Computer Aided Product Design

Engine Component Simulation

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1. Introduction

A mechanical system may be defined as a device or number of interconnected devices for which it is possible to define a specific relationship between a disturbance applied to the system and the response of the system to that disturbance.

The term mechanism is sometimes used as freely as the term system but in the study of mechanics its use is generally restricted to apply to devices for which the input and output are both displacements and for which the relationship between the input and output can be expressed irrespective of any forces which may be transmitted by the devices. The latter restriction means that all the members of the mechanism are essentially rigid though they need not be in the purely practical sense.

The goal of this assignment which consists of two sections (hand calculation and computer simulation) is to simulate a simple crankshaft rotation, find out the angular velocity and angular acceleration of the crankshaft in different angles and finally compare the result with some hand calculations in the first part of the assignment.

2. Literature review and analyses

2.1 Classification of mechanisms

Mechanism can be defined as an assemblage of essentially rigid elements or the links which the relative motion between the individual elements is constraints.
The immediate effect of this definition is that the relationship between the motions of the various parts of a mechanism may be studied and specified, without reference to any forces which may be transmitted. This does not mean that the relationship between the motion of a mechanism and the forces applied to it is of small importance, but simply that it can be treated as a separate matter.
It is obvious that motion can only be transmitted through a series of elements if there is contact between successive elements. Additionally, if there is a string of elements then requires a certain minimum number of coordinates to define the configuration of the mechanism.

2.2 Degree of freedom

In mechanics, degree of freedom (DOF) is the set of independent displacements and/or rotations that specify completely the displaced or deformed position and orientation of the body or system. This is a fundamental concept relating to systems of moving bodies in mechanical engineering, aeronautical engineering, robotics, structural engineering, etc.
A particle that moves in three dimensional spaces has three translational displacement components as DOFs, while a rigid body would have at most 6 DOFs including three rotations. Translation is the ability to move without rotating, while rotating is angular motion about some axis.

If DOF is:

- Equal to zero, then system is kinematics.
- One or above zero, then system is dynamic, simulation could be dynamic or static.
- Below zero or a minus number, then this is not a system at all.

2.3 Space mechanisms:

In space a body has six degree of freedom, three of translation and three of rotation. As each pair is formed, one to five degree of freedom is lost and for the whole mechanism we have:

DOF = 6(Parts -1)-constraints-number of motion(s)   (1)

Where motion is equal to 1 DOF and the ground should be deemed as one part. The above equation is a general equation which applies to all mechanical systems composed of rigid elements.

2.4 Motion analysis:

When designing a mechanical system such as an automotive suspension or an aircraft landing gear, we need to understand how various components (pneumatics, hydraulics, electronics, and etc) interact as well as what forces (noise, vibration and harshness) those components generate during operation. Motion simulation is one of the solutions for analyzing the complex behaviors of mechanical assemblies.

Motion analysis allows the engineers test virtual prototypes and optimizes designs for performance, safety and comfort without having to build and test numerous physical prototypes.

NX motion simulation is a family of interactive motion simulation software modules. This program allows us to import geometry from most major CAD systems or to build a solid model of the mechanical system from scratch. A full library of joint and constraints is available for creating articulated mechanisms. Once the virtual prototype is complete, NX checks the model and then runs simultaneous equations for kinematics, static, quasi-static and dynamic simulation. Results are viewable as graph, data plots, reports or colorful animation that can be easily share with others.

2.5 Constraint types:

There are over few different types of constraint are available in NX motion simulation software which the usage of each is depending on the application and requirement of the system .some of the constraints are as follow:

- Revolute
- Hook
- Fixed
- Spherical
- Universal

3. Section one – Mathematical calculation

This part of the assignment is requiring determining the angular acceleration and angular velocity at 60^o, 120^o and180^o degrees of the crankshaft rotation.

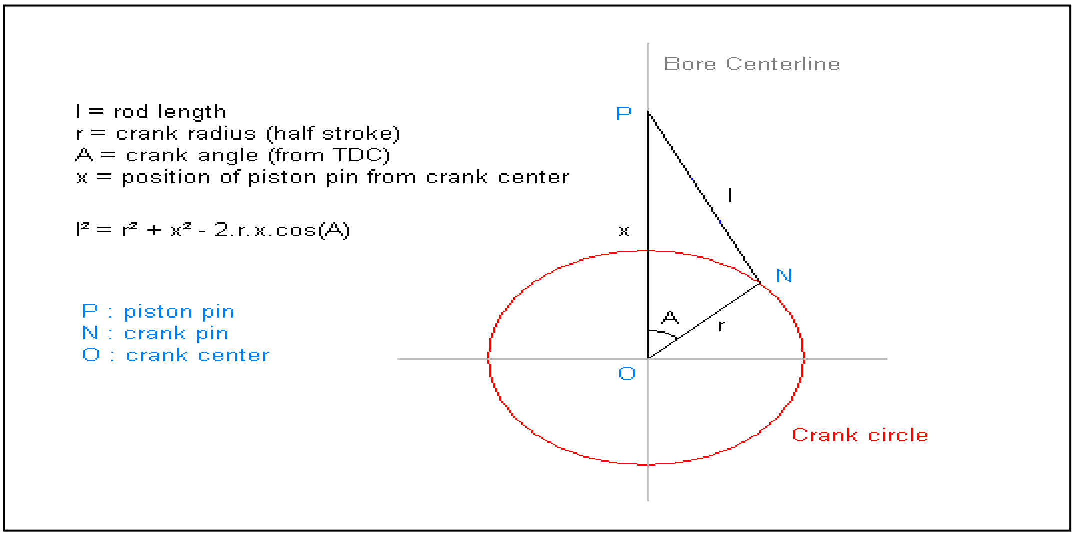

Figure 1, Geometric layout of piston pin, crank pin and crank center

3.1 Definitions

l = rod length (distance between piston pin and crank pin)

r = crank radius (distance between crank pin and crank center, i.e. half stroke)

A = crank angle (from cylinder bore centerline at TDC)

x = piston pin position (upward from crank center along cylinder bore centerline)

v = piston pin velocity (upward from crank center along cylinder bore centerline)

a = piston pin acceleration (upward from crank center along cylinder bore centerline)

ω = crank angular velocity in rad/s

(EPI Inc, 2010)

The given information is as follow:

Assuming the shaft rotating from point" O"

Position of the piston shows with "B"

And connection between the shaft and rod is "A"

OA = 30 mm

AB =120 mm

Angular velocity= 10 rad/s

Angular acceleration = 40 rad/s^2

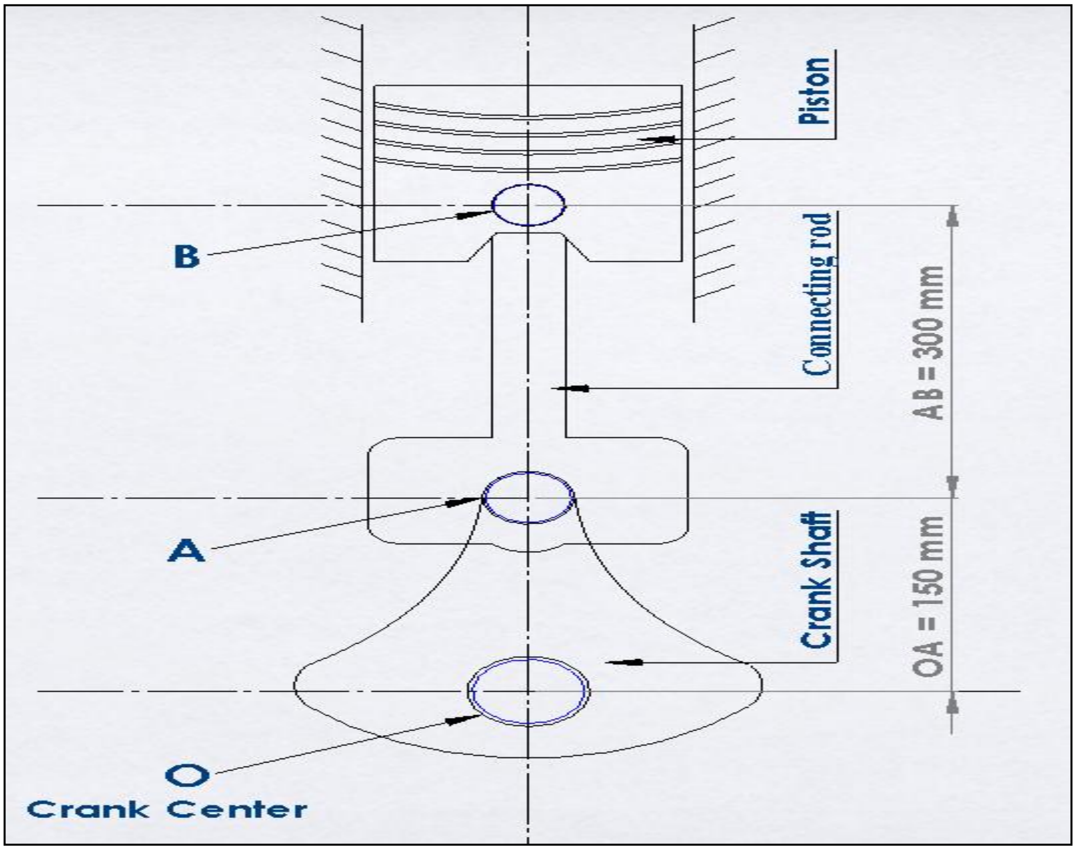

Figure 2: Connection between crank shaft, connecting rod and piston

3.2 Crankshaft rotation at 60°

The model and free body diagram of the crankshaft at 60 degrees is as follow:

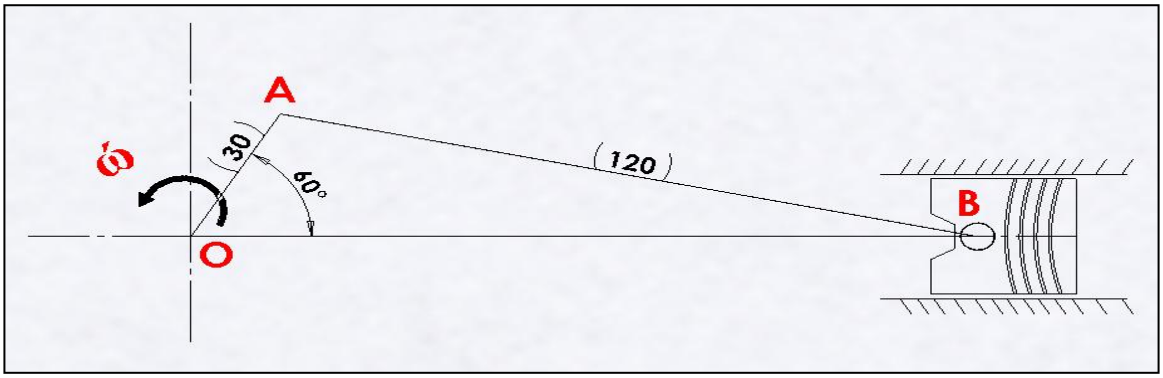

Figure 3: FBD of crankshaft in 60 degrees

V_{OA}= angular velocity x OA

Therefore $V_{OA} = 10 \times 30 = 300$ mm/s

From above data the velocity diagram for (V_{OA}) can be drawn perpendicular to (OA) and also velocity diagram for (V_{AB}) can be drawn perpendicular to (AB). As there is no angular change between the piston (B) and rotation point (o) the velocity diagram of (ob) can be determined by simply connecting point of (V_{ab}).

The following images demonstrate above discussion:

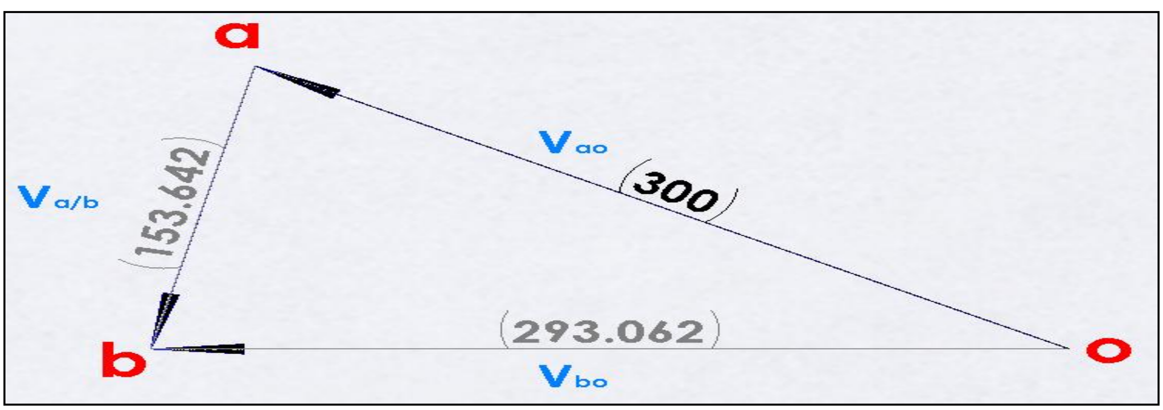

Figure 4: Velocity diagram (60 degrees)

From the velocity diagram we can determine the following result :

V_{ab} =153.642 mm/s
V_{ob} = 293.062 mm/s

Drawing the acceleration diagram starts with the calculation of normal and tangential acceleration of (OA) and (AB) and the angular acceleration of (OB) can be determined from the drawing.

Normal acceleration (OA):

$$\frac{Voa^2}{OA} = \frac{300^2}{30} = 3000 \text{ mm/s}^2$$

Tangential acceleration (OA):

Angular acceleration x OA

$$= 40 \times 30 = 1200 \text{ mm/s}^2$$

Normal acceleration (AB)

$$\frac{Vab^2}{AB} = \frac{153.642^2}{120} = 196.71 \text{ mm/s}^2$$

The acceleration diagram would be as follow:

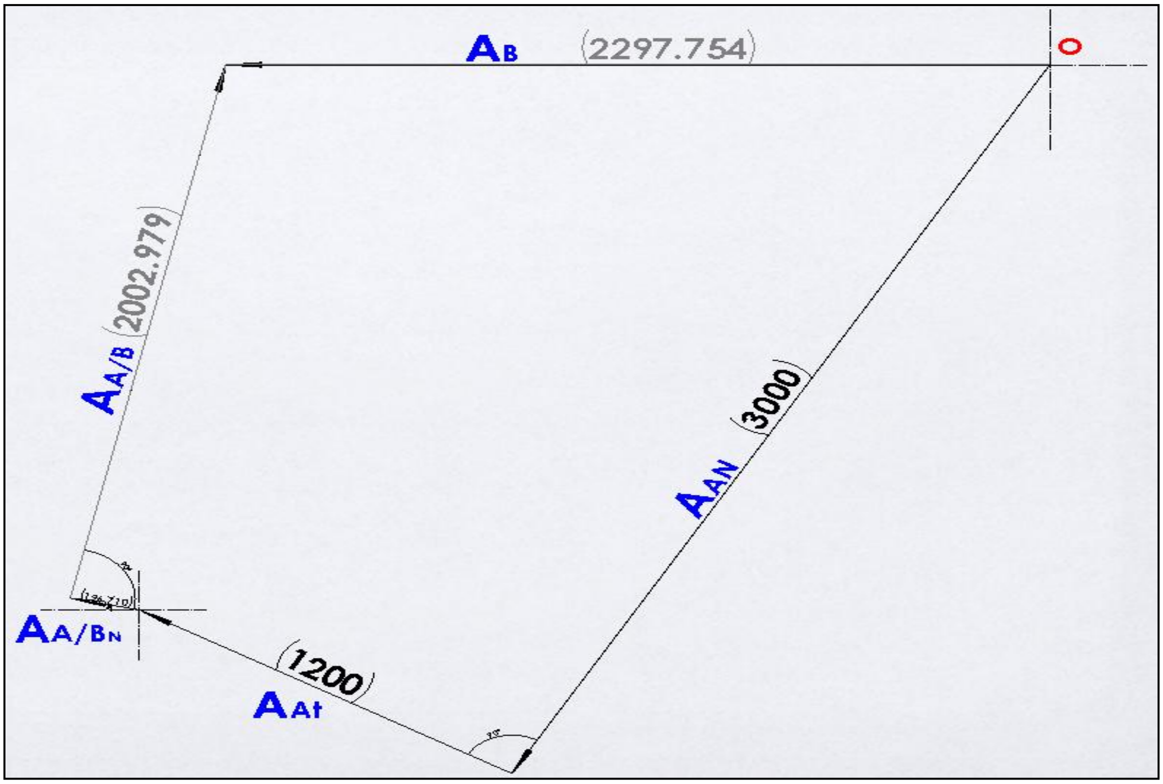

Figure 5: Acceleration diagram (60 degrees)

From the drawing the Tangential acceleration of (AB) is: 2002.979 mm/s^2

Also acceleration of the piston (OB) is: 2297.754 mm/s^2

3.3 Crankshaft rotation at 120^o

The model and free body diagram of the crankshaft at 120 degrees is as follow:

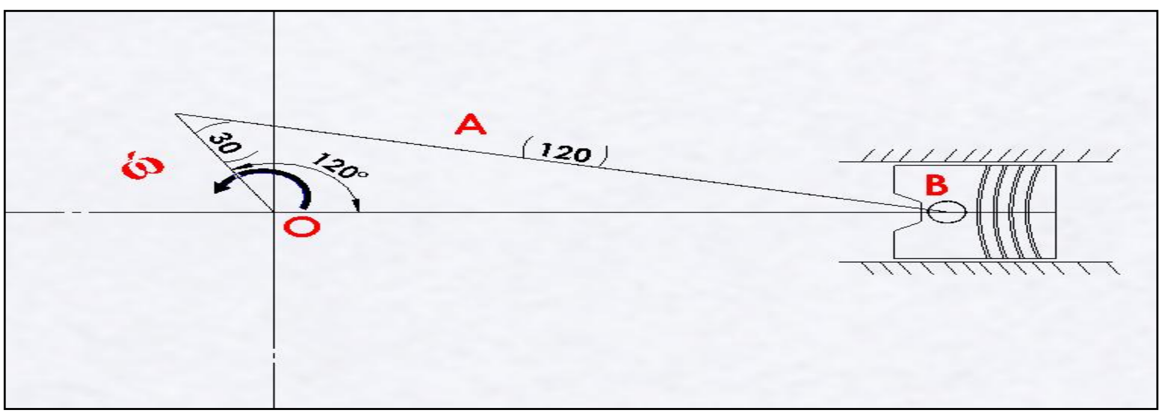

Figure 6: FBD of crankshaft in (120 degrees)

V_{OA}= angular velocity x OA

Therefore V_{OA} = 10 x 30 = 300 mm/s

From above data the velocity diagram for (V_{OA}) can be drawn perpendicular to (OA) and also velocity diagram for (V_{AB}) can be drawn perpendicular to (AB).

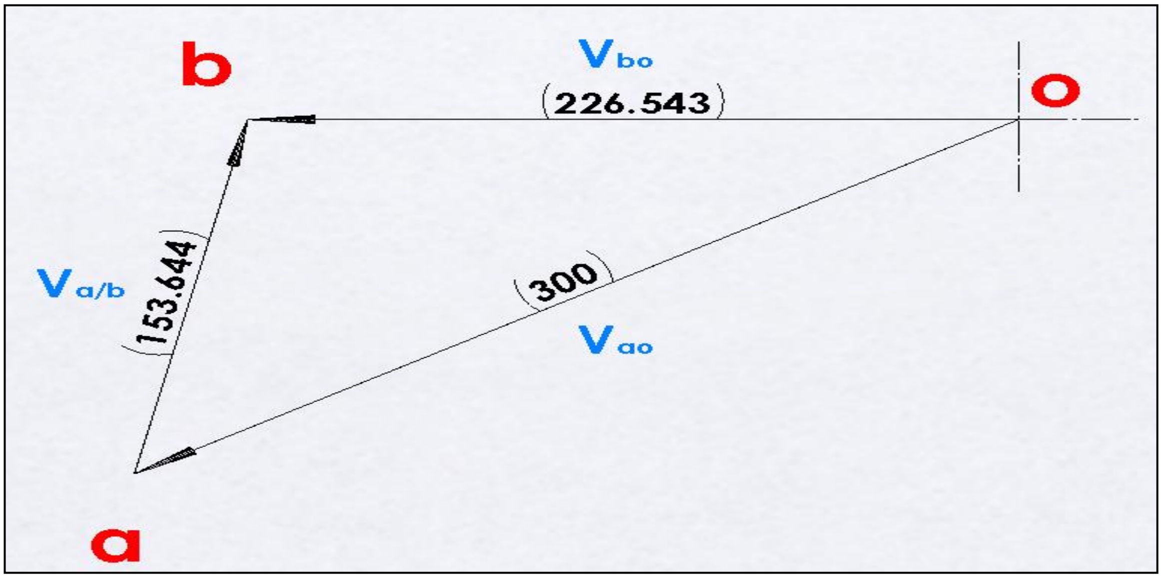

Figure 7: Velocity diagram (120 degrees)

From the velocity diagram could find the following :

V_{ab}= 153.644 mm/s

V_{ob}= 226.543 mm/s

Drawing the acceleration diagram starts with the calculation of normal and tangential acceleration of (OA) and (AB) and the angular acceleration of (OB) can be determined from the drawing.

Normal acceleration (OA):

$$\frac{Voa^2}{OA} = \frac{300^2}{30} = 3000 \text{ mm/s}^2$$

Tangential acceleration (OA):

Angular acceleration x OA

= 40 x 30 = 1200 mm/s^2

Normal acceleration (AB)

$$\frac{Vab^2}{AB} = \frac{153.642^2}{120} = 196.71 \text{ mm/s}^2$$

The acceleration diagram would be as follow:

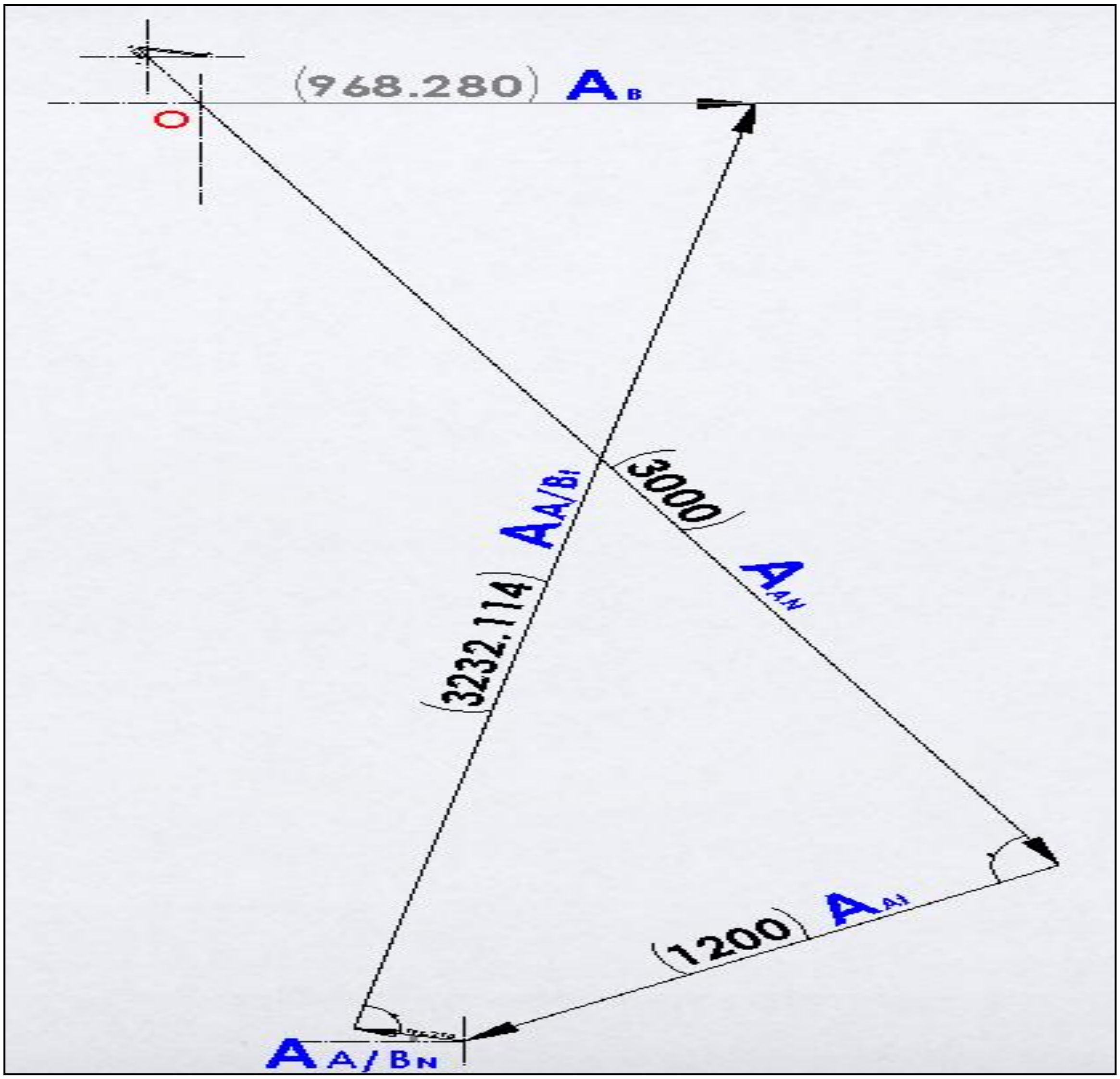

Figure 8: Acceleration diagram (120 degrees)

From the drawing the Tangential acceleration of AB is: 3232.114 mm/s^2

Also acceleration of the piston (OB) is: 968.280 mm/s^2

3. 4 Crankshaft rotation at 180^o

The model and free body diagram of the crankshaft at 180 degrees is as follow:

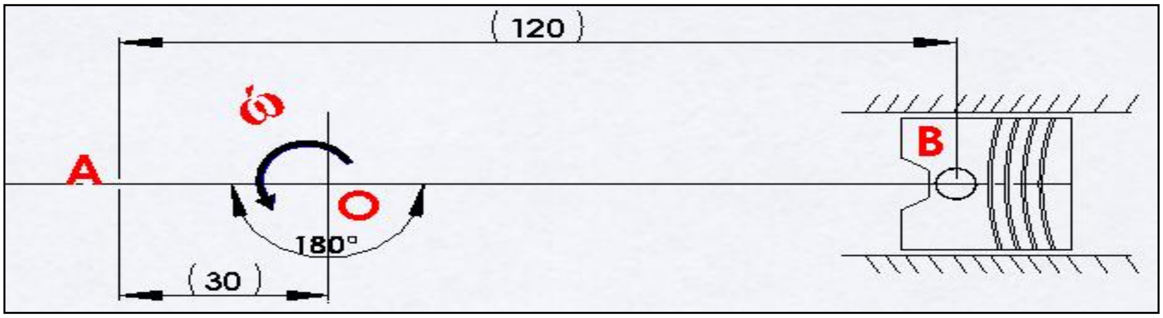

Figure 9: FBD of crankshaft in (180 degrees)

V_{OA}= angular velocity x OA

V_{OA} = 10 x 30 = 300 mm/s

Due to the position of (A) and the piston (B) the velocity of (AB) is same as the velocity of (OA) but in the different direction, the following velocity diagram demonstrates this discussion.

V_{ab} = 300 mm/s

V_{ob} = -V_{ab} = -300

V_B = 0

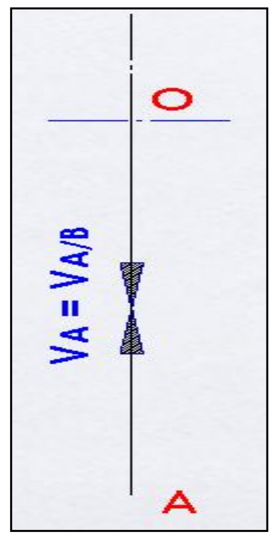

Figure 10: velocity diagram (180 degrees)

Drawing the acceleration diagram starts with the calculation of normal and tangential acceleration of (OA) and (AB) and the angular acceleration of (OB) can be determined from the diagram.

Normal acceleration (OA):

$$\frac{Voa^2}{OA} = \frac{300^2}{30} = 3000 \text{ mm/s}^2$$

Tangential acceleration (OA):

Angular acceleration x OA

$= 40 \times 30 = 1200$ mm/s^2

Normal acceleration (AB)

$$\frac{Vab^2}{AB} = \frac{-300^2}{120} = -750 \text{ mm/s}^2$$

The acceleration diagram would be as follow:

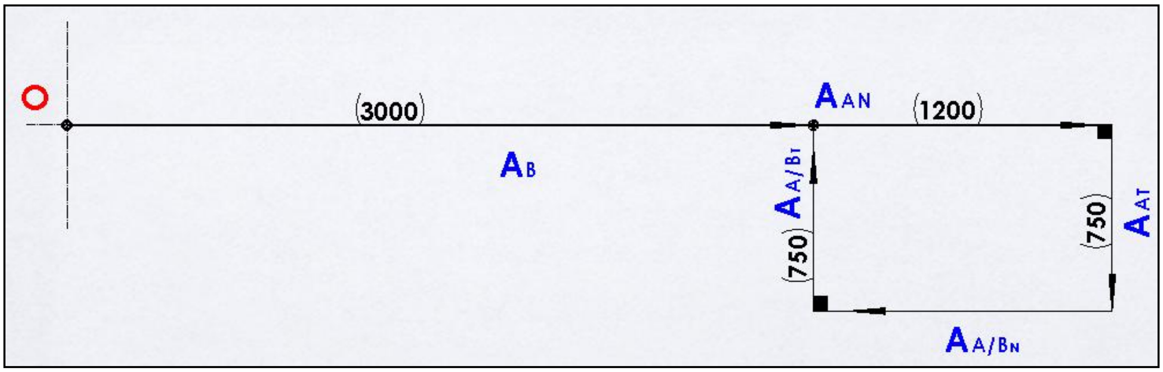

Figure 11: Acceleration diagram (180 degrees)

From the above diagram the angular acceleration of OB is: 750 mm/s^2

4. Section two (computer Simulation)

Below figure indicates the single piston which was assembled in NX 6 software with different constraints for the motion simulation of angular velocity and angular acceleration.

1. Wrist pin
2. Crank and Crank throw

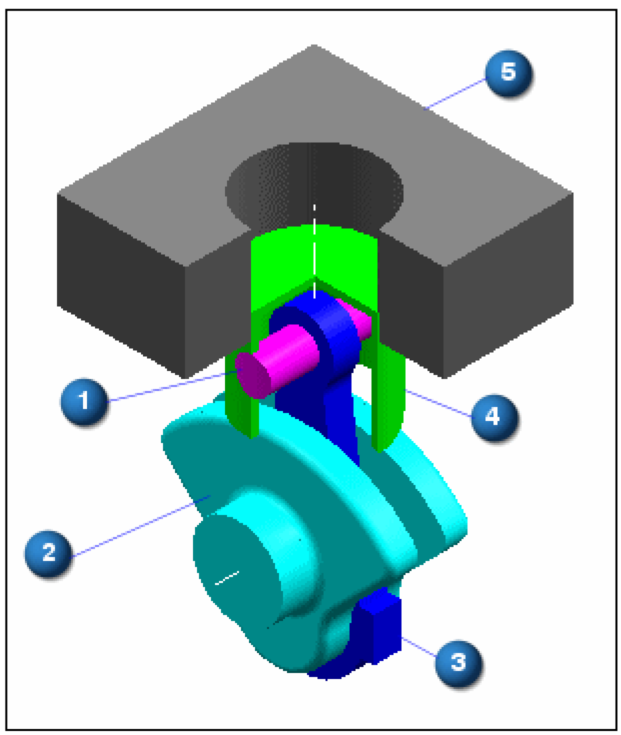

Figure 12: NX 6 tutorial/training

3. Connecting rod
4. Piston
5. Block reference

There are different types of constraints that were used in this simulation, each of these constraints were used for a specific reason which depended on the required degree of freedom and type of motion.

Types of joints used in this simulation are as follow:

- ***revolute joint (one degree of freedom)***

A revolute used on one end of the crankshaft which is the same position of the motion as this joint allows only one degree of freedom, therefore it only allows the shaft to move within the direction of motion. This joint is connecting the crankshaft to the rotation point (ground).

- ***Spherical Joint (three degrees of freedom)***

A spherical joint with three degrees of freedom was used to connect the crank shaft to the connecting rod.

- ***Slider Joint(one degree of freedom)***

A slider joint with one degree of freedom was used to connect the piston head to the block. This allows the piston to move only in the X direction.

- ***Universal Joint (one degree of freedom)***

A universal joint with one degree of freedom was used to connect the piston pin to the connecting rod.

4.1 Kinematic simulation

The rotational speed was set as 95.45 rpm.

Before starting the kinematic simulation the angular velocity of 10 rad/s has been converted to 573 degree/second which was set as initial velocity, also the initial displacement was set to 180 simply by editing the revolute joint.

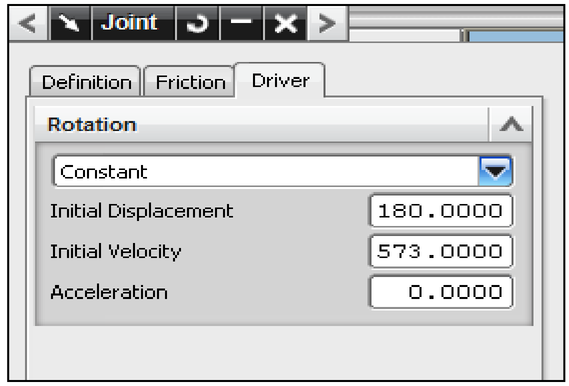

Figure 13

4.2 Result of Kinematic simulation

Below graphs indicate the angular velocity and angular acceleration for the kinematic simulation.

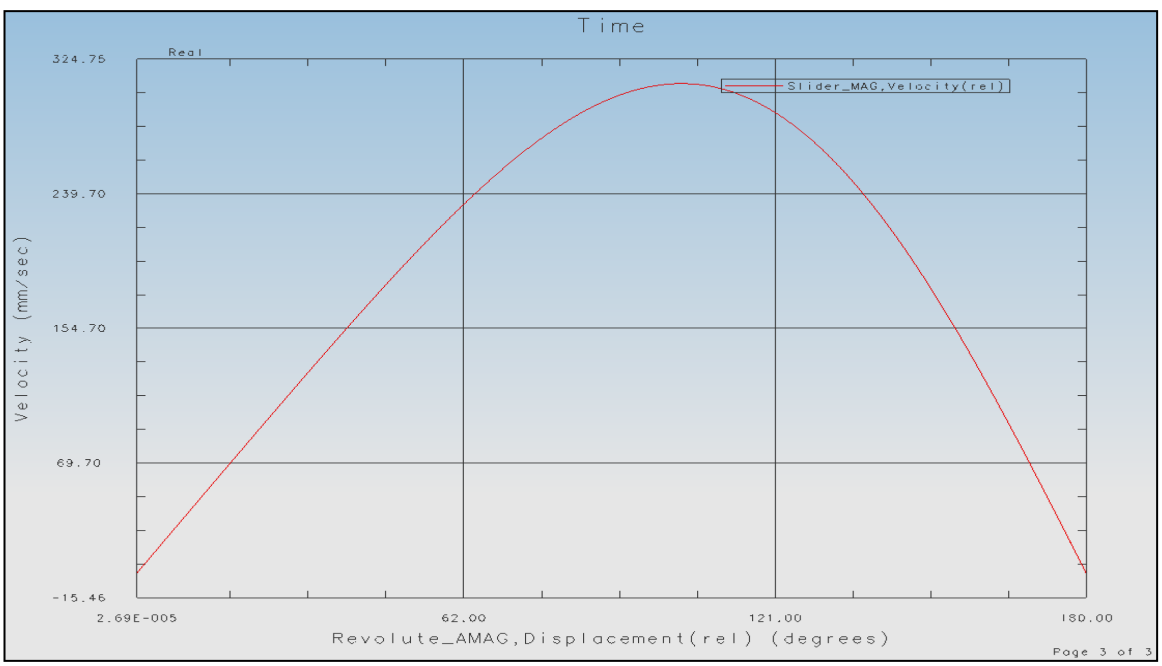

Figure 14: Velocity of piston (60,120,180 degrees)

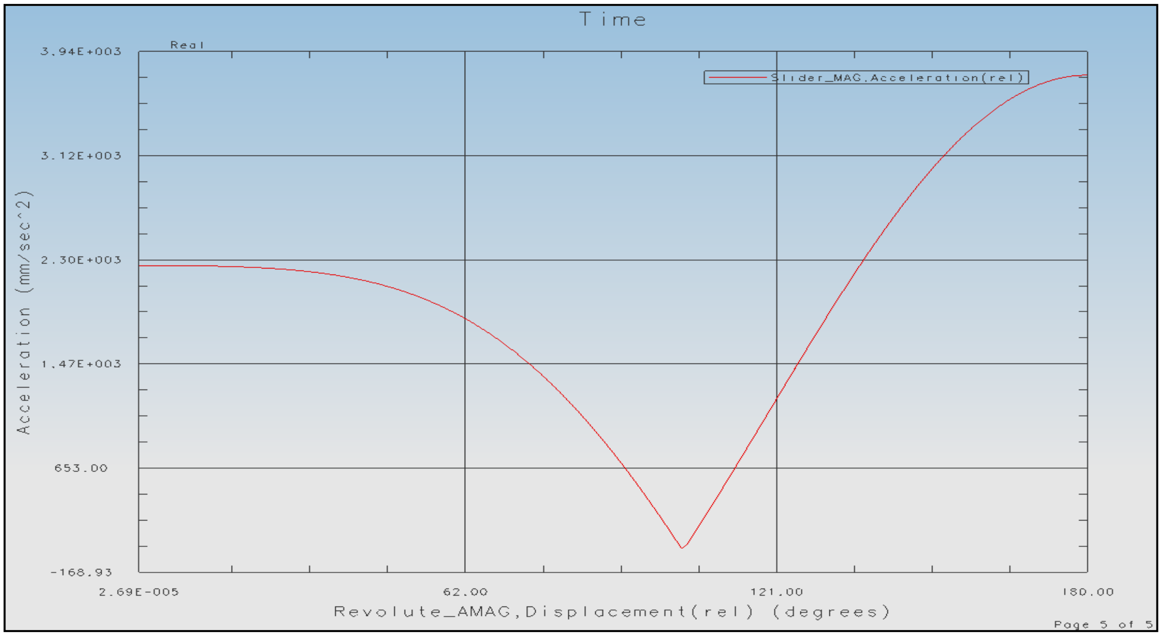

Figure 15: Velocity of piston (60,120,180 degrees)

4.3 Dynamic simulation

Same as in kinematic simulation, for the dynamic simulation angular velocity of 40 rad/s^2 has been converted to 2291.8 degree/second which was set as acceleration. Also the initial displacement was set to 180 simply by editing the revolute joint/driver.

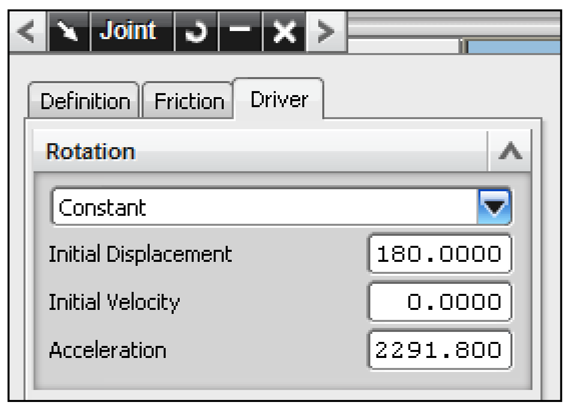

Figure 16

4.4 Result of Dynamic simulation

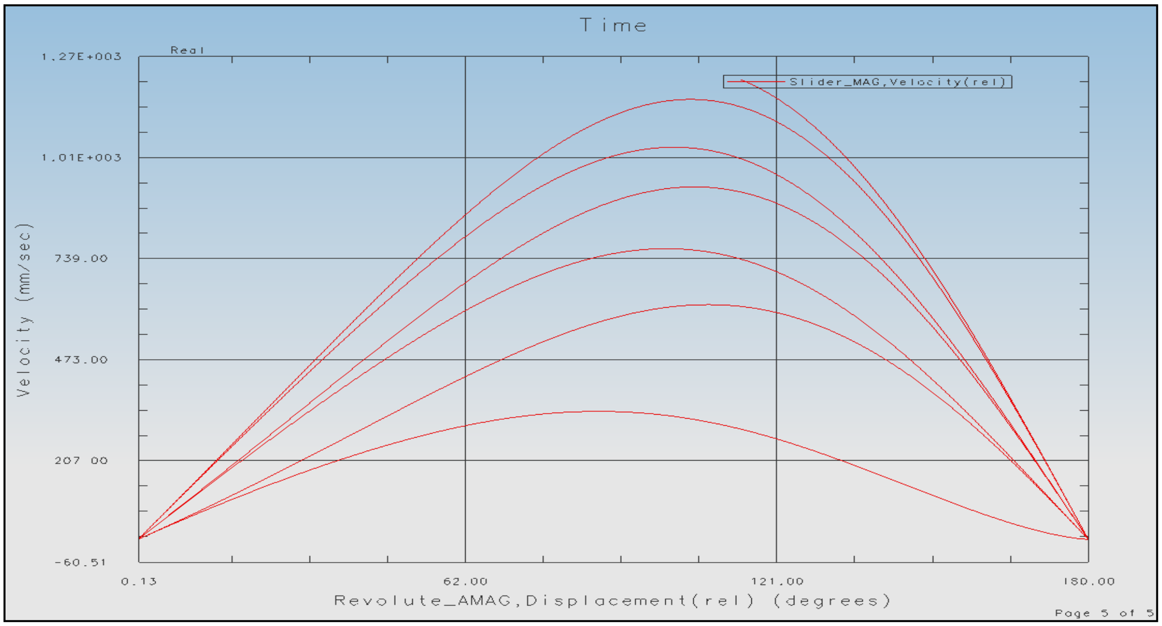

Figure 17: Velocity of piston (60,120,180 degrees)

Below graphs indicates angular velocity and acceleration for the dynamic motion simulation.

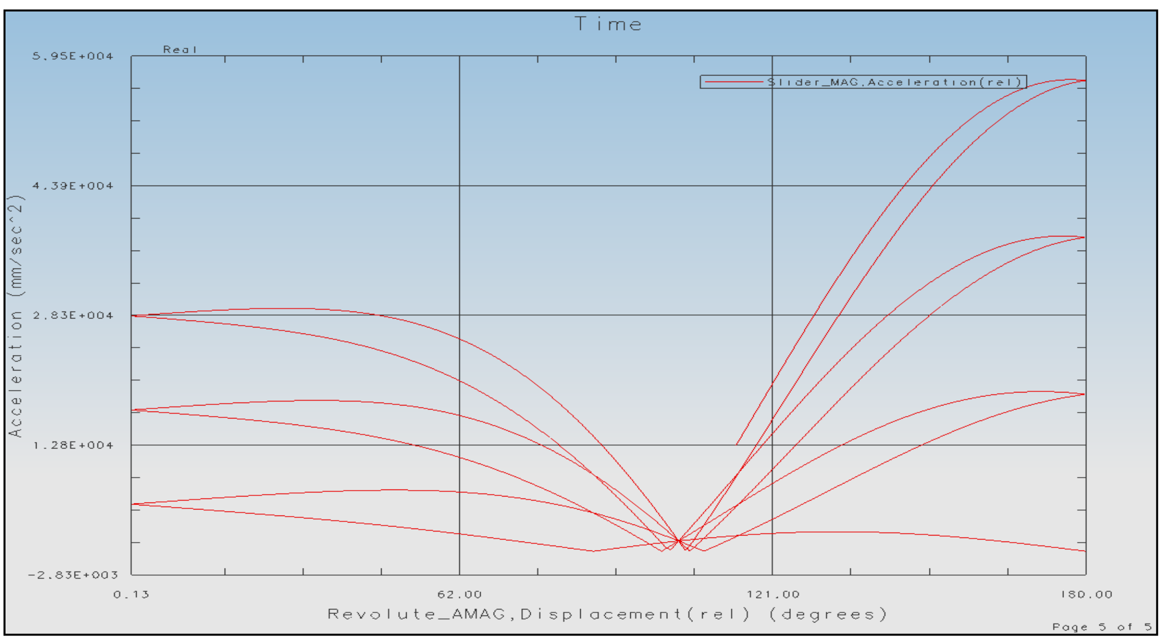

Figure 18: Acceleration of piston (60,120,180 degrees)

4.5 Comparison of results:

Result comparison			
	Hand calculation	Kinetic simulation	Dynamic simulation
Velocity of piston (60 degrees)	293.062	293.094	0.541
Velocity of piston (120 degrees)	226.543	226.559	4.313
Velocity of piston (180 degrees)	0	0	0
Acceleration of piston (60 degrees)	2297.754	1125.631	61.857
Acceleration of piston (120 degrees)	968.280	1874.50	246.659
Acceleration of piston (180 degrees)	750	2250.17	549.955
Velocity units (mm/s) --------- Acceleration units (mm/s^2)			

Table 1

5. Discussion

According to the hand calculation and computer simulation result the velocity of the piston from the hand calculation match with computer modeling. As it is obvious from the result regarding the acceleration calculation the hand calculation did not match with computer simulation. The reason for this is the separation of tangential and normal acceleration in the hand calculation. The output value from the software is the final value of the acceleration which means adding or subtracting the tangential acceleration with normal acceleration.

6. Conclusion

Mechanical mechanisms have lots of applications in industries. In this assignment a crankshaft and piston mechanism were designed and worked well. All the vector diagrams for angular velocity and acceleration were drawn in Solidworks 2009. Once all the hand calculations were completed for the angles of 60, 120 and 180 degrees, the motion simulation was used for the kinematic and dynamic simulations. Results of simulations, including the graphs, were compared with hand calculation. This assignment was a very useful learning material for dynamic simulation and analysis. It was beneficial in terms of having a better understanding of multi-body dynamics and systems. One of the tools used in the process was NX motion simulation software which gave a great advantage for understanding how the motion simulation works.

7. References

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