Figure 3.15: Explode Drawing.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In order to achieve the result, this chapter focused on the result and discussion based on objective which is analytical analysis and simulation by CATIA software. Based on analytical analysis, the result is all about to check each part for it strength, minimum FOS, and maximum displacement. All part of design used ASTM A36 steel as the material on each part of design. The purpose using this material is because less expensive, high strength, sustainable and modifiable. There is several type of strength for material steel such as Table 4.1. According to analytical analysis, there are two parts that will be analyzed which is crank and pin. In addition, the purpose of this analysis is to find their strength of material when applied maximum distributed force.

Table 4.1: Typical Tensile Strength of Some Materials.

Material	Yield strength (MPa)	Density (g/cm^3)
Steel, ASTM A36	250	7.8
Steel, 1090 mild	247	7.58
Steel, 2800 Maraging Steel	2617	8.00
Steel, AerMet 340	2160	7.86

Steel, high strength alloy ASTM A514	690	7.8

Using CATIA software, the simulation is focused on movement of gripper to complete for one cycle with continuously. Each part has different value of properties and produces the different result of Factor of Safety (FOS). FOS is defined as ratio of actual strength of material to design load. Moreover, FOS cannot be greater than 1.0 to prevent from failure occur on structure. FOS will be calculated using equation 4.1.

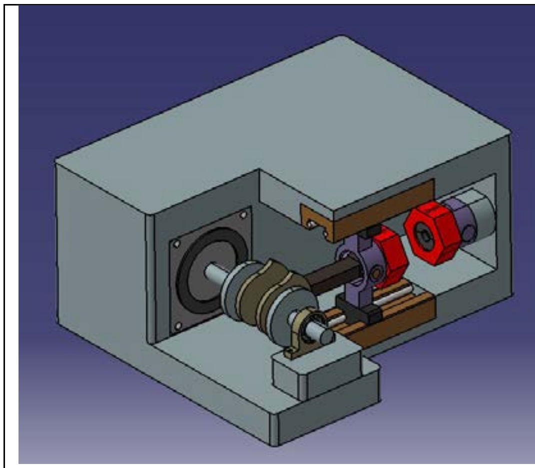
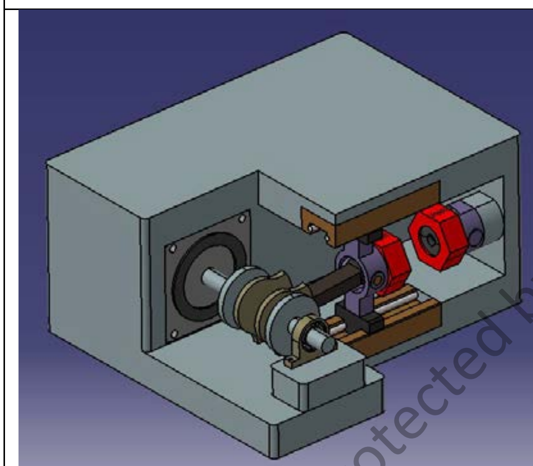
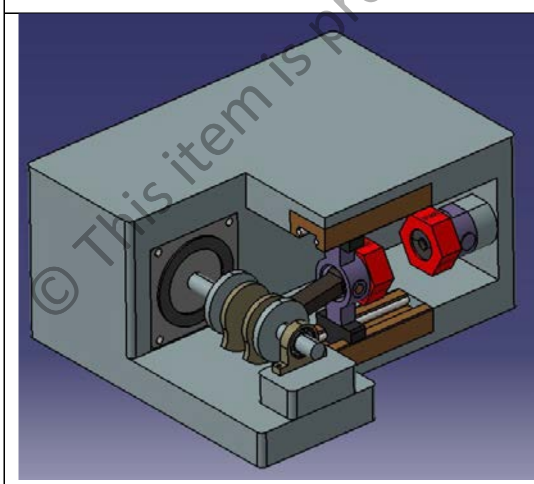
$$\text{Factor of Safety, FOS} = \frac{\text{Yield strength}}{\text{Design Load}} \qquad (4.1)$$

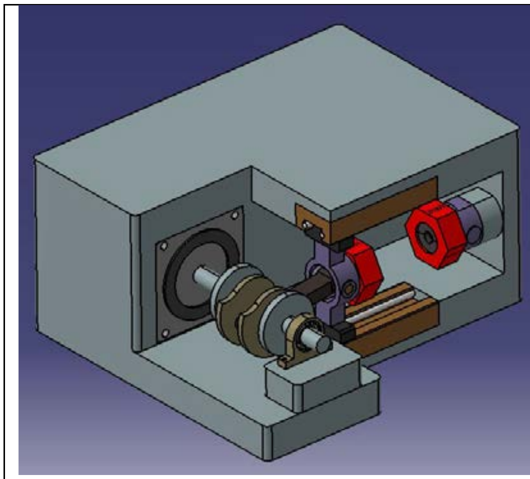
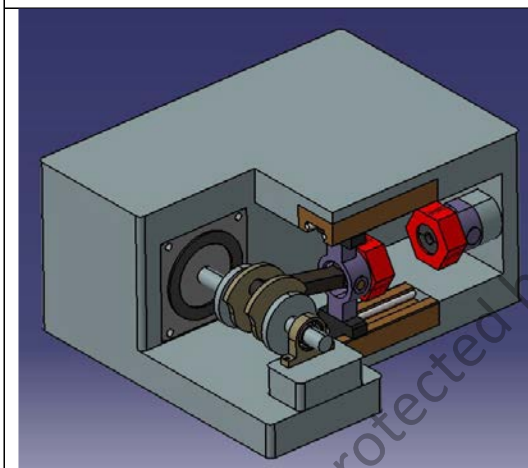
4.2 Animation using CATIA software

Based on simulation that had been figured, gripper and crank selected as main function to make horizontally motion such on Table 4.2. The animation generated by using Digital Mockup Kinematics on CATIA software. Gripper move horizontally and give the different force when the motor start rotates. The animation show the motion of gripper will be tested without locate a specimen. Based on animation, the value of force is different on each angle on each view of motion gripper.

Table 4.2: Motion of Gripper.

Motion of gripper	Description

	• Position in static • Specimen will be setup on original place • Angle: 0 degree • No specimen
	• Crank move • Angle: 20 degree • Force: -362.371N • Gripper start move on slider with horizontally • No specimen
	• Crankmove at 80 degree • Force: -14.4709N • Gripper move horizontally • No specimen

	• Crankmove at 120 degree • Force: 197.3566N • Gripper move horizontally • No specimen
	• Crank at 280 degree • Force: -14.7756N • Gripper move horizontally • No specimen

4.2.1 Kinematic Analysis

Based on animation had been figured, each of angle crank motion will be calculated when machine operated. Each of angles will give different force when gripper starts to pull. The calculation will show about finding force without apply specimen on machine. Figure 4.1 shows free body diagram on how to find force (P) on each angle.

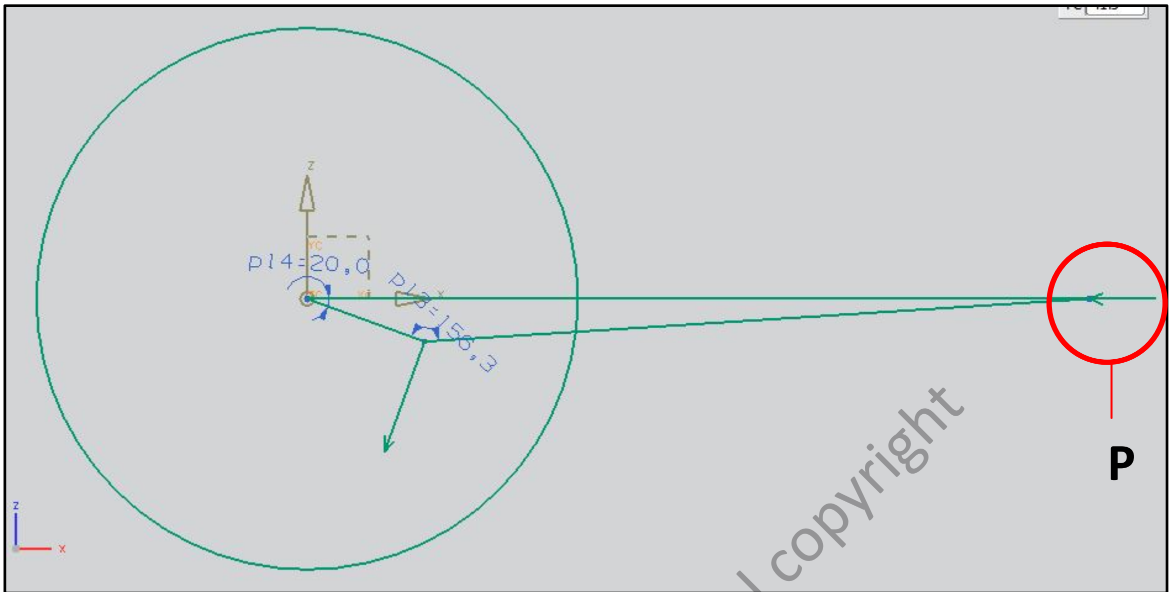


Figure 4.1: Free Body Diagram

Assumption:

Length of rod: 80mm (Specification of design)

Radius of pin: 15mm (Specification of design)

Speed rotation, N: 200rpm (Based on specification of motor)

Angular velocity: $\frac{2\pi N}{60}$ = 20.9467 (rad/sec)

Ma = mass crank + mass rod = 0.337kg

Mb = 2(mass slider) + mass grip = 1kg

4.2.2 Force Analysis

Force analysis had been made on crank and pins. Force was calculated to define on each angle. Table 4.3 shows the result of calculation for each angle on crank. The calculation will be related to mass, radius, length, and angular velocity to define force for each angle. Furthermore, the result will be located on graph such on Figure 4.2. Force is calculated as on Equation 4.2.

$$Fx = -Ma\ (R\omega^2\cos(\theta)) - Mb\ [R\omega^2(\cos(\theta) + \tfrac{R}{L}\cos(2\theta))] \tag{4.2}$$

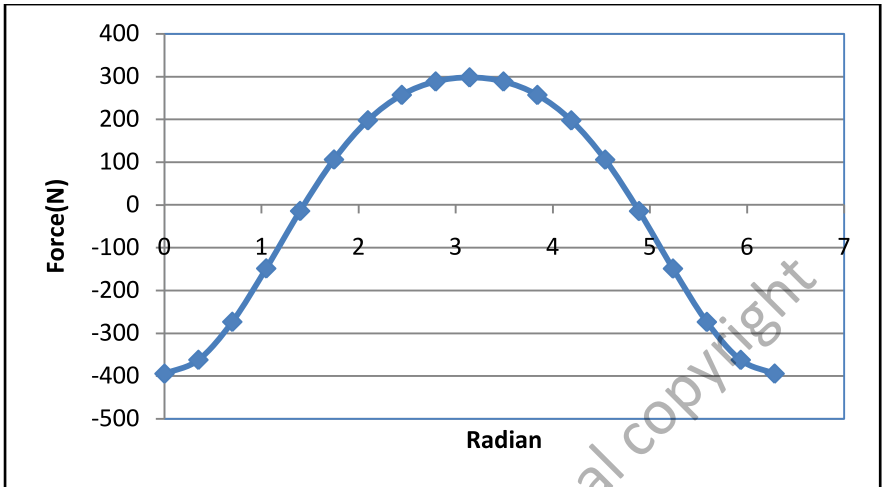


Figure 4.2: X-component, force acting on crank for each angle.

Table 4.3: Result of force acting on crank.

Angle	Radian	Angula r velocity	Radius(in)	Length(in)	Mass kg (a)	Mass kg (b)	Force
0	0	20.947	0.59	3.15	0.337	1	-394.596
20	0.3491	20.947	0.59	3.15	0.337	1	-362.371
40	0.6982	20.947	0.59	3.15	0.337	1	-273.526
60	1.0473	20.947	0.59	3.15	0.337	1	-148.759
80	1.3964	20.947	0.59	3.15	0.337	1	-14.4709
100	1.7456	20.947	0.59	3.15	0.337	1	105.7335
120	2.0947	20.947	0.59	3.15	0.337	1	197.3566
140	2.4438	20.947	0.59	3.15	0.337	1	256.7557
160	2.7929	20.947	0.59	3.15	0.337	1	288.1136
180	3.142	20.947	0.59	3.15	0.337	1	297.6225
200	3.4911	20.947	0.59	3.15	0.337	1	288.0679
220	3.8402	20.947	0.59	3.15	0.337	1	256.6522
240	4.1893	20.947	0.59	3.15	0.337	1	197.1808
260	4.5384	20.947	0.59	3.15	0.337	1	105.4828
280	4.8876	20.947	0.59	3.15	0.337	1	-14.7756
300	5.2367	20.947	0.59	3.15	0.337	1	-149.072
320	5.5858	20.947	0.59	3.15	0.337	1	-273.785
340	5.9349	20.947	0.59	3.15	0.337	1	-362.518
360	6.284	20.947	0.59	3.15	0.337	1	-394.596

Based on result, the minimum value is -394.596N which start with 0 degree while the maximum value is 297.6225N on 180 degree. Table 4.4 shows the result of calculation for displacement for each angle on crank. Furthermore, the result of displacement will be plot on graph such on Figure 4.3. Displacement will be defined as distance of gripper on slider when were pulled or push. Calculation will be related to radius and length of part design. Force will be calculated as on Equation 4.3.

$$S(\theta) = L - \frac{R^2}{4L} + R[\sin(\theta) + \frac{R}{4L}(\sin(2\theta)] \quad (4.3)$$

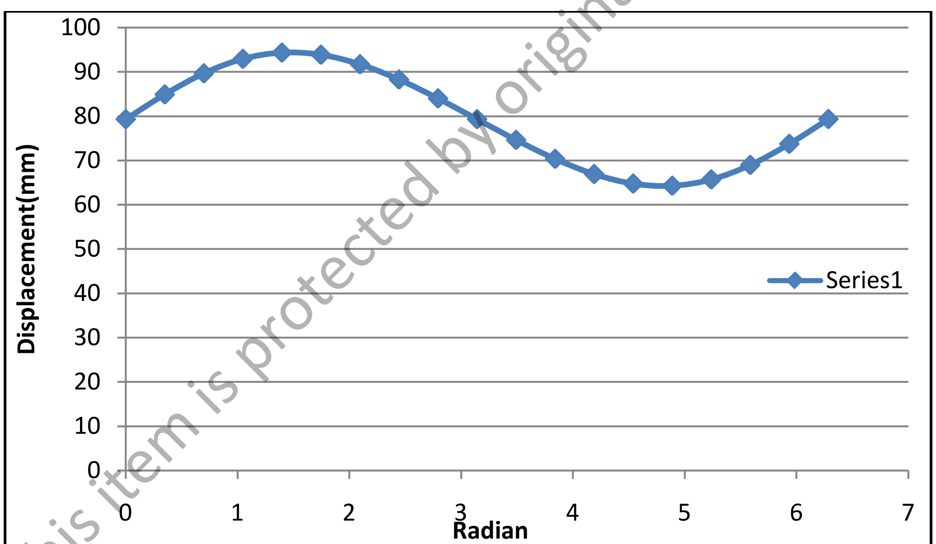


Figure 4.3: X-component, displacement between slider.

Table 4.4: Result of displacement between slider.

Angle	Radian	Angular velocity	Radius	Length	Displacement	Stroke(mm)
0	0	20.947	15	80	79.297	8.203125
20	0.3491	20.947	15	80	84.88	2.620176
40	0.6982	20.947	15	80	89.632	-2.13219
60	1.0473	20.947	15	80	92.897	-5.3971
80	1.3964	20.947	15	80	94.31	-6.80971
100	1.7456	20.947	15	80	93.828	-6.32762

120	2.0947	20.947	15	80	91.676	-4.1761
140	2.4438	20.947	15	80	88.243	-0.74268
160	2.7929	20.947	15	80	83.971	3.529497
180	3.142	20.947	15	80	79.291	8.208662
200	3.4911	20.947	15	80	74.613	12.88736
220	3.8402	20.947	15	80	70.342	17.15809
240	4.1893	20.947	15	80	66.911	20.58904
260	4.5384	20.947	15	80	64.763	22.73707
280	4.8876	20.947	15	80	64.285	23.21491
300	5.2367	20.947	15	80	65.702	21.79781
320	5.5858	20.947	15	80	68.971	18.52888
340	5.9349	20.947	15	80	73.726	13.77371
360	6.284	20.947	15	80	79.31	8.189759

Based on result, the minimum value on displacement graph is 64.285mm and the maximum value is 94.31mm. The maximum value show the highest distance of gripper on slider when pulled. In addition, acceleration also can be defined by a calculation such on Table 4.5. Result will be identified based on graph such on Figure 4.4. Slider acceleration will be calculated on Equation 4.4.

$$A(\theta) = [\ -R\omega^2(\sin(\theta) + \frac{R}{L}\cos(2\theta))] \quad (4.4)$$

Table 4.5: Result of acceleration on slider.

Angle	Radian	Angular velocity	Radius	Length	Acceleration
0	0	20.947	15	80	0
20	0.3491	20.947	15	80	-3044.56
40	0.6982	20.947	15	80	-5446.24
60	1.0473	20.947	15	80	-6768.67
80	1.3964	20.947	15	80	-6903.3
100	1.7456	20.947	15	80	-6058.61
120	2.0947	20.947	15	80	-4629.77
140	2.4438	20.947	15	80	-3013.74
160	2.7929	20.947	15	80	-1456.22
180	3.142	20.947	15	80	1.675579
200	3.4911	20.947	15	80	1459.716

220	3.8402	20.947	15	80	3017.494
240	4.1893	20.947	15	80	4633.461
260	4.5384	20.947	15	80	6061.432
280	4.8876	20.947	15	80	6904.259
300	5.2367	20.947	15	80	6766.991
320	5.5858	20.947	15	80	5441.779
340	5.9349	20.947	15	80	3037.984
360	6.284	20.947	15	80	-7.37255

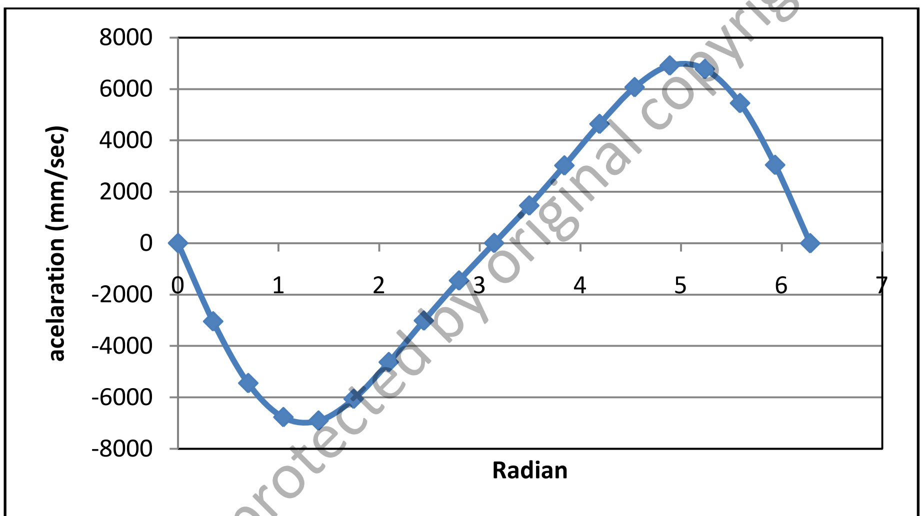


Figure 4.4: X-component, accelerationon slider.

Table 4.6 shows the result for the velocity of motor while it rotates. The result will be plot on graph such on Figure 4.5 which to know the minimum value and maximum value of velocity on each angle. Based on result velocity, the value will be referring on Equation 4.5

$$V(\theta) = \omega R[\cos(\theta) + \frac{R}{2L}\cos(2\theta)] \quad (4.5)$$

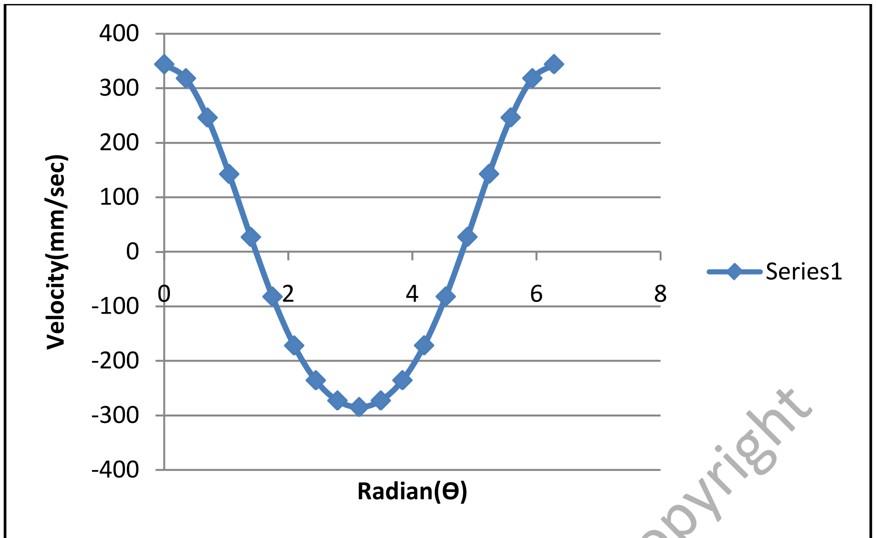


Figure 4.5: X-component, velocity of slider.

Table 4.6: Result of Slider Velocity.

Angle	Radian	Angular velocity	radius	length	Velocity (mm/sec)
0	0	20.947	15	80	343.6563
20	0.3491	20.947	15	80	317.8096
40	0.6982	20.947	15	80	245.7827
60	1.0473	20.947	15	80	142.328
80	1.3964	20.947	15	80	26.82077
100	1.7456	20.947	15	80	-82.3055
120	2.0947	20.947	15	80	-171.888
140	2.4438	20.947	15	80	-235.622
160	2.7929	20.947	15	80	-272.712
180	3.142	20.947	15	80	-284.744
200	3.4911	20.947	15	80	-272.655
220	3.8402	20.947	15	80	-235.504
240	4.1893	20.947	15	80	-171.708
260	4.5384	20.947	15	80	-82.0698
280	4.8876	20.947	15	80	27.08928
300	5.2367	20.947	15	80	142.5912
320	5.5858	20.947	15	80	245.9944
340	5.9349	20.947	15	80	317.9279
360	6.284	20.947	15	80	343.6561

4.3 Analysis using CATIA software

Analytical analysis is done to evaluate the strength of material based on yield strength and Von Misses value. There are two parts that had been analyzed which is pin and crank. Force that will apply on both parts is 613.33N based on Equation 4.5 that had been figured. Two of parts will be generated on structural analysis to define their load and constraints to perform a computation.

$$\text{Force} = \frac{\text{Torque}}{\text{Radius}} \qquad (4.5)$$

Before analyze the material need to be chosen to apply on structural design. There is general process for static analysis which is from define material, apply restraints, apply load, perform computation, create images, analyze the result, and lastly refine the analysis. Furthermore, meshing is important part where to determine the result of calculations based on its size and type. The smaller value of size, the result will be better and take long time to simulate. Figure 4.6 shows there are two types of meshing which is linear and parabolic. The different between linear and parabolic is parabolic is more accurately than linear because of number of nodes such on Figure 4.7.

Figure 4.6: Octree Tetrahedron.

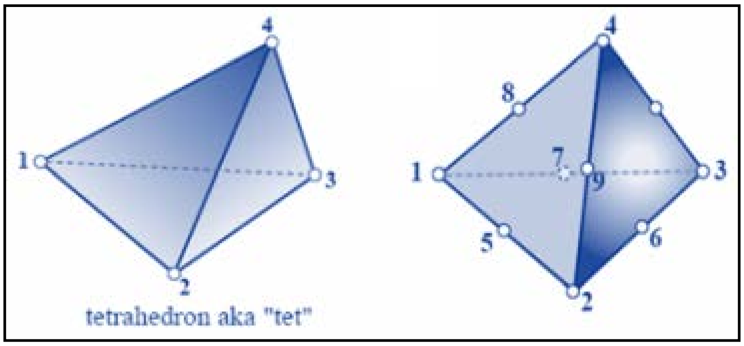


Figure 4.7: Linear Tetra and Parabolic Tetra.

4.3.1 Crank analysis

Maximum stress need to be defined from analysis to compared yield strength of material and know the strength of material start to deform or not. There is several type of structural analysis that had been defined which is deformed mesh; von misses stress, displacement, stress principal and estimated local error. All of this has different of their structural surface. Table 4.7 will show type of material that had been analyzed based on steel material.

Table 4.7: Material of Crank.

Material	Steel
Young Modulus	2e+011 N/m^2
Poisson Ratio	0.266
Density	7860 kg/m^3
Thermal Expansion	1.17e-005/Kdeg
Yield Strength	2.5e+008 N/m^2

Table 4.8: Factor of Safety.

Von Misses Stress	Yield strength	FOS
8.47e+006N/m^2	2.5e+008N/m^2	29.5

Deform mesh will be displayed about no of nodes and element that had been applied on structural design such as Figure 4.8. For Von Misses stress, the maximum value had been figured which are 8.47e+006N/m^2 such as Figure 4.9. Based on this, value of Von Misses stress will be compared with yield strength to know the design is failure or not. From result, value of Von misses stress is lower than yield strength which means the design will be not failure such on Table 4.8.

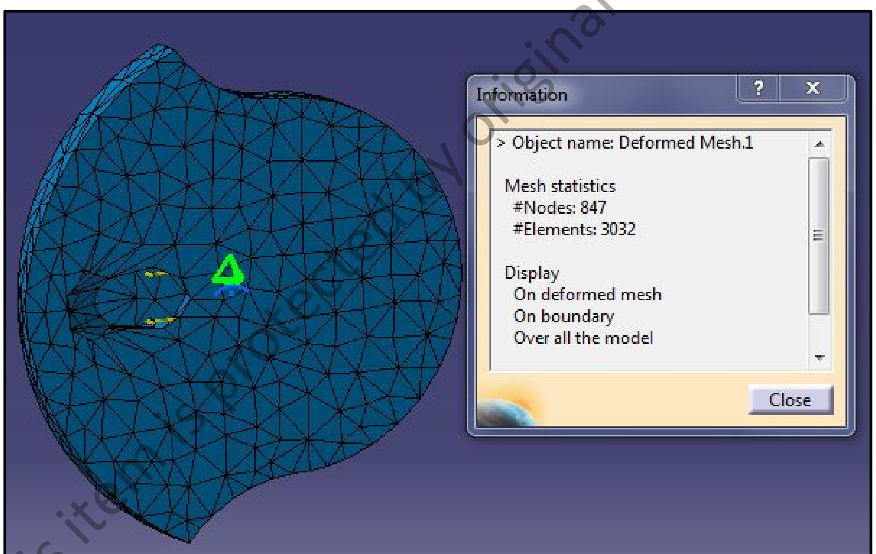


Figure 4.8: Deformed Mesh.

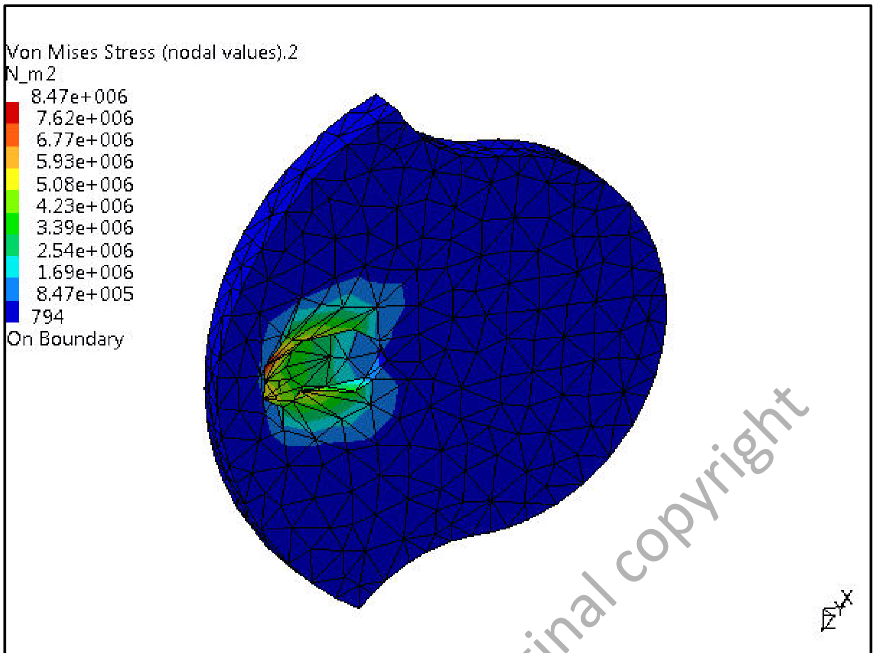
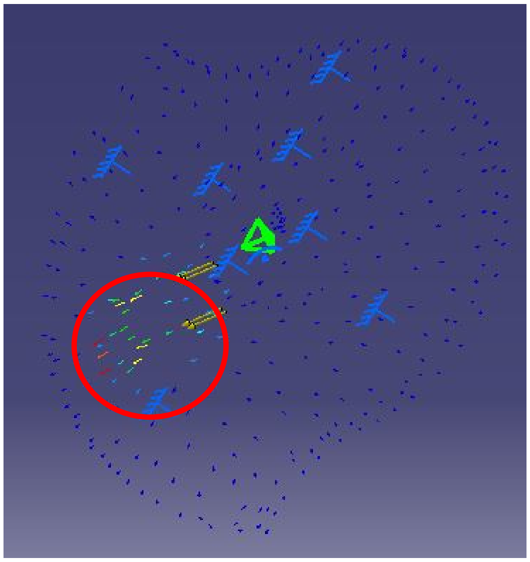
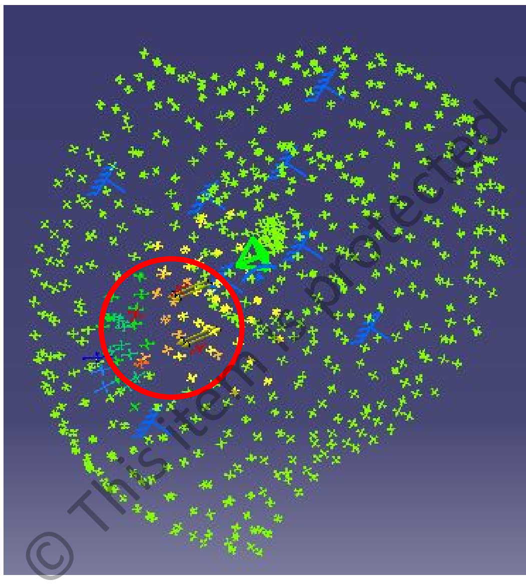


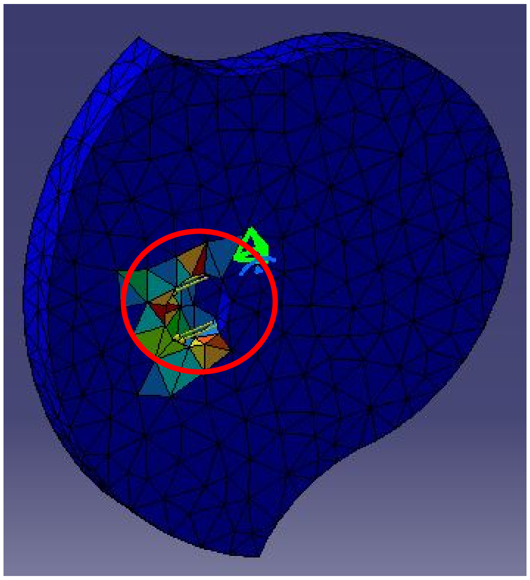
Figure 4.9: Von Misses Stress.

Table 4.9 shows the position of maximum stress value that had been analyzed.The red color show on displacement, stress principal, and estimated local error which mean it is the maximum stress value. Red color means the maximum value of stress that was applied on that area. Each of structural analysis will be given different minimum and maximum value. Moreover, displacement, stress principal, and estimated local error will show different type structure of force.

Table 4.9: Structural Analysis of Crank.

Analysis	Description

Displacement 	Minimum value: 0mm Maximum value: 0.000165138mm
Stress Principal 	Minimum value:-6.82291e+006N/m^2 Maximum value: 4.96242e+006N/m^2

Estimated Local Error 	Minimum value:2.60694e-015J Maximum value: 2.01796e-007J Estimated Precision: 8.2001e-006J Strain Energy: 1.46529e-005J Global estimated error: 46.7584%

4.3.2 Crank Improvement Analysis

After analyzed crank, value of Von Misses stress had been decreased than before while improves it. Size of crank need to be redesign to make more strength and long lifespan while use it. Thickness of crank had been change from 5mm to 7mm and diameter of pin from 8mm to 10mm as shown in Figure 4.10.

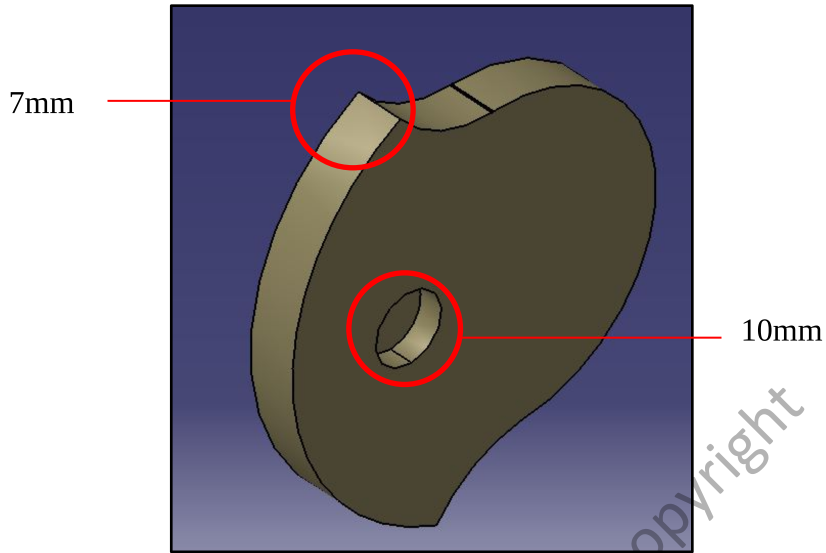


Figure 4.10: Crank.

The result was compared with Von Misses value from before and after. Based on this, thickness effected on result while improve it and the value of Von Misses stress became decreased than before. Table 4.10 shows the different value of Von Misses stress before and after analyzed for both. In addition, the design will be failed if the maximum value of Von Misses stress reaches at critical point or yield point for ductile material or the maximum value of Von Misses stress more than it strength. Figure 4.11 shows the maximum value of Von Misses stress at certain area.

Table 4.10: Von Misses Stress Value.

Before	After
8.47e+006N/m^2	3.86e+006N/m^2

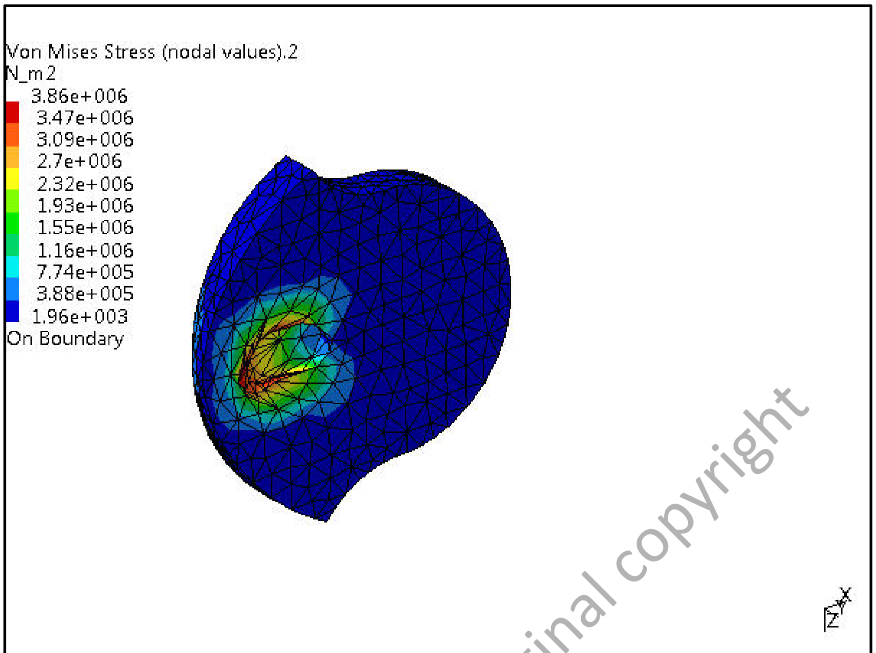


Figure 4.11: Von Misses Stress.

4.3.3 Pin analysis

Other than that, for second analysis is made on two pins with same size and area. There are on middle of crank and other one at middle of gripper. Pin will be analyzed to find strength and material that suitable. Steel had been applied on pinfor analyzed with several type of structure analysis which is deformed meshed, Von Misses stress, displacement, principal stress, and estimated error. Table 4.11 will show material steel that had been analyzed based on application material. Furthermore, the result factor of safety is shownin Table 4.12.

Table 4.11: Material of Pin.

Material	Steel
Young Modulus	2e+011N/m^2
Poisson Ratio	0.266

Density	7860kg/m^3
Thermal Expansion	1.17e-005/Kdeg
Yield Strength	2.5e+008N/m^2

Table 4.12: Factor of Safety.

Von Misses Stress	Yield strength	FOS
6.92e+006N/m^2	2.5e+008N/m^2	36.1

Based on figure 4.12, nodes and element had been applied on deformed mesh analysis. Based on result, the maximum value of Von Misses stress that had been figure is 6.92e+006N/m^2 such on Figure 4.13. The value still lower than yield strength and the design cannot failure.

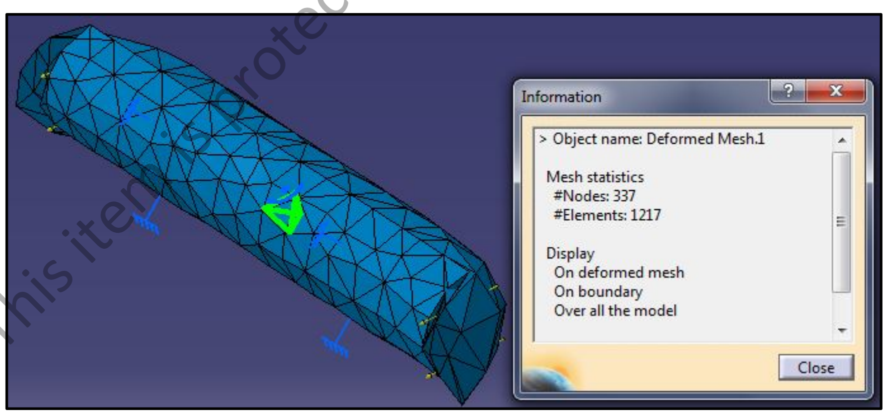


Figure 4.12: Deformed Mesh.

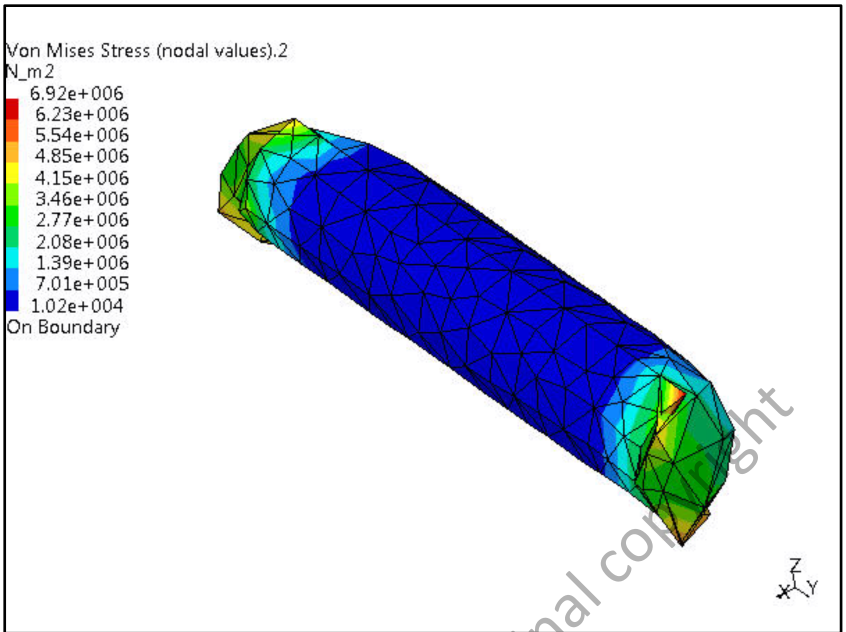
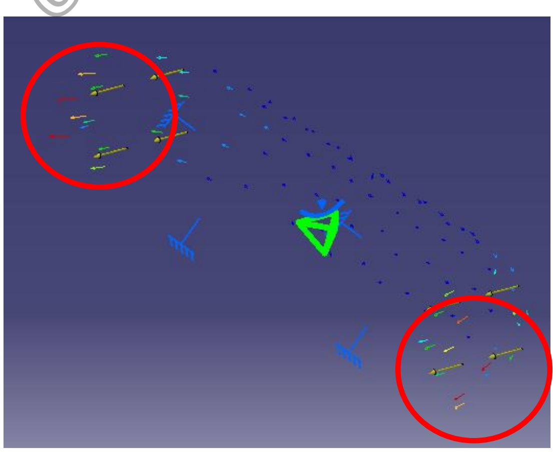
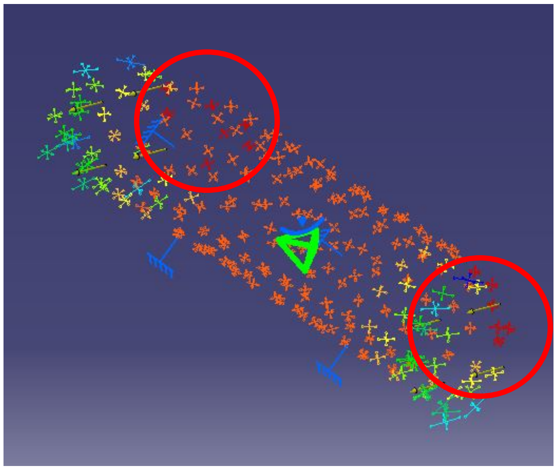
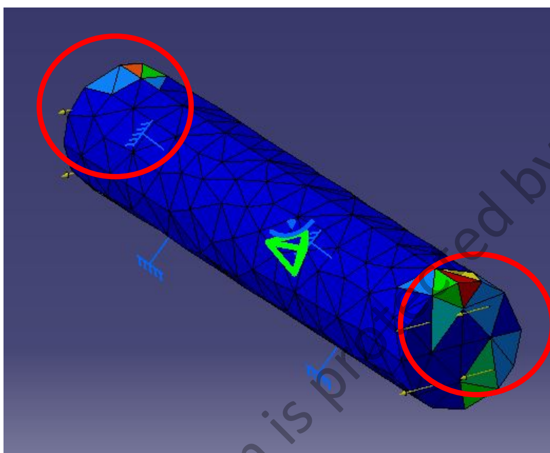


Figure 4.13: Von Misses Stress.

Table 4.13shows the position of maximum stress value that had been analyzed. The maximum stress value shows on red color as before. Each of structural analysis will be given different minimum and maximum value. In addition, displacement, stress principal, and estimated local error will show different type structure of force.

Table 4.13: Structural Analysis of Pin.

Analysis	Description
Displacement 	Minimum value: 0mm Maximum value: 0.000149702mm

Stress Principal 	Minimum value:-7.48136e+006N/m^2 Maximum value: 1.5874e+006N/m^2
Estimated Local Error 	Minimum value:3.94867e-014J Maximum value: 1.60029e-007J Estimated Precision: 4.05558e-006J Strain Energy: 7.58795e-006J Global estimated error: 45.9219 %

4.3.4 Pin Improvement Analysis

Diameter of the pin had been change from 8mm to 10mm to improve the strength of pin and long life span. Based on result, maximum value of Von Misses stress had been decreased when improves the thickness or diameter of pin. Figure 4.14 shows the thickness of pin had been change from before.

10mm

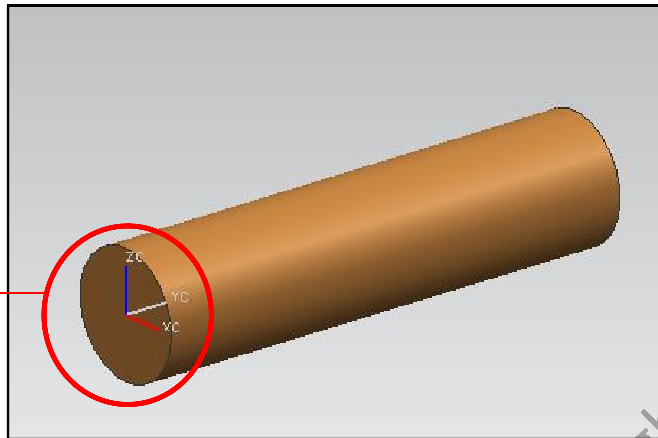


Figure 4.14: Pin.

After improve it, the result will be compared with Von Misses value before. The comparison will show on Table 4.14 and the value became decrease than before after improve it. The thickness will affected on result if improve it where the design will be not fail if maximum value of Von Misses stress not reach at yield point. Figure 4.15 shows critical area on pin that had been analyzed.

Table 4.14: Von Misses Stress Value.

Before	After
6.92e+006N/m^2	3.36e+006N/m^2

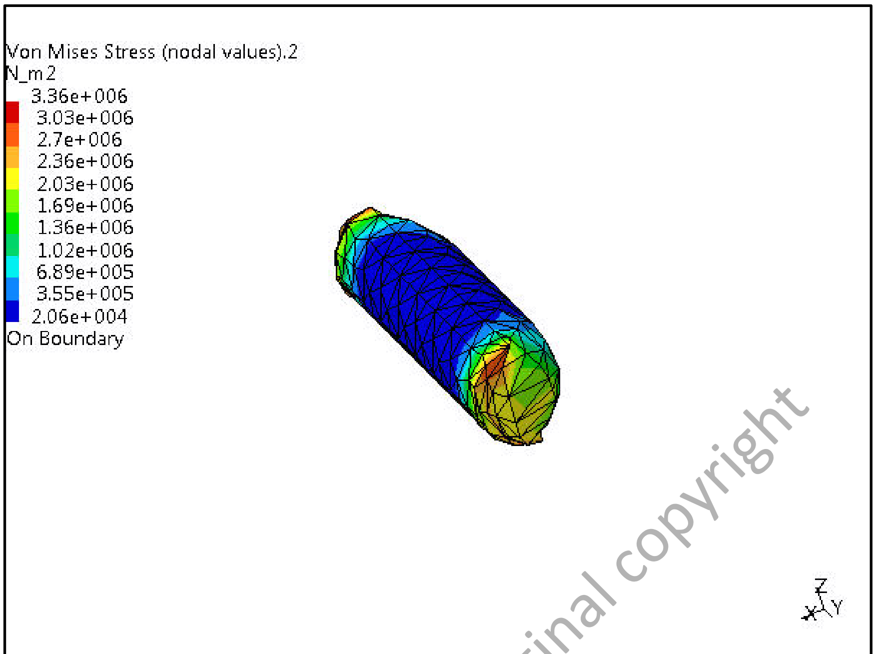


Figure 4.15: Von Misses stress.

4.4 Product Costing

Product costing related to the managing of account or serve management on design product. It will be related to the fixed cost and variable cost. Fixed cost explained about tool or equipment that use on fabrication product where variable cost is item or part of component that were used on designing product. Manufacturing cost defined as total cost for overall to selling the product. Table 4.15shows type of component part design for estimating cost of one product.

Table 4.15: Part Design.

Item	Quantity	Cost Per Unit (RM)	Total Cost (RM)
Slider	2	RM450.00	Rm900
Motor	1	RM231.98	Rm231.98
Bearing	1	RM67.83	RM67.83
Shaft	1	RM15.00	RM15.00
Round plate	2	RM23.97	Rm47.94
Rod steel	1	RM15.00	RM15.00
Steel square tube	1	RM40.00	Rm40.00
Zinc	1	Rm40.00	Rm40.00
Total			RM1357.75

4.5 Summary

Analysis and simulation on design product had been achieved on the result by using CATIA software. Based on analysis, using of steel material cannot failure because the maximum of value Von Misses still not exceed on yield strength of material. The analysis had been figure on crank and pin. For the simulation, bell shape graph had been form based on proven theoretically calculation. The calculation had been identified by force, angular velocity, and mass of part design to form a graph. For overall, fatigue tensile will be form based on simulation and analysis that had been identified.