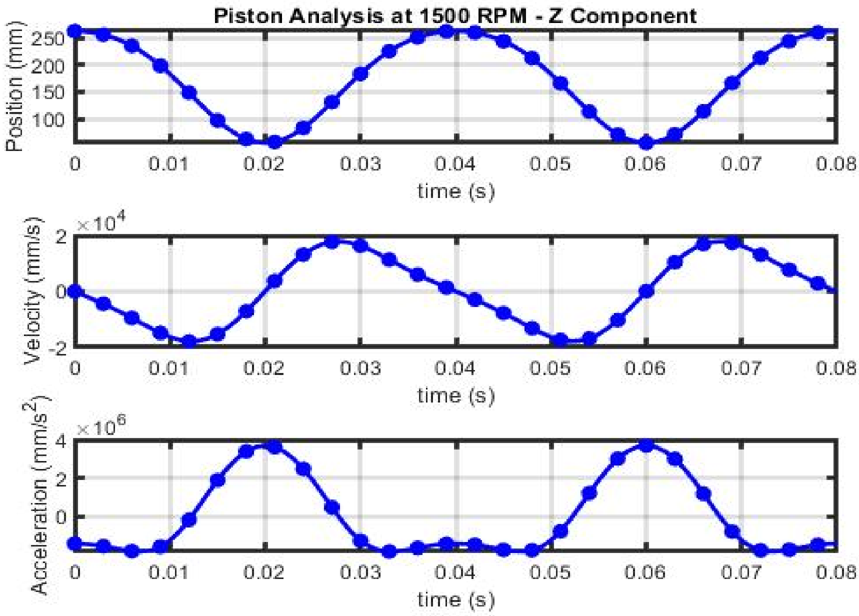

Figure 50: Piston analysis of Z-Component at 1500 RPM

- **Explanation:** In the graph above, at time 0, the velocity of the point is 0. When the point starts to move towards the TDC, the velocity increases in the negative direction as can be seen in the graph. When the point reaches the midpoint between the TDC and the BDC, the velocity starts to decrease in the same direction it started and the acceleration increases in the positive direction. When the point reaches the TDC at 0.02s, the acceleration is maximum and the velocity is 0. The velocity now starts to increase in the positive direction since the point has changed direction and the acceleration starts to decrease in the positive direction. The velocity again starts to decrease from the midpoint between the TDC and the BDC and is 0 when the point reaches the BDC at 0.04s. This completes a single revolution of the crankshaft. The same trend is repeated in the next 0.04s, thus completing the two revolutions of the crankshaft.

X-Component:

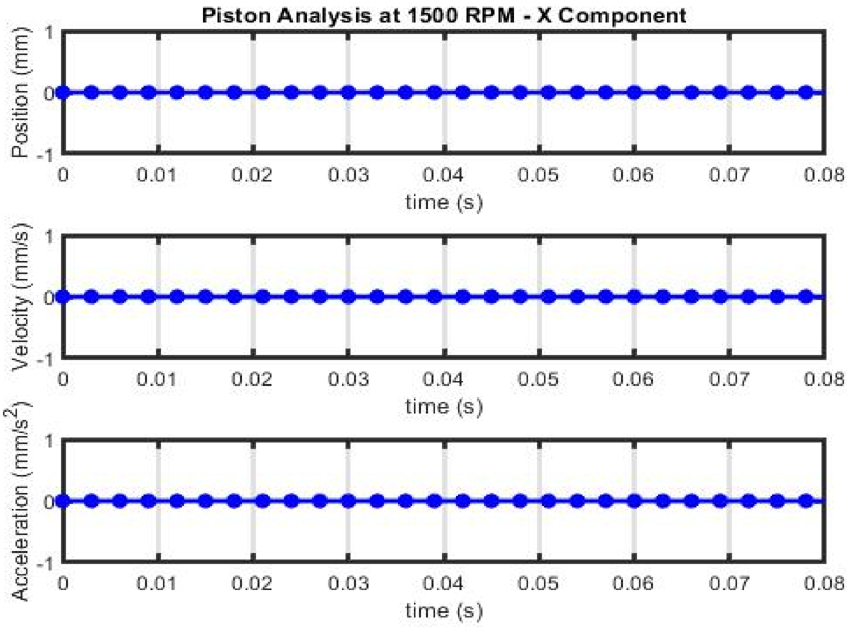

Figure 51: Piston analysis of X-Component at 1500 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive x-direction.

Y-Component:

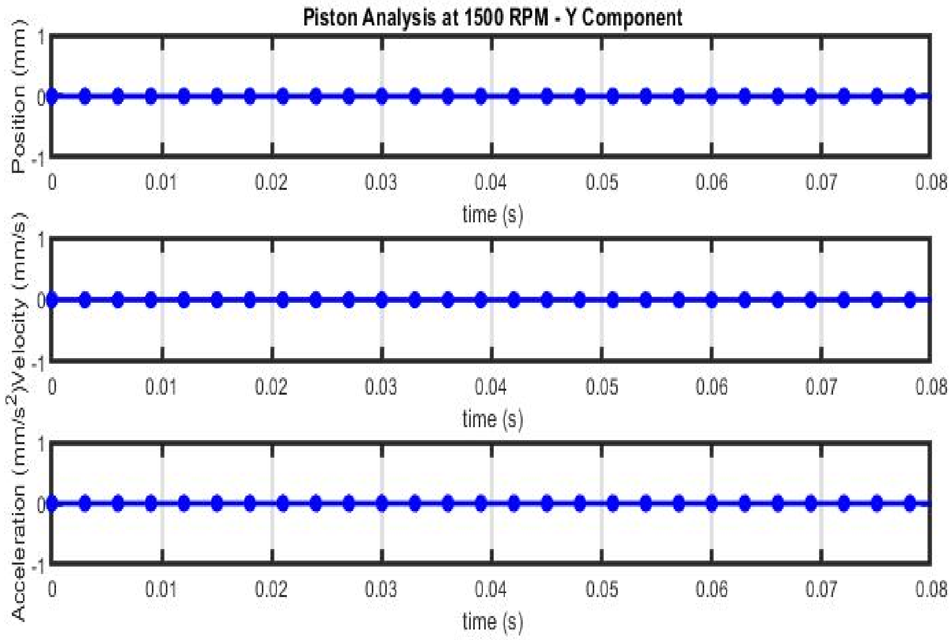

Figure 52: Piston analysis of Y-Component at 1500 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive y-direction.

Magnitude:

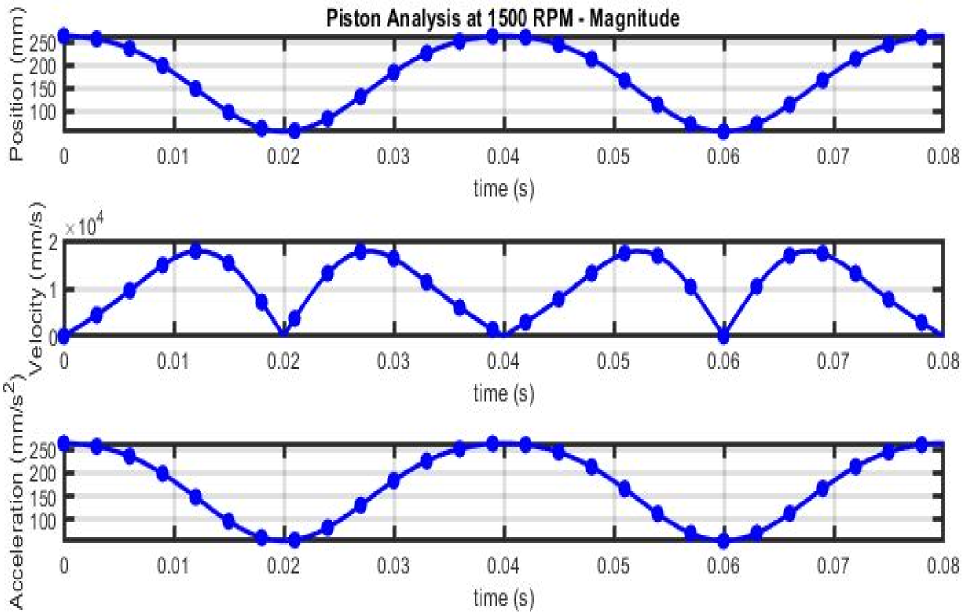

Figure 53: Piston analysis of the magnitudes at 1500 RPM

- **Explanation:** This graph shows the magnitudes of the position, velocity and the acceleration of the piston point. Magnitude is just the square root of the squared sum of all the components. Since in our case, the only component relevant is in the z-direction, therefore, the graph is very similar to what we got for the z-component. The only difference is that there are not negative values since we are squaring every value.

Wrist pin point analysis at 1500 RPM:

Z-Component:

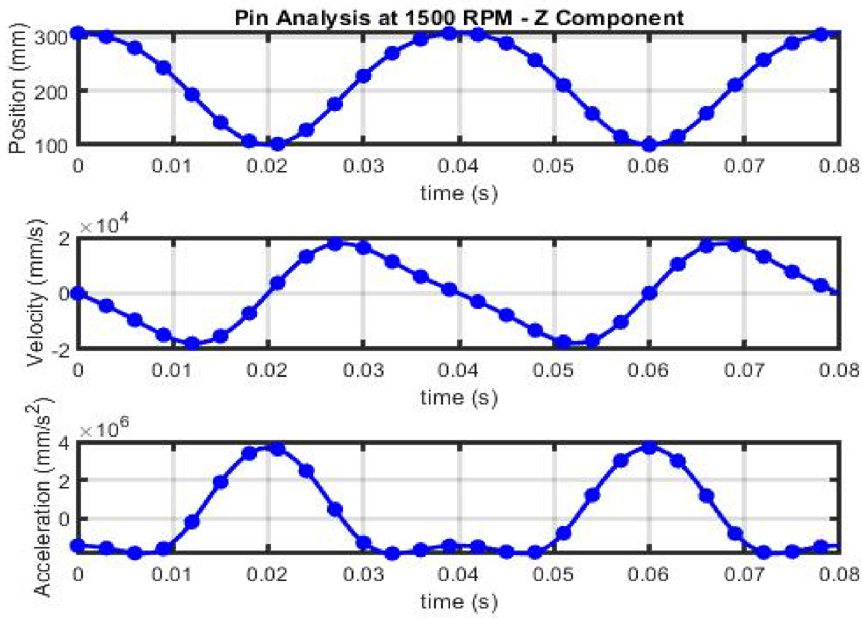

Figure 54: Wrist pin analysis of Z-Component at 1500 RPM

- **Explanation:** In the graph above, at time 0, the velocity of the point is 0. When the point starts to move towards the TDC, the velocity increases in the negative direction as can be seen in the graph. When the point reaches the midpoint between the TDC and the BDC, the velocity starts to decrease in the same direction it started and the acceleration increases in the positive direction. When the point reaches the TDC at 0.02s, the acceleration is maximum and the velocity is 0. The velocity now starts to increase in the positive direction since the point has changed direction and the acceleration starts to decrease in the positive direction. The velocity again starts to decrease from the midpoint between the TDC and the BDC and is 0 when the point reaches the BDC at 0.04s. This completes a single revolution of the crankshaft. The same trend is repeated in the next 0.04s, thus completing the two revolutions of the crankshaft. We can notice that the trends for both the piston point and the wrist pin are exactly the same, which makes sense because essentially both are undergoing the same motion.

X-Component:

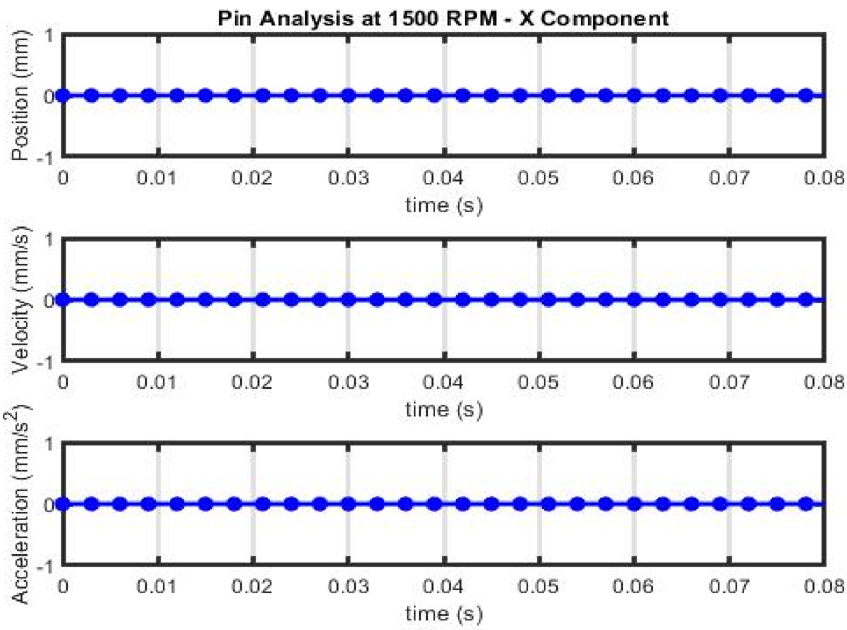

Figure 55: Wrist pin analysis of X-Component at 1500 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive x-direction.

Y-Component:

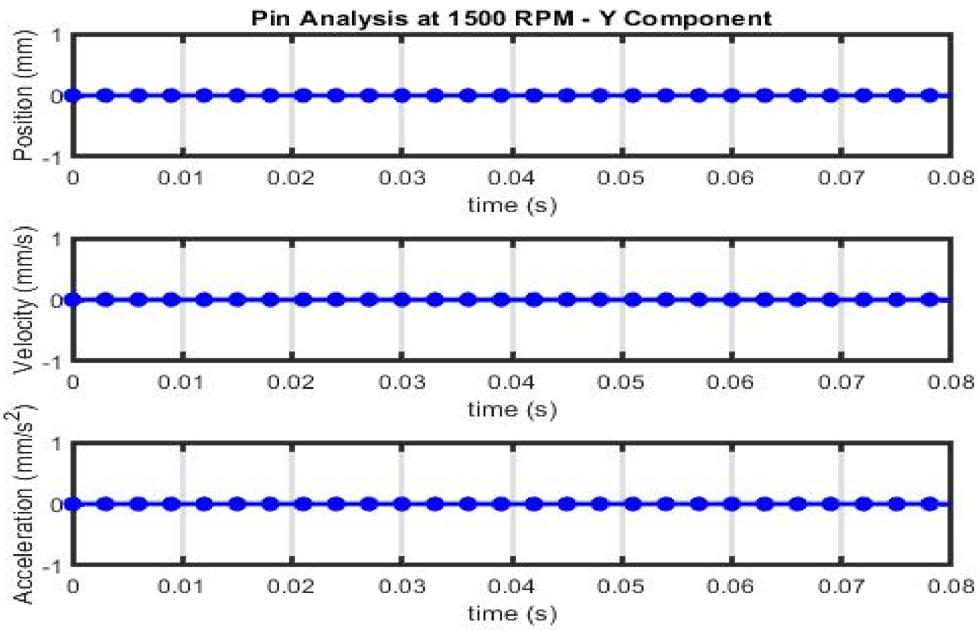

Figure 56: Wrist pin analysis of Y-Component at 1500 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive y-direction.

Magnitude:

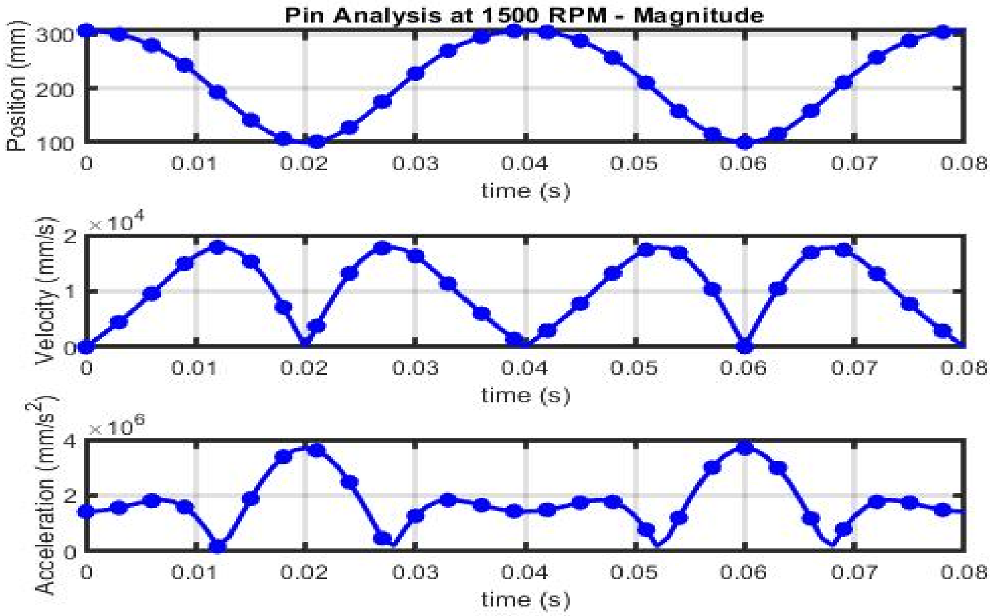

Figure 57: Wrist pin analysis of the magnitudes at 1500 RPM

- **Explanation:** The graph for the magnitudes is the same as the piston.

Connecting point analysis at 1500 RPM:

Z-Component:

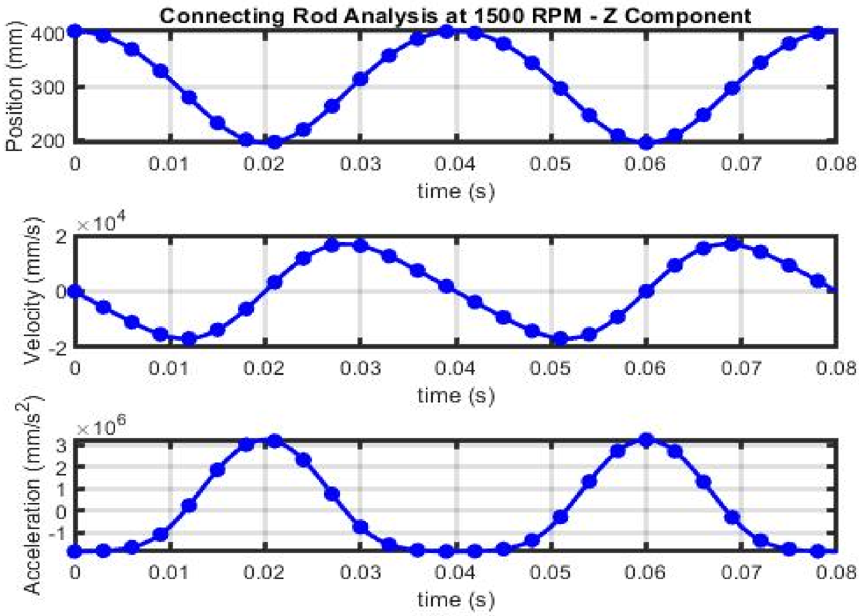

Figure 58: Connecting rod analysis of Z-Component at 1500 RPM

- **Explanation:** In the graph above, at time 0, the velocity of the point is 0. When the point starts to move towards the TDC, the velocity increases in the negative direction as can be seen in the graph. When the point reaches the midpoint between the TDC and the BDC, the velocity starts to decrease in the same direction it started and the acceleration increases in the positive direction. When the point reaches the TDC at 0.02s, the acceleration is maximum and the velocity is 0. The velocity now starts to increase in the positive direction since the point has changed direction and the acceleration starts to decrease in the positive direction. The velocity again starts to decrease from the midpoint between the TDC and the BDC and is 0 when the point reaches the BDC at 0.04s. This completes a single revolution of the crankshaft. The same trend is repeated in the next 0.04s, thus completing the two revolutions of the crankshaft. We can notice that the trends for the z-components of the connecting rod, piston and the wrist pin are exactly the same, which makes sense because essentially all the points are undergoing the same motion.

X-Component:

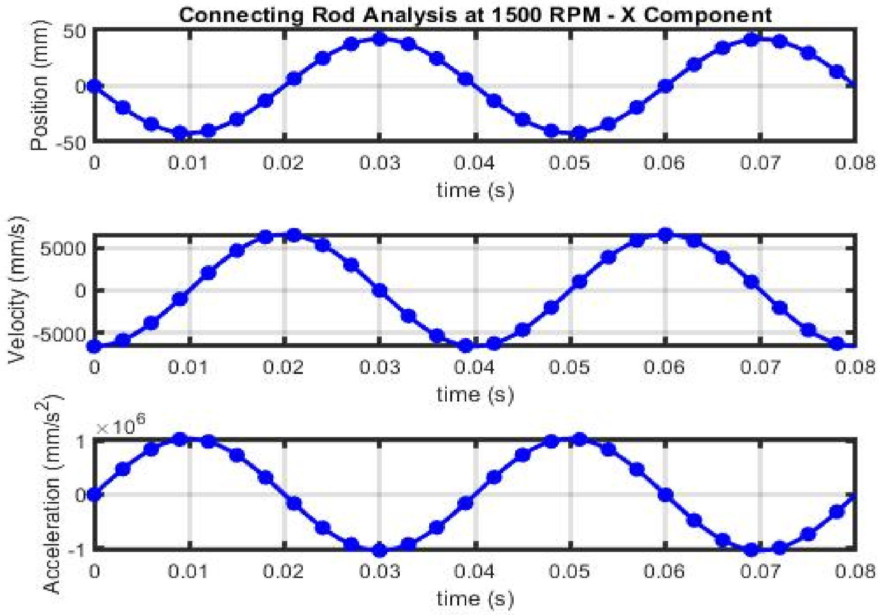

Figure 59: Connecting rod analysis of X-Component at 1500 RPM

- **Explanation:** The x-component of the connecting undergoes a to-and-fro motion as can be seen in the graph. The point first starts to move towards the TDC and the velocity reaches 0 when the point reaches the midpoint. When the point reaches the TDC, it is at the same point as it was at the beginning. The point again undergoes the same motion but this time in the opposite direction and reaching its original position at the BDC.

Y-Component:

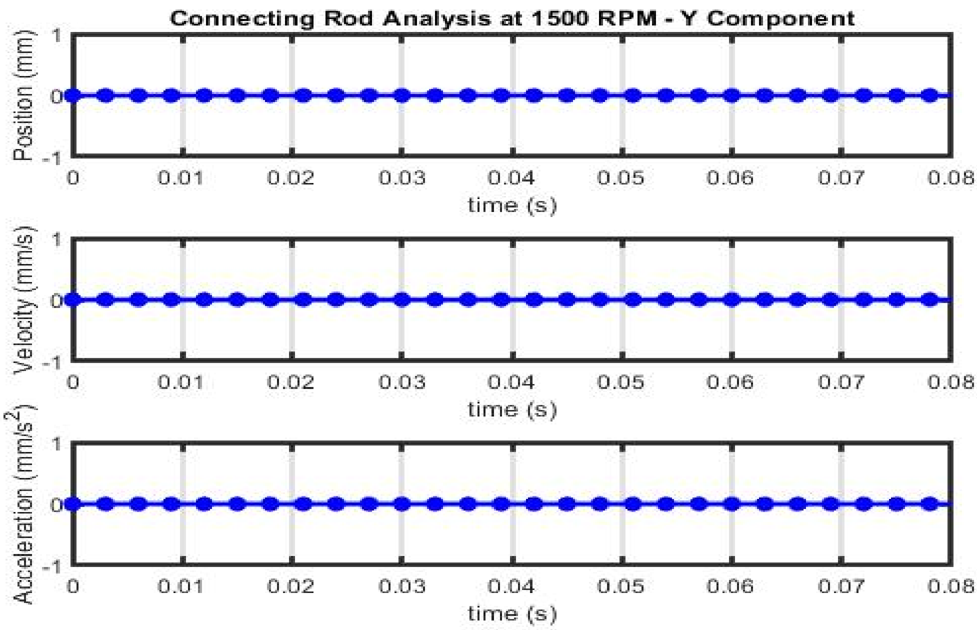

Figure 60: Connecting rod analysis of Y-Component at 1500 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive y-direction.

Magnitude:

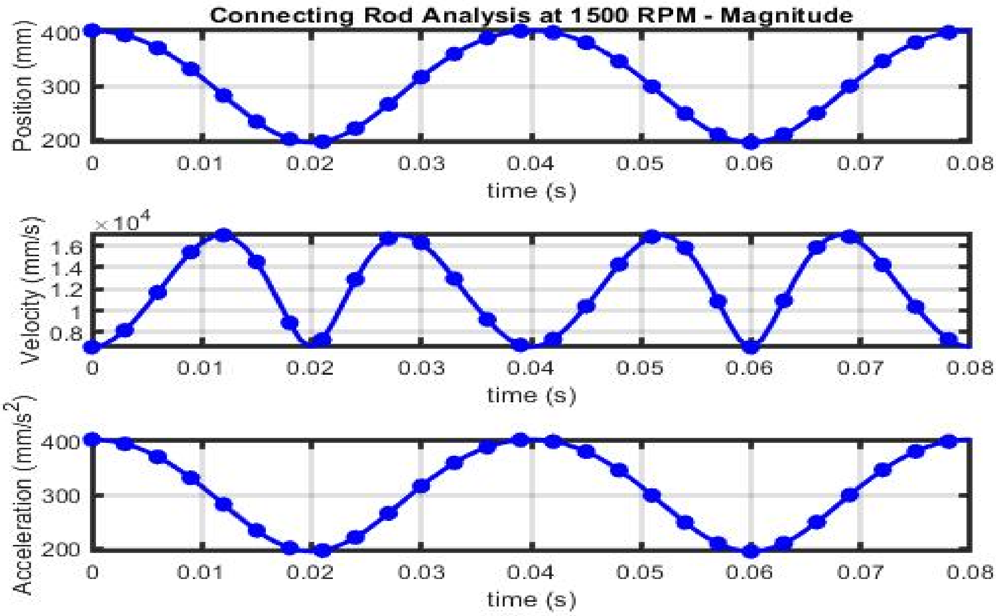

Figure 61: Connecting rod analysis of the magnitudes at 1500 RPM

- **Explanation:** The graph for the magnitudes for the connecting rod combines both the x and the z components and it undergoes a trend similar to the trends in the graphs of the magnitudes of the piston and wrist pin.

Now we will analyze the points by doubling the speed from 1500 RPM to 3000 RPM. The general trend is similar between the two speeds, however, the crankshaft takes half the time to complete two revolutions at 3000 RPM than it was taking at 1500 RPM.

Piston point analysis at 3000 RPM:

Z-Component:

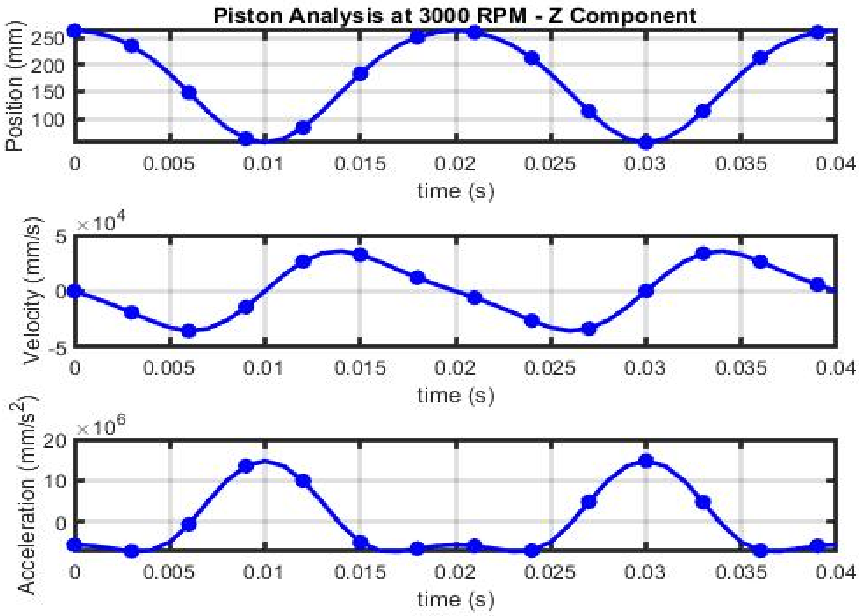

Figure 62: Piston analysis of Z-Component at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

X-Component:

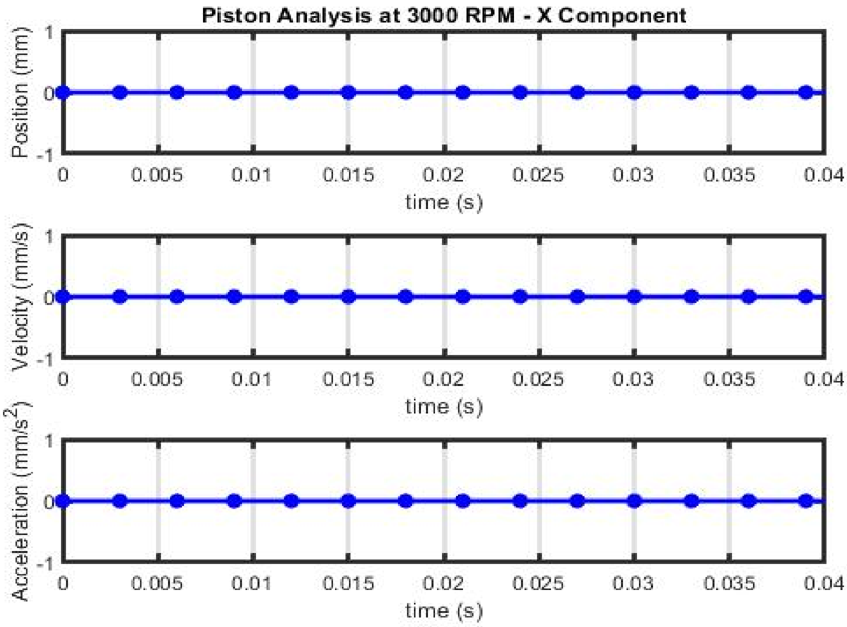

Figure 63: Piston analysis of X-Component at 3000 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive x-direction.

Y-Component:

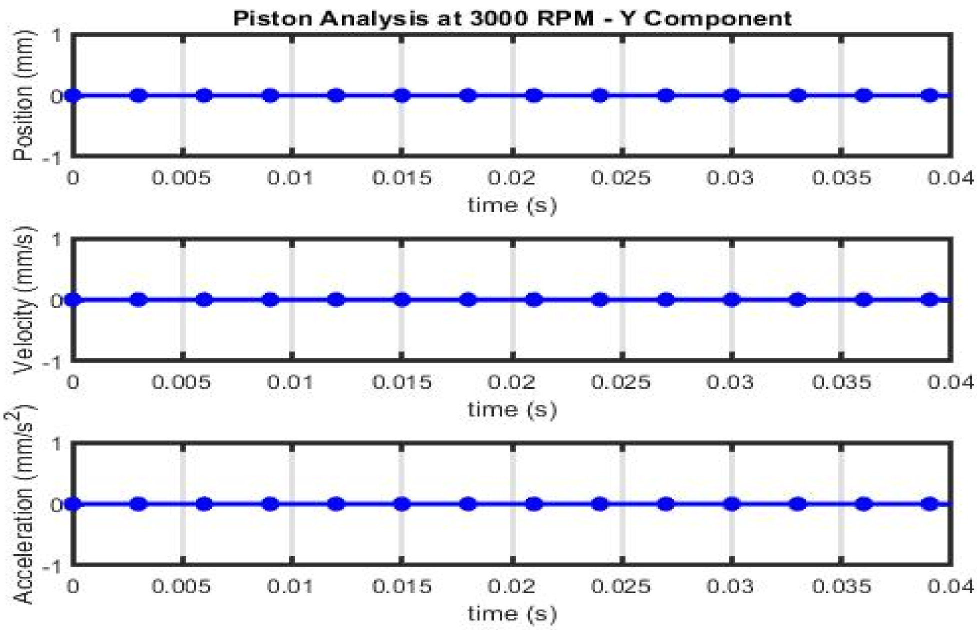

Figure 64: Piston analysis of Y-Component at 3000 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive y-direction.

Magnitude:

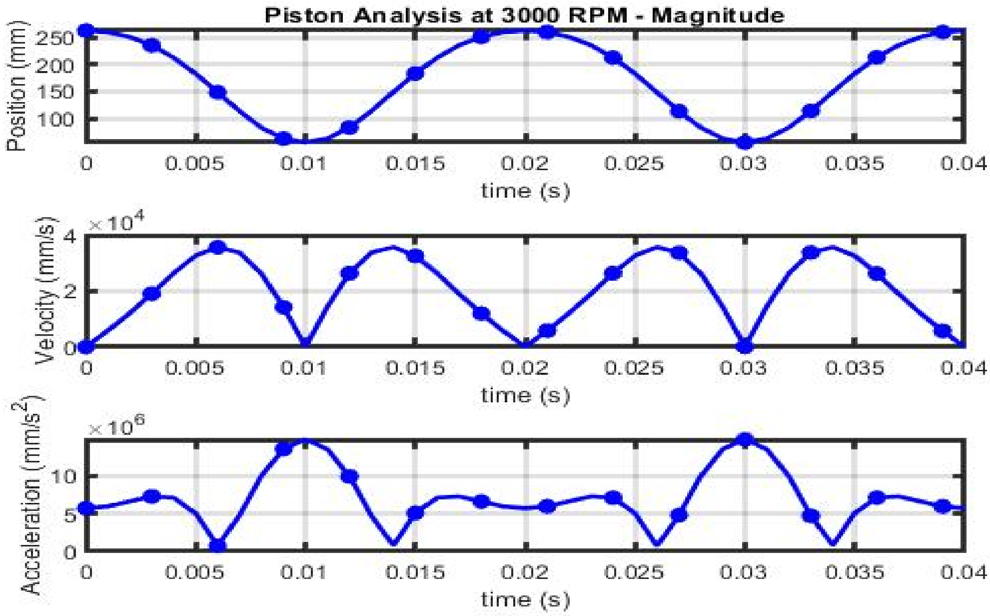

Figure 65: Piston analysis of the magnitudes at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

Wrist pin point analysis at 3000 RPM:

Z-Component:

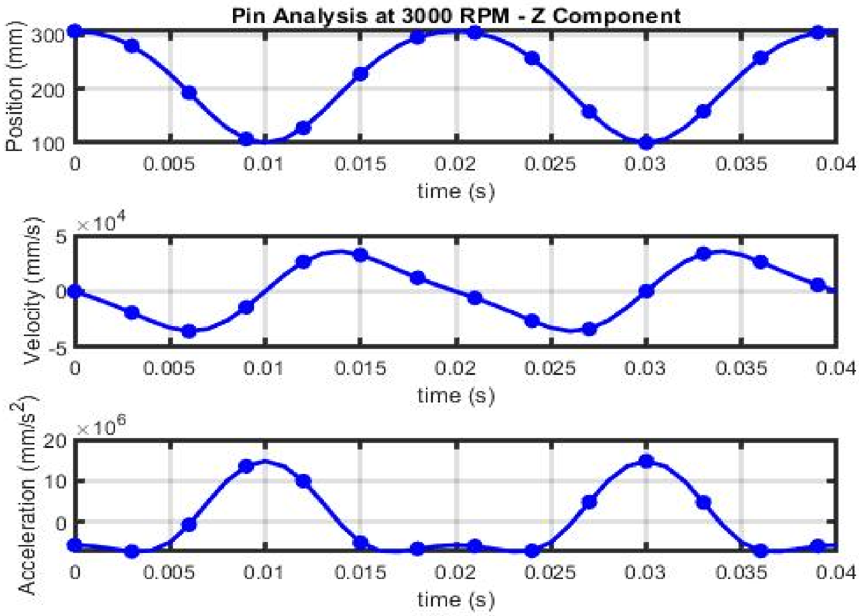

Figure 66: Wrist pin analysis of Z-Component at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

X-Component:

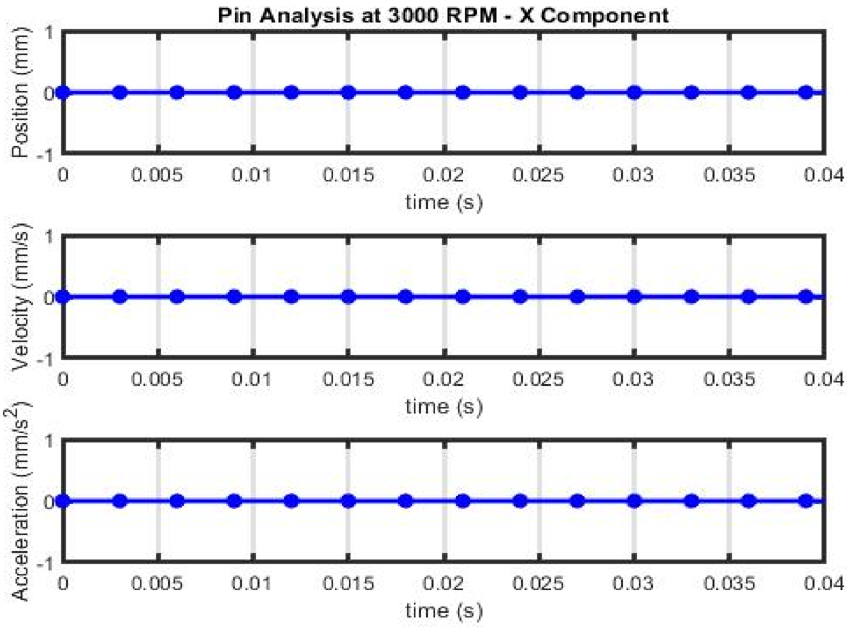

Figure 67: Wrist pin analysis of X-Component at 3000 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive x-direction.

Y-Component:

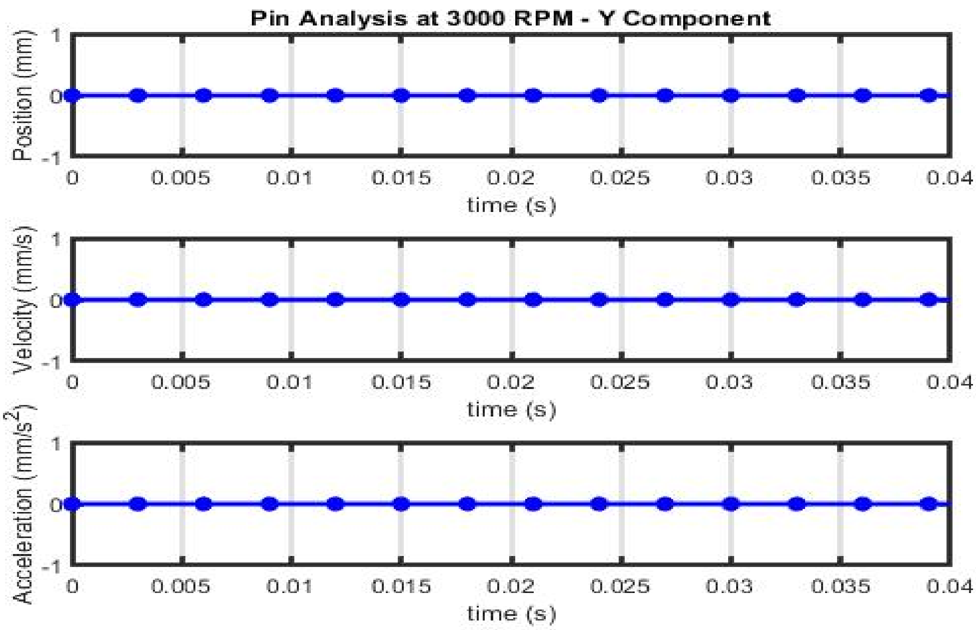

Figure 68: Wrist pin analysis of Y-Component at 3000 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive y-direction.

Magnitude:

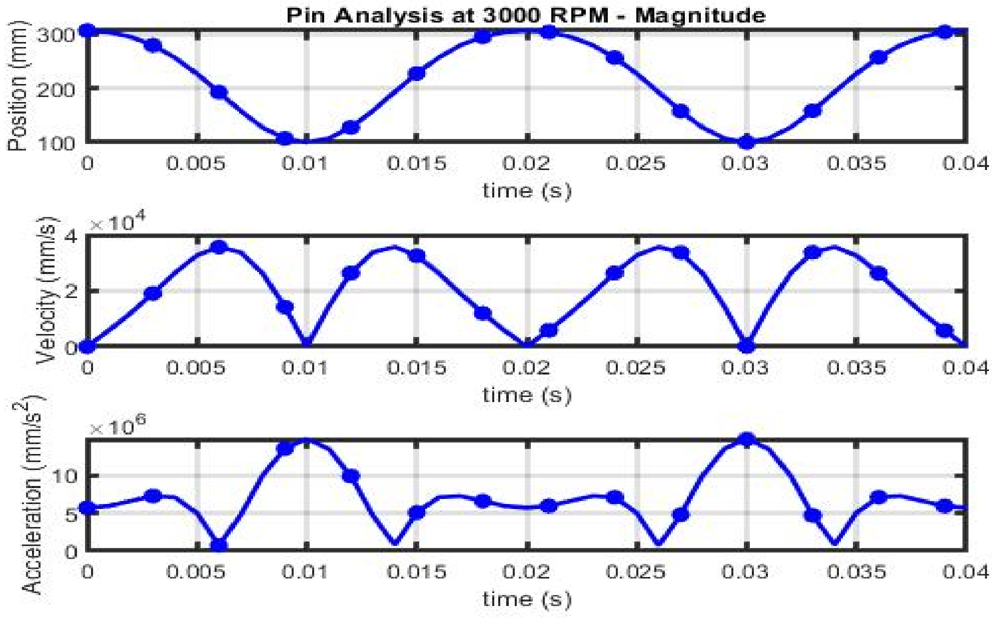

Figure 69: Wrist pin analysis of the magnitudes at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

Connecting point analysis at 3000 RPM:

Z-Component:

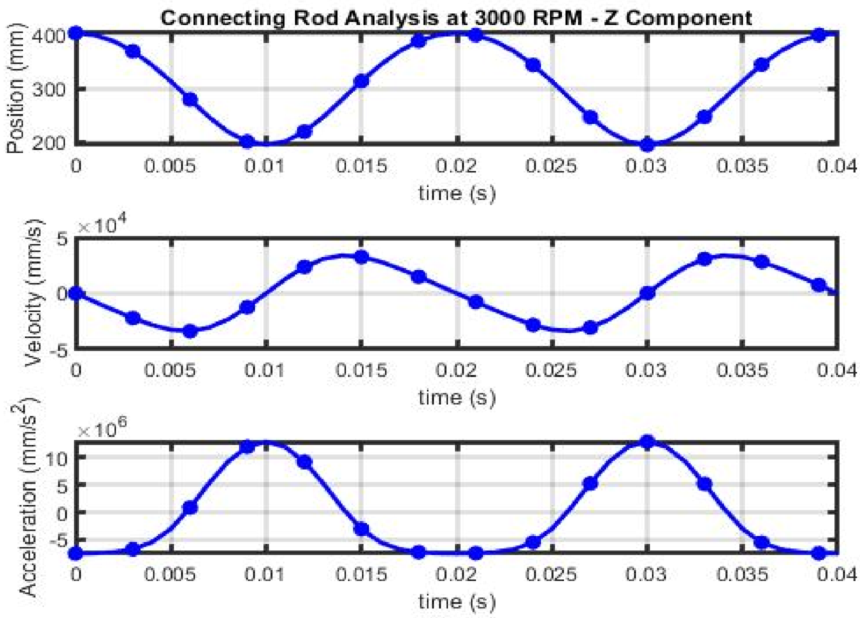

Figure 70: Connecting rod analysis of Z-Component at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

X-Component:

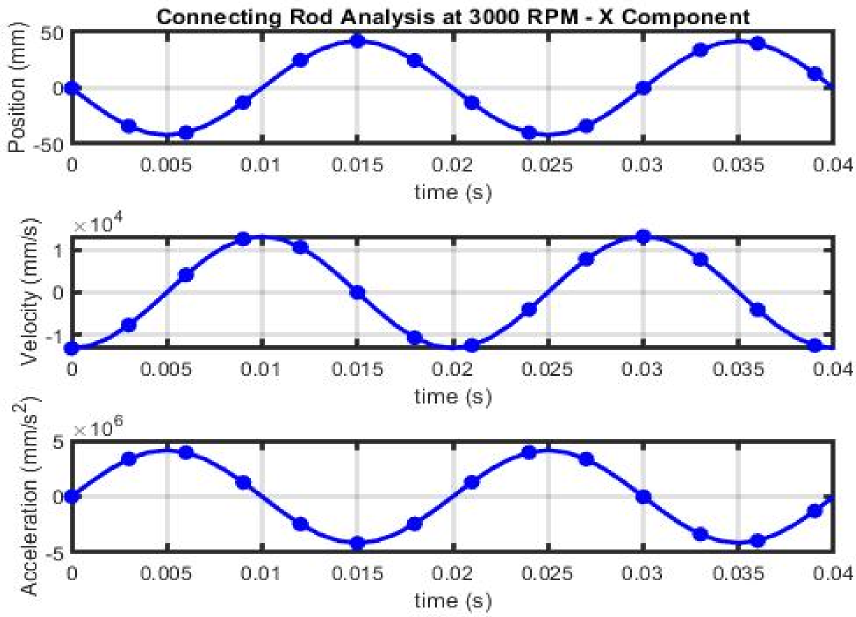

Figure 71: Connecting rod analysis of X-Component at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

Y-Component:

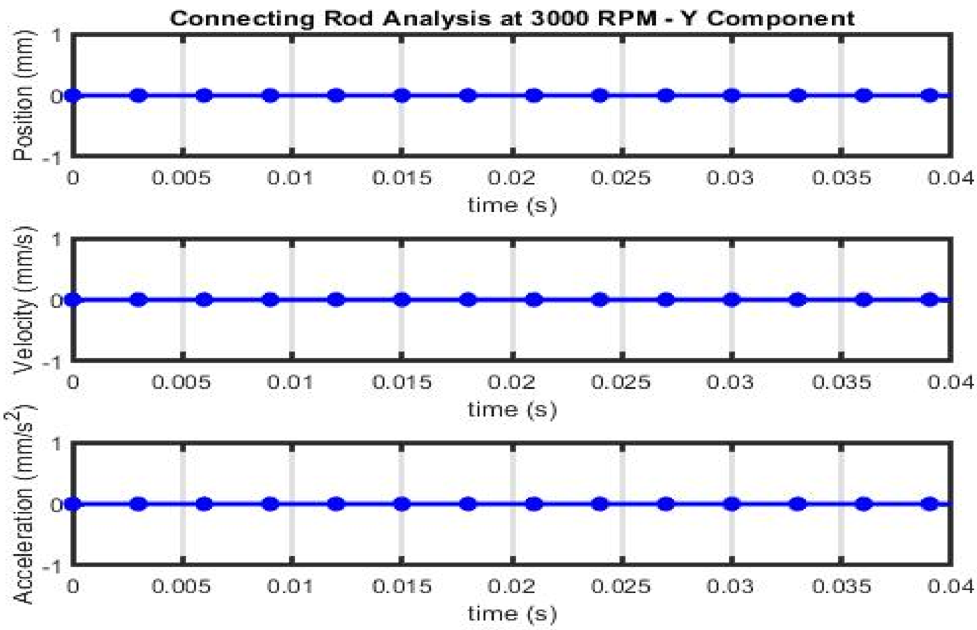

Figure 72: Connecting rod analysis of Y-Component at 3000 RPM

- **Explanation:** The graph is a constant 0 line for the position, velocity and the acceleration because there is no motion in the positive y-direction.

Magnitude:

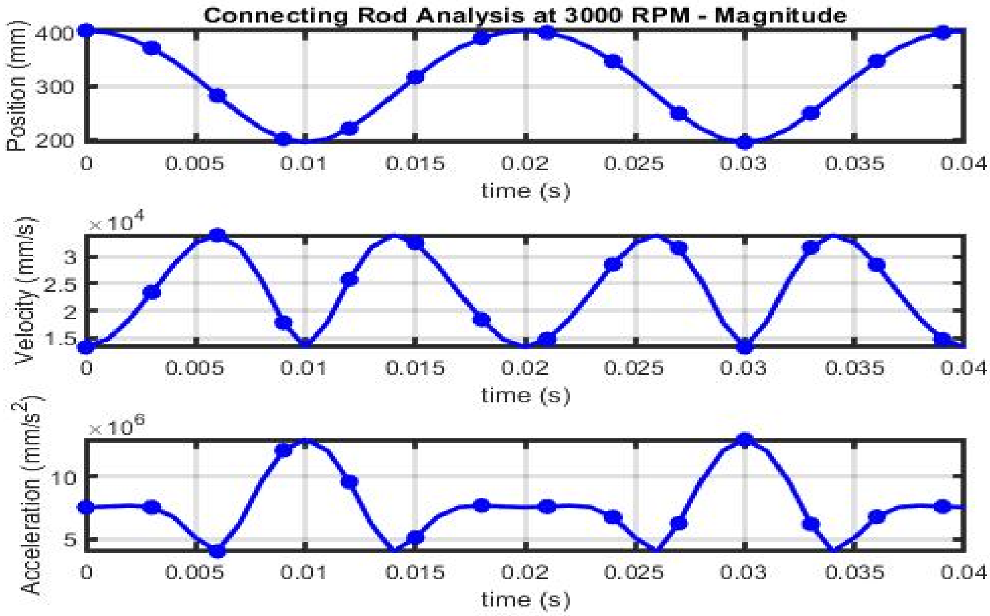

Figure 73: Connecting rod analysis of the magnitudes at 3000 RPM

- **Explanation:** The trend is very similar to what was observed for the case of 1500 RPM, and the only major difference that one can find is that the maximum velocity reached by the point has increased since we are analyzing the motion of the point at double the previous speed.

CONCLUSION

This project provided us all a great opportunity to understand the design and working of an internal combustion engine. We implemented all the concepts learned in the course to model a single cylinder single piston internal combustion engine according to the given list of constraints. Furthermore, we performed in-depth kinematic analysis of the developed engine assembly and formulated important insights through it. Finally, we created the model related documents such as engineering drawings and bill of materials which would help us in explaining our work to an audience.

References

[1] AgEdLibrary.com. (n.d.). The Internal Combustion Engine and Its Importance to Agriculture (Rep.). Retrieved from https://www.gctsd.k12.ar.us/images/AMIPackets/HS/Murray/SmallGasEngines/AMI2.pdf