Design of SCARA Robot with Vacuum Gripper

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Major Project Report

Submitted in partial fulfillment of the requirements

for The Degree of

Master of Technology in Mechanical Engineering (CIM)

By

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (CIM) at Nirma University and has not been submitted elsewhere for a degree / diploma.

2. Due acknowledgement has been made in the text to all other material used.

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I, Pratik R Vyas, Roll. No. 10MMCM10, give undertaking that the Major Project entitled “Design of SCARA Robot with Vacuum Gripper” submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (CIM) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "Design of SCARA Robot with Vacuum Gripper" submitted by Mr Pratik R Vyas (10MMCM10), Towards the partial fulfillment of the requirements for the Degree of Master of Technology in Mechanical Engineering (CIM) of Institute of Technology, Nirma University, Ahmadabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abstract

The use of robots have become very essential in the manufacturing industries, it can accomplish repetitive and complex tasks quiet easily and also allows automation of the same. With the technological advancement, robotics has become more precise and accurate. The purpose of this project is to study the use of a three link robotic arm (SCARA), with various actuators, controllers, and drivers. The arm is designed following the physical principles governing static and dynamic requirements of motion. Component design and selection is made to meet performance and physical properties. Fixture for vacuum gripper is designed to lift the glass object. Analysis of the robotic arm is carried out using ANSYS.

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Nomenclature

M_t = Torque of motor (N-mm)

$(P_1)_t$ = Tangential load on the worm wheel (N)

$(P_1)_a$= Axial force on worm gear (N)

Z_1 = No. of starts on worm gear

Z_2 = No. of teeth on gear

a = Center distance of the gears (mm)

d_1= Diameter of the worm gear (mm)

d_2= Diameter of the worm wheel (mm)

d_3=length of worm (mm)

d_4=length of vacuum attachment (mm)

i = Gear ratio

m = Module of the gears

q = Diametrical quotient

α= Pressure Angel for Gear

γ=Helix Angel for worm gear

E= Young's Modulus

ν = Poisson's Ratio

Chapter 1

Introduction

1.1 Introduction

In today's world, the need for speed and accuracy in production has become more and more important. Especially, in industry, the productivity and having good quality is very important. Therefore, computer controlled machines have been used for years. More and more of the loading/unloading tasks have been executed by the robots in recent years. In other words, industrial robots are beginning to revolutionism the industry. Robots are now useful in a wide variety of industrial applications, such as material handling, painting, welding, etc. In most of these applications, the operation of the robots are cheaper, faster and less dangerous. Changes of social and living environments require supporting works and lives. Mechanical,Electronics And Informatics are key technologies to achieve the support system.A robot, which is made by combining these technologies has to meet four basic condition to see in our lives are:compactness, lightweight, safety and cost effective. However, it is difficult to satisfy all the conditions. There is lot of studies done on working of robot but still not satisfied all these conditions.

1.2 Project Statement

The project is entitled as "Design of SCARA Robot with Vacuum Gripper". The SCARA robot is to be designed for an application of assembly. The purpose is to assemble a glass panel.

1.3 Objective

The objective of the project are:

1. To conceptualize the model for required application using PRO/E software.

2. To design the various components of the conceptualized model

3. To analyse the structural components using ANSYS.

1.4 What is Robot?

The term robot comes from Czech and means "forced labour". The term in its present interpretation was invented by the Czech writer Karel Capek in his satirical play R.U.R. "Rossum's Universal Robots". He depicted robots as machines, which resembled people but worked tirelessly .Robot is defined in dictionaries as "an automatic device that performs functions ordinarily ascribed to human beings". This definition is true but not sufficient. A robot can have both an automation and intelligence. It has automation that it is a machine that can control, in some degree or other, its own actions. It is a general manipulator in the sense that it is a machine built with the capacity to do many different things, perform many different intelligent actions. Robotics is a field of interest that combines theory and application, ideas with actual practical machine.

More explanatory definition for the industrial robot is given by the Robot Institute of America, "A robot is a reprogrammable multi-functional manipulator designed to move material, parts, tools or specialized devices, through variable programmed motions for the performance of a variety of tasks." An industrial robot is a general- purpose manipulator consisting of several rigid links connected in series by revolute or prismatic joints. One end of the chain is attached to a supporting base, while the other end is free and attached with a tool to manipulate objects or perform assembly tasks. The motion of the joints result in the relative motion of the links.

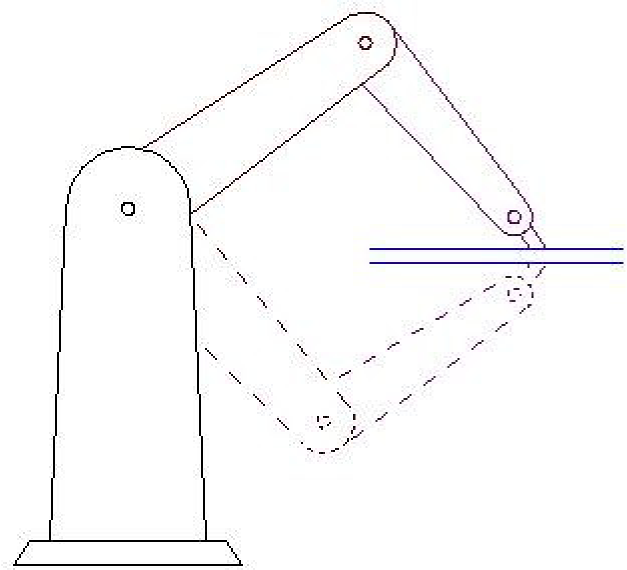

Figure 1.1: Welding Robot

The motion of the end-effectors is generated by controlling the position and velocity of the robot's axes of motion. Basically the robot needs six axes of motion (or degrees of freedom) to reach an arbitrary point with a specic orientation in space. A different orientation might completely change the position of the robot arm. For example, to place a weld on the top side of the beam below requires completely different orientation from that required to place a weld at almost the same point but on the bottom side of the beam.

1.5 Thesis Organization

The chapters are organized as follows:

Chapter 1: The first chapter has introductory information regarding robotics. Also includes Aim of the project, Problem identification and objectives of the project.

Chapter 2 : This chapter discusses literature reviews on SCARA robot. It also includes literature review of types of arm configuration and different parameters involved.

Chapter 3: This chapter involves the kinematic analysis of the SCARA robot arm.

Chapter 4: This chapter includes the design calculation of the various components involved in the assembly.

Chapter 5: Chapter discusses the results of analysis of the SCARA robot arm using ANSYS.

Chapter 6: This chapter includes the design of vacuum cup which has is used for lifting the glass.

Chapter 7: This chapter involves the summary and the future scope of the project.

Chapter 2

Literature Review of Robotic System

Robotics is a special engineering science which deals with designing, modeling, controlling and robots' utilization. Nowadays robots accompany people in everyday life and take over their daily routine procedures. The range of robots' utilization is very wide, from toys through office and industrial robots finally to very sophisticated ones needed for space exploration. A large family of manufacturing equipment among the variety, which exists, is the one which supplies the motion required by a manufacturing process, such as: arc-welding, spray painting, assembly, cutting, polishing, milling, drilling etc. Of this class of equipment, an increasingly popular type is the industrial robot. Different manipulator configurations are available as rectangular, cylindrical, spherical, revolute and horizontal jointed. A horizontal revolute configuration robot, selective compliance articulated robot arm (SCARA) has four degrees of freedom in which two or three horizontal servo controlled joints are shoulder, elbow and wrist. Last. SCARA designed at Japan, is generally suited for small parts insertion tasks for assembly lines like electronic component insertion. Although the final aim is real robotics, it is often very useful to perform simulations prior to investigations with real robots. This is because simulations are easier to setup, less expensive, faster and more convenient to use. Building up new robot models and setting up experiments only takes a few hours. A simulated robotics setup is less expensive than real robots and real world setups, thus allowing a better design exploration. Simulation often runs faster than real robots while all the parameters are easily displayed on screen.

2.1 Types Of Robot

Typically, robots are used to perform jobs that are dicult, hazardous or monotonous for humans. They lift heavy objects, paint, weld, handle chemicals, and perform as- sembly work for days at a time without suering from fatigue. Robots are dened by the nature of their movement. This section describes the following classications of robots:

- Cartesian
- Cylindrical
- Polar
- Articulated
- SCARA

2.1.1 Cartesian Robot

Cartesian, or gantry, robots are dened by movement limited by three prismatic joints . The workspace is denied by a rectangle resulting from the coincident axes.

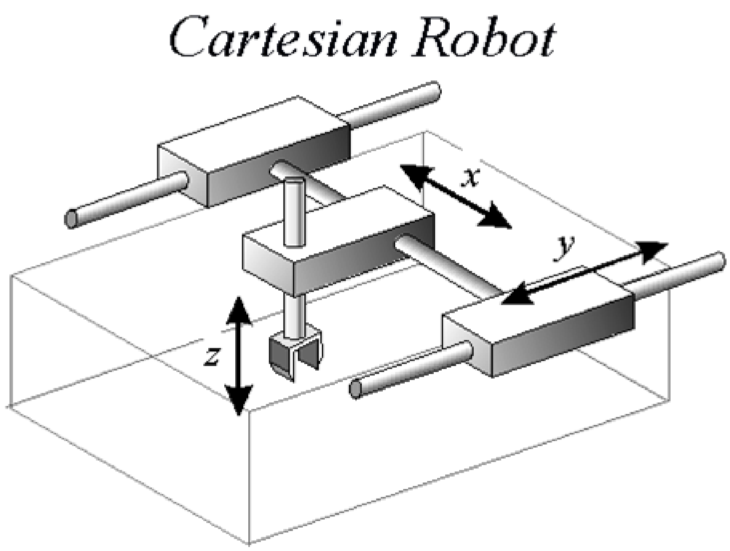

Figure 2.1: Cartesian Robot Movement

2.1.2 Cylindrical Robot

If one of the Cartesian robot's prismatic joints is exchanged for a revolute joint, a cylindrical robot is formed. A cylindrical robot's movement is dened by a cylindrical coordinate system. Figure below demonstrates this unit's thick shelled cylindrical workspace.

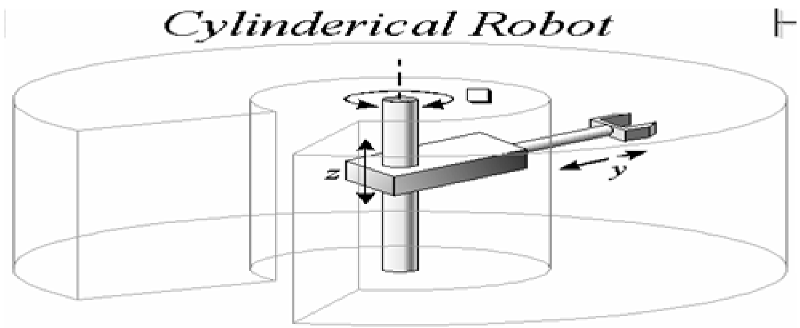

Figure 2.2: Cylindrical Robot Movement

2.1.3 Polar Robot

Trading two prismatic joints for revolute joints forms a spherical robot. Spherical, or polar, robots are devices whose axes form a polar coordinate system. This robot arm works within a thick shelled spherical workspace, shown in (figure)

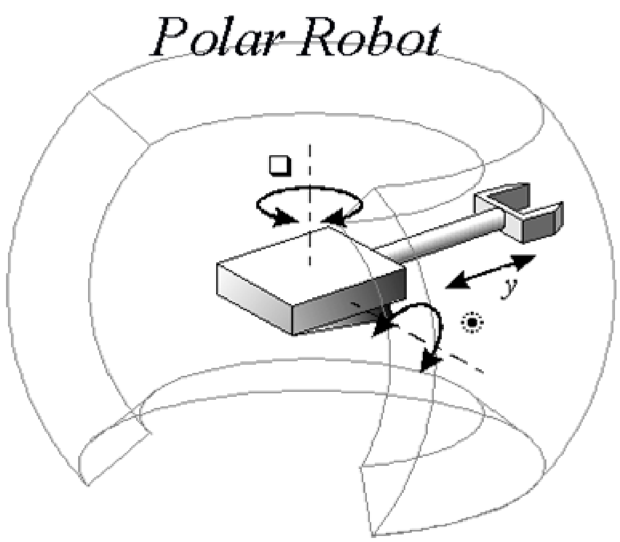

Figure 2.3: Spherical Robot Movement

2.1.4 Articulated Robot

Substituting a revolute joint for the nal prismatic joint turns the arm into an articulated arm. Any robot whose arm has at least three rotary joints is considered to be an articulated robot . The workspace is a complex set of intersecting spheres.

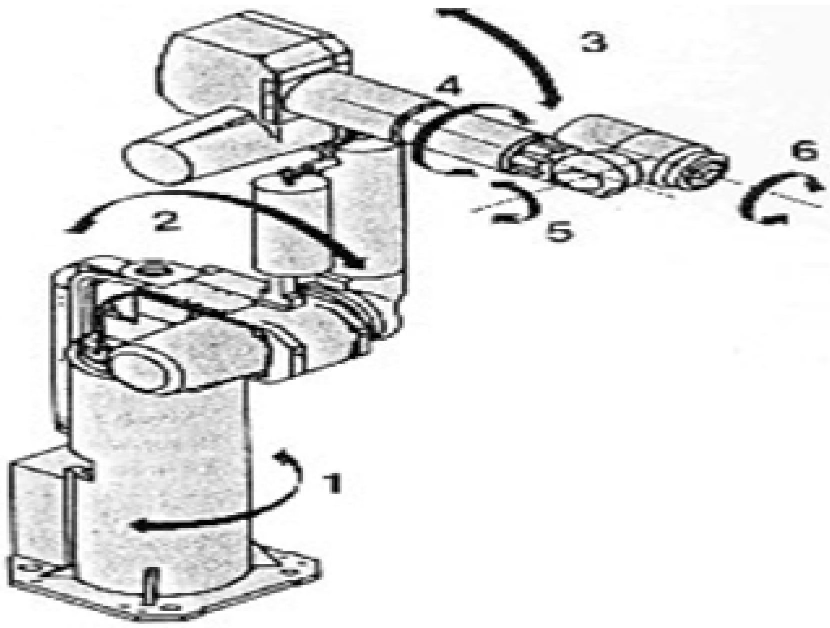

Figure 2.4: Articulated Robot Motion

2.1.5 SCARA

SCARA (which stands for Selectively Compliant Articulated Robot Arm) is a specialty robot which has two parallel rotary joints to provide compliance in a plane. A third prismatic joint allows the arm to translate vertically. SCARA robots dier from articulated robots in that its workspace consists of two concentric cylinders, demonstrated in gure 6. This robot arm is specialized for assembly operations that involve placing parts on top of one another. The gripper can raise, lower, and rotate to orient the component to be assembled.

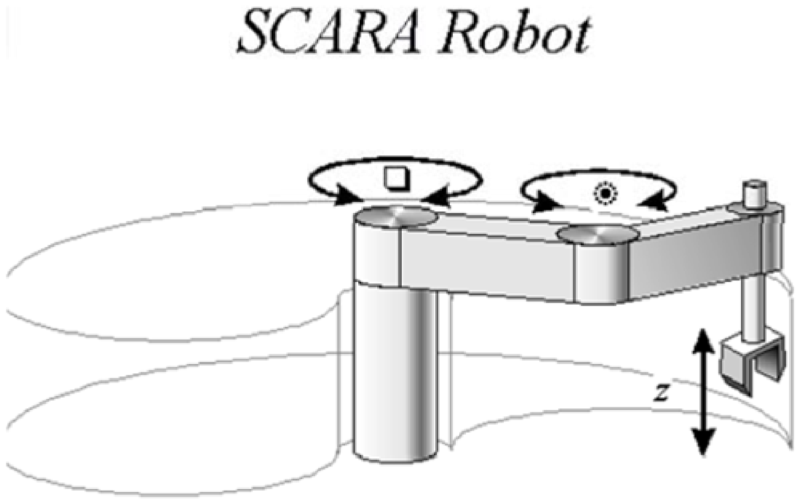

Figure 2.5: SCARA Robot Motion

2.2 Robotic System Components

Robotic system components can be grouped into one of three categories:

- Actuator - The mechanism that provides the necessary forces to move the me- chanical structure.
- Controller circuit - Supplies the actuators with the input required to achieve the desired position, force, speed, etc.
- Mechanical structure - This comprises all of the linkages and joints capable of movement.

2.2.1 Actuator Types

The proper selection of actuator will dictate how eective a robot is in performing a specific task. Actuators can be either mechanical or electrical and have varying strengths and weaknesses as demonstrated in table 1. The basic actuators used for controlling motion include:

- Air Motors
- Hydraulic and pneumatic actuator
- Stepper Motors

- Servomotors

Actuator Type	Strengths	Weakness
Air Motor	Low Cost	Audible compressor noise
	Easily Maintained	Inefficient system
	Simple to operate	Difficult to regulate speed
Hydraulic Motor	High loads possible	Slow system
	Simple to operate	Inefficient system
		High maintenance requirements
Stepper Motor	Simple control	Cannot vary load
	Constant load	Can lose steps
	Accurate position	Resonance problems
Servo Motor	High performance	Higher cost system
	Small motor size	Performance limited by controls
	Can operate at high speeds	Speed limited by electronics

Table 2.1: Actuator Comparison Chart

The most commonly used actuators in robotics are electric motors, be it either a stepper or servo type. Stepper motors perform best in open loop systems and servomotors are best suited for closed loop applications. These two specic actuators will be discussed in some detail along with open and closed loop systems.

2.2.2 Stepper Motor

Stepper motors, or steppers, are mechanically simple when compared to other motors in that there are no internal brushes or contacts. Armature rotation is achieved by switching the magnetic field sequentially.

Types of Steppers

Steppers can be grouped into three categories that differ in terms of internal construction based on the use of permanent magnets and/or iron rotors with laminated steel stators:

- Permanent magnet
- Variable reluctance
- Hybrid

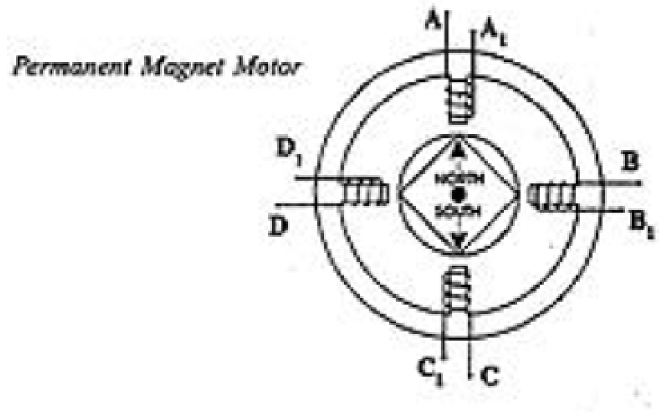

Figure 2.6: Permanent Magnet Motor

2.2.3 Servomotor

The term "servomotor" does not refer to one single kind of motor. Instead it refers any type of motor that receives a command signal from a controller. In this same respect, any closed loop system can be referred to as a servo system. Figure diagrams the operation of a typical servo system.

This exibility allows for several suitable types of electric motors to be used in servo systems. These electric motors include:

- Permanent Magnet DC Motor
- Brush less DC Motor
- Induction AC Motor

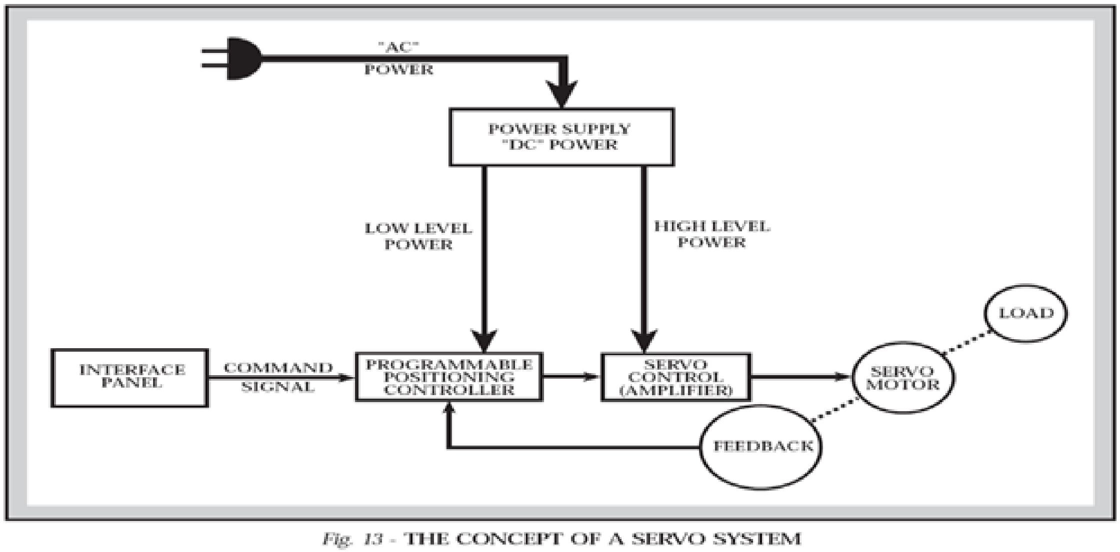

Figure 2.7: Example of a Servo System

2.2.4 Permanent Magnet DC Motor

The DC permanent magnet motor is based on a similar concept to permanent magnet stepper motors, but it is the mechanical inverse. Whereas the PM stepper relies on stationary coils and a movable magnet attached to the rotor, a DC PM motor has a stationary electromagnet. The coil is wrapped around the rotor and is coupled via brushes to a commutator, which can switch the direction of the current and cause the motor to 22 rotate clockwise or counter clockwise (gure 2.8). Since the motor shaft will rotate freely while an electric current is present, an encoder must be used to provide feedback to a controller.

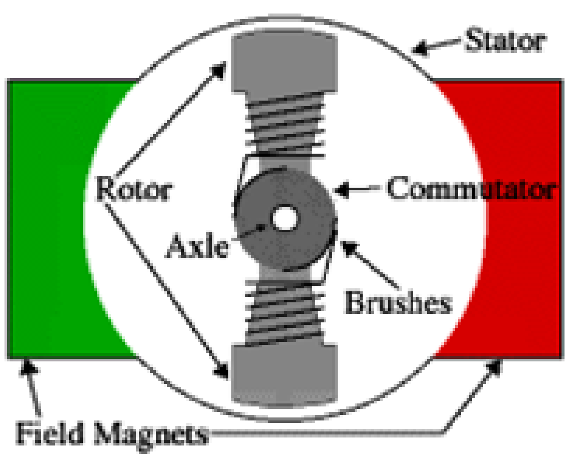

Figure 2.8: Permanent Magnet DC Motor

DC PM Motors are common and can be very cost effective, however many of the motor's problems are related to the interface between the brushes and commutator. Contact between the two components causes friction and can be disrupted at higher speeds. A brushless DC motor addresses these issues.

2.2.5 Brushless DC Motor

A brushless DC motor replaces the commutator and brushes with an electronic con- troller. This controller maintains the proper current in the stationary coils. Figure 9 shows a basic diagram of a brushless DC motor.

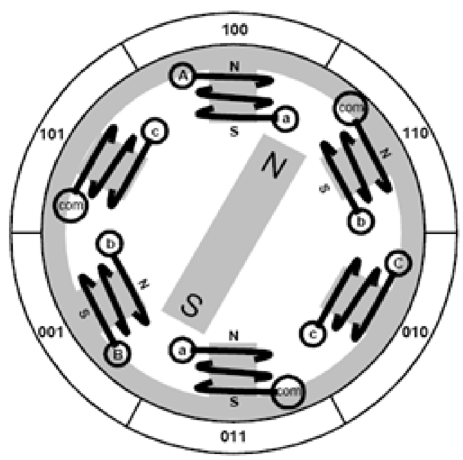

Figure 2.9: Brush less DC Motor

It should be noted that the internal layout of a brushless DC motor looks very similar to a permanent magnet stepper, yet a brushless motor relies on a feedback device such as a Hall Eect sensor to keep track of the position of the rotor. This provides for precise speed control. The brushless DC motor has a much higher initial cost than a conventional DC motor, but these costs can usually be justied by the increased performance and elimination of the maintenance needed to replace the brush contacts.

2.2.6 Induction Motor

AC induction motors rely on a minimum of two alternating current signals applied out of phase to cause the motor shaft to rotate. How the north pole of the motor shaft is attracted to the active south pole of the magnet.

2.2.7 System Types

In general, systems can be one of two types: Open Loop or Closed Loop.

Open Loop :

The premise of an open loop system is that the controller sends a signal to the driver based on the set point. The driver in turn will move the actuator the appropriate amount. No further action is taken unless the set point changes. Figure diagrams of this system.

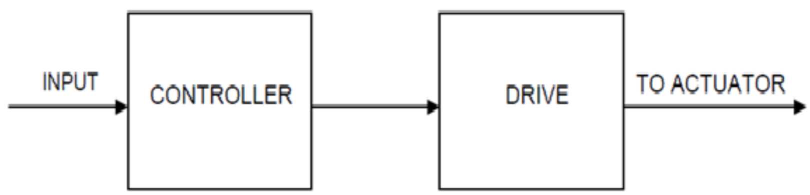

Figure 2.10: Open Loop System Diagram

Open loop systems are most effective when it is desirable for an actuator to move constantly until commanded to stop or when the actuation is extremely accurate. The latter case is true of stepper motors, since the steps are a constant increment.

Closed Loop : A closed loop system operates as shown in figure 2.10. A command signal is sent to the motor and a feedback signal is returned to the controller indicating the motor's current state. The controller compares the command and feedback signals and ad- justs its output accordingly.

Closed loop systems are eective when the process demands control over a variety of complex motion proles. Closed loop allows for precise control over speed and posi- tion through the use of feedback devices such as tachometers, encoders, or resolvers. Because of additional components required, a closed loop system is more complex and can cost more initially; but these issues are oset by the added degrees of control.

The low power command signal is amplified by the servo controller to produce movement of the motor and load. As the motor moves the load, an appropriate feedback signal is generated and returned to the positioning controller. The controller in turn evaluates this signal and determines whether or not the motor is operating properly. If the command signal and feedback signal are not equal, the controller will correct the position signal until the dierence between the two is zero.

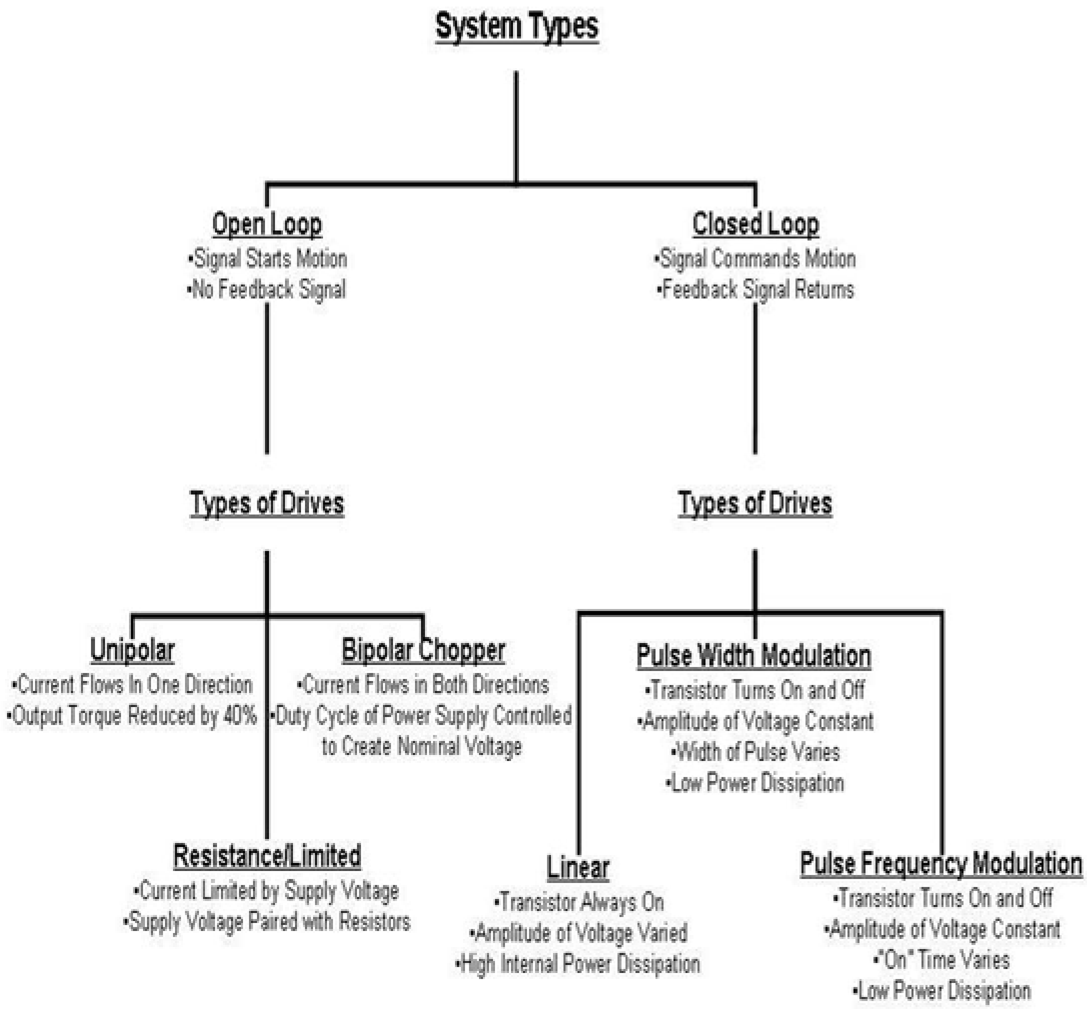

Figure 2.11: Open Loop vs Closed Loop System Comparison

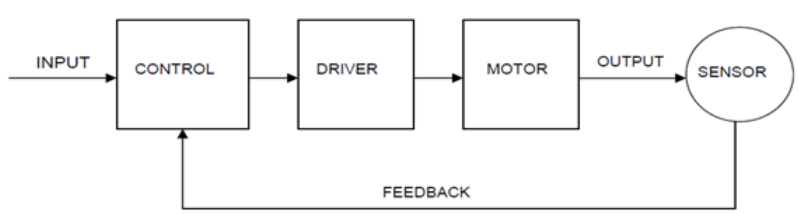

Figure 2.12: Closed Loop System

2.2.8 End Effector of Robot

The end effector is connected to the main frame of the robot through the wrist. A typical wrist including three rotary axes allowing roll, pitch and yaw. Although most wrists use three rotary axes, there are applications, which require only two axes of motion. The wrist should be designed to be as light as possible. Reductions of weight at the wrist increase the maximum allowable load and reduce the moment of inertia, which improves the dynamic performance of the robot arm.

End effectors fall into two categories: grippers and tools for process applications, such as welding torches, painting guns, drills, and grinders. Grippers are used in handling, machine loading, and assembly applications. In most grippers the mechanism is actuated by a pneumatic piston, which moves the 9 gripper fingers. When the robot is handling glass products or parts with highly polished surfaces, a vacuum type gripper can be used.

2.3 Programming of Robots

To state an algorithm, it is necessary, of course, to be able to write it down and express it logically, but it is also necessary, if it is to be executed by a machine, to state the algorithm in terms of some programming language. There are three methods used in the development of software for industrial or personal robots.

First method is the teaching method. This method consists in showing a robot what to do, with an accessory call "teaching pendant".

The second method of programming a robot is the comprehensive method. This method is known in the industry as "world modelling" method. Instead of showing a robot what to do, this method simulates a robot procedure using three dimensional geometric models. By simulating robot actions on a screen using geometry based on Cartesian coordinates, each step can be indicated by using the model. The problem with this method is that it assumes that the robot will operate the way the model operates.

The third method consists of a robot and computer programming language. In most cases, a high-level programming language is used along with a suitable subset of motion and manipulation commands. The focus of this method is on the end-eector or manipulator, and on the instructions of what the end-effector is to do in each step of the way. There are various kinds of programming languages used in robotics.

Chapter 3

Kinematic Analysis

3.1 Introduction

Kinematics is the science of motion. Robot is considered as a series of links connected by joints. Joints of robots have one degrees of freedom. There are two types of joints. Revolute (or rotationary) joints provide one degree of rotation and prismatic joints provide one degrees of translation. The robot user/programmer is interested in the position and orientation (pose) of the end-effector. However, the robot is controlled by the joint actuators and actuators control the joints in terms of angles.

There are two main parts of these analyses, forward and inverse. In forward analyses, one knows the angular position, velocity and acceleration of each motor and wants to know position, velocity and acceleration of the end eector. In inverse analyses, features of the end-eector are known and one wants to know the features of each motor. In robot programming applications, inverse kinematic analyses are useful, because programmer wants to manipulate the end eector of the robot.

In the kinematic analyses, the translational and rotational relations between adjacent links must be described. Hartenberg & Denavit proposed a matrix method for this purpose. First HD convention parameters will be expressed and position analyses will be done accordingly.

After the position analyses, velocity and accelerations will be done. In these analyses, a special matrix, Jacobian matrix will be formed and velocity & acceleration analyses will be done.

3.2 Hartenberg-Denavit (HD) Convention

A systematic technique for establishing the displacement matrix for each two adjacent links of a mechanism was proposed by Hartenberg and Denavit in 1955. This convention will be used in this investigation. The HD convention is mainly implemented in robot manipulators, which consist of an open kinematic chain in which each joint contains one degree of freedom and the joint is either revolute or prismatic.

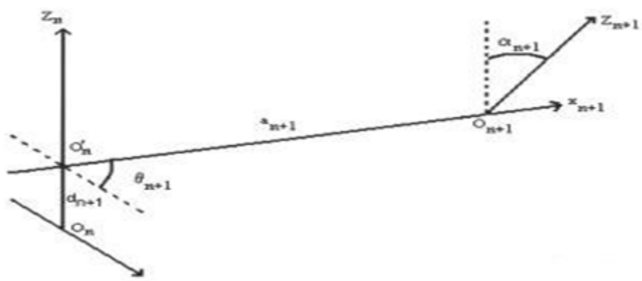

Figure 3.1: HD Convention Parameters

$$C^j_{i-1} = \begin{bmatrix} cos(\theta_i) & cos(\alpha_i)sin(\theta_i) & sin(\alpha_i)sin(\theta_i) \\ sin(\theta_i) & cos(\alpha_i)cos(\theta_i) & sin(\alpha_i)cos(\theta_i) \\ 0 & sin(\alpha_i) & cos(\alpha_i) \end{bmatrix}$$

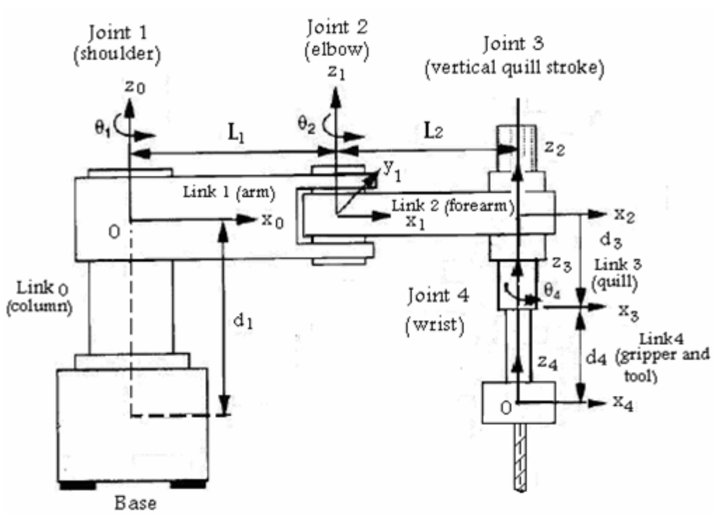

Figure 3.2: SCARA robot

The Figure 3.1 shows various DH parameters of Cylindrical Robot.

i	θ_i	D_i	A_i	α_i
1	θ_1	0	L_1	0
2	θ_2	0	L_2	0
3	0	D_3	0	0
4	θ_4	D_4	0	0

Table 3.1: D-H parameters of cylindrical robot

3.3 Kinematics

By using (D-H) convention, the transformation matrices result in:

$$T_1^0 = A_1 = \begin{bmatrix} c_1 & -s_1 & 0 & L_1c_1 \\ s_1 & c_1 & 0 & L_1s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_2^1 = A_2 = \begin{bmatrix} c_2 & -s_2 & 0 & L_2c_2 \\ s_2 & c_2 & 0 & L_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^2 = A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_4^3 = A_4 = \begin{bmatrix} c_4 & -s_4 & 0 & 0 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & -d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

After multiplication and use of addition matrices, one gets the total transformation matrix:

$$T_4^0 = \begin{bmatrix} c_{124} & -s_{124} & 0 & L_2c_{12} + L_1c_1 \\ s_{124} & c_{124} & 0 & L_2s_{12} + L_1s_1 \\ 0 & 0 & 1 & -d_3 - d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

And,

Taking the values,

$L_1 = 175\ mm$

$L_2 = 225\ mm$

$\theta_1 = 90^o$

$\theta_2 = 90^o$

$d_3 = 100\ mm$

$d_4 = 400\ mm$

$\theta_4 = 180^o$

Putting these values in the above matrix.

$$T_4^0 = \begin{bmatrix} 1 & 0 & 0 & -225 \\ 0 & 1 & 0 & 175 \\ 0 & 0 & 1 & -500 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3.4 Inverse Kinematics

Desired location of the SCARA robot:

$$T_H^R = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The final equation representing the robot is:

$T_H^R = A_1 A_2 A_3 A_4 = T_4^0$

From above euqtion, the values of the desired location (P_x,P_y,P_z).

$$\begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & -225 \\ 0 & 1 & 0 & 175 \\ 0 & 0 & 1 & -500 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Which Is,
Cordinates (P_x,P_y,P_z)= (-225,175,-500).
So, the cordinates of desired location is (-225,175,-500).

Chapter 4

Design Calculations

In this project work analysis of SCARA robot is carried out. The specification of the robot and calculated data are as per the table 4.1. The 3D assembly view of the proposed model is shown in Figure 4.1

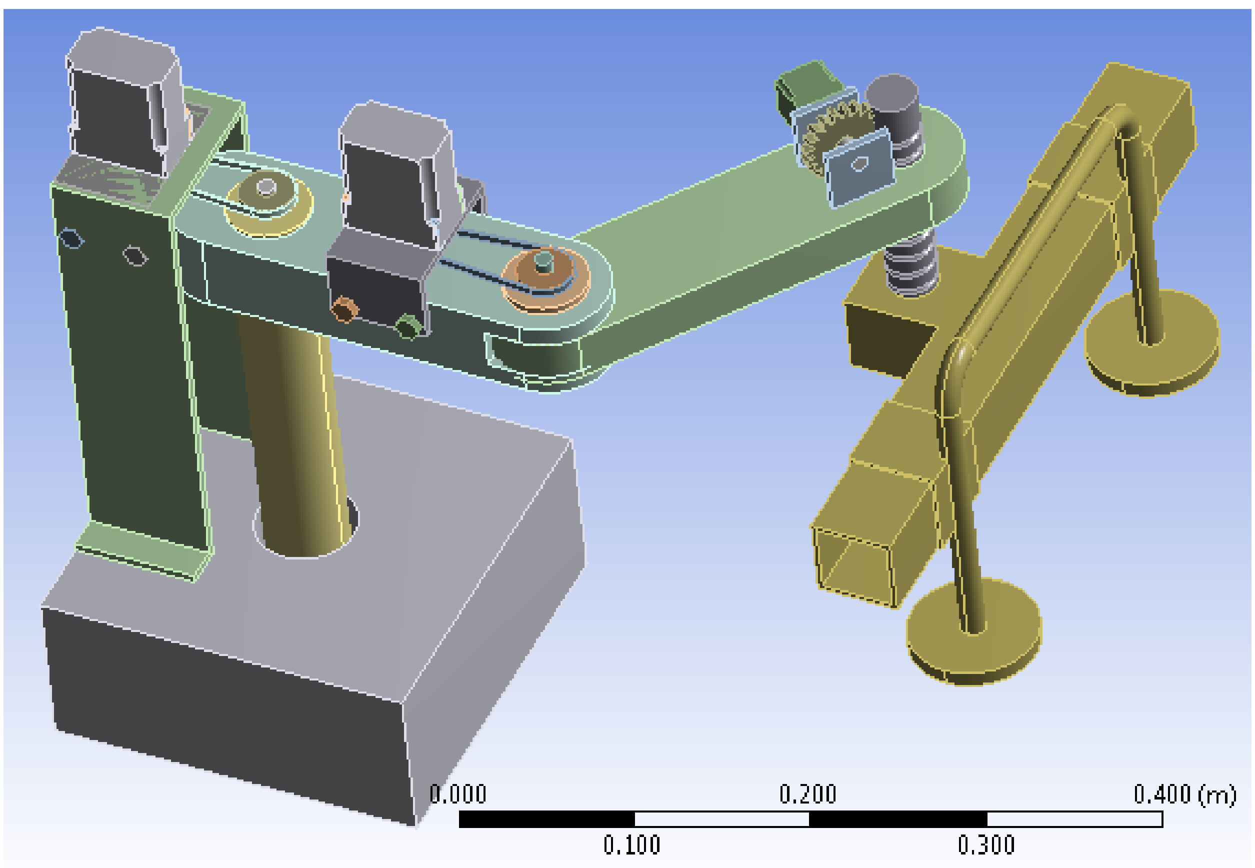

Figure 4.1: Model of Robot

Sr. No	Name	Specification
1	Type	SCARA
2	Pay Load	2 kg
3	Lifting Height	100 mm
4	Drive configuration	Servo Motor of 0.303N-m & 5000 RPM
5	Worm Wheel diameter	80 mm
6	Worm Diameter	32 mm
7	Frame Material	Aluminium
8	Diameter of Vacuum Cup	33 mm

Table 4.1: Specification of Robot

Sr. No	Links	Movement
1	Link 1 (Link with fork)	180^o (Revolute)
2	Link 2 (Middle Link)	180^o (Revolute)
3	Link 3 (Lead Screw)	100 mm (Prismatic)

Table 4.2: Specification of Link Movement

4.1 Specifications of Links

Links:

Gripper Beam:

Beam attached to the gripper is hollow beam with cross sections of 50mm×50mm with 3mm thickness.

Its length should be more than the gripper length of 300mm, here it is taken as 400 mm.

Link 1 (Link with Fork) :
It is a rectangular beam with cross sections of 75mm×50mm and length of 175 mm.

Link 2 (Middle Link) :
It is a beam with cross-section area of 75mm×30mm and length of 225 mm.

Worm:

It has diameter of 32 mm and length of the lead screw it 200 mm,it should be more than lifting height, which is 100 mm.

4.2 Design of Worm Gear

4.2.1 Terminology of Worm Gear

A pair of worm gear is specified and designated by four quantities in the following manner,

$$Z_1/Z_2/q/m \tag{4.1}$$

Z_1 = number of starts on the worm

Z_2 = number of teeth on the worm wheel

q = diametral quotient

m = module *(mm)*

The diametral qoutient is given by,

$$q = \frac{d_1}{m} \tag{4.2}$$

where, d_1 = pitch circle diameter of the worm.

A schematic diagram of the worm and worm wheel is shown in figure below.d_1 and d_2 are pitch circle diameters of the worm and the worm wheel respectively.

The worm is similar to a screw with multi start threads.

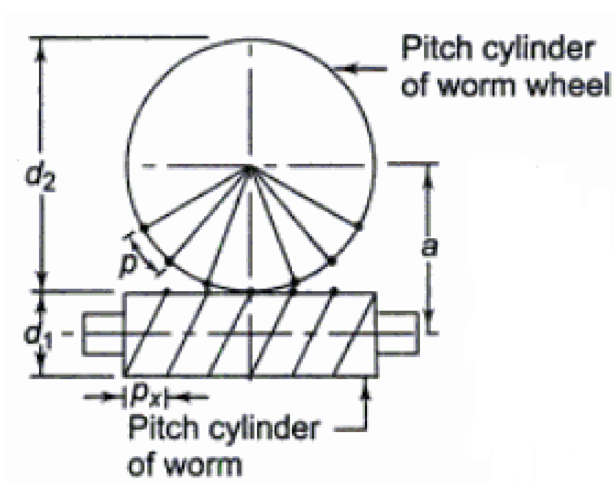

Figure 4.2: Worm Gear Terminology

When one thread of the worm is developed, it becomes hypotenuse of a triangle as shown in figure 4.3. The base of this triangle is equal to the circumference of the worm, while the altitude is equal to the lead of the worm. Therefore,

$$tan\gamma = \frac{1}{\pi d_1} \tag{4.3}$$

Where γ is the lead angle of the worm.

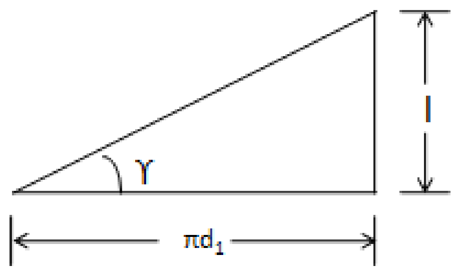

Figure 4.3: Development of Worm thread

$$tan\gamma = \frac{Z_1}{q} \tag{4.4}$$

From the figure 4.2, the cemtre distance is given by,

$$a = \frac{d_1 + d_2}{2} \tag{4.5}$$

Where, a is the centre to centre distance.
Therefore, we get,

$$a = \frac{m(q + Z_2)}{2} \tag{4.6}$$

The speed ratio is given by,

$$i = \frac{Z_2}{Z_1} \tag{4.7}$$

4.2.2 Downward Force on Worm Gear

- Weight of Glass = 2 kg = 20 N
- Weight of Gripper beam :11.7 N

4.2.3 Weight calculation of the gripper assembly

Volume of gripper beam,

$$V = lbh \tag{4.8}$$

$$V = 400 \times [(2 \times 50 \times 3) + (2 \times 44 \times 3)]$$

$$V = 225600mm^3$$

Weight,

$$W_{ga} = \rho V \tag{4.9}$$

$$W_{ga} = 7860 \times 225600 \times 10^{-9}$$

$$W_{ga} = 1.17kg$$

Taking total weight of gripper assembly = 2 kg, Total downward force,W

W= weight of Pay Load + weight of gripper assembly

W= $2\ kg + 2\ kg$

W= $4\ kg$

4.2.4 Axial Force on Worm Gear

A par of worm gears is taken as such from the standard sizes of worm gears.

2/40/8/4

where,
$Z_1 = 2$
$Z_2 = 40$
$q = 8$

$m = 4$

Pressure angle of gear is considered as 20^o.

Now,

Diameter of Worm gear :

$$m = \frac{d_1}{q} \tag{4.10}$$

$$d_1 = 4 \times 8$$

$$d_1 = 32mm$$

Diameter of Worm wheel :

$$m = \frac{d_2}{Z_2} \tag{4.11}$$

$$d_2 = 4 \times 40$$

$$d_2 = 80mm$$

Centre distance:

$$a = \frac{d_1 + d_2}{2} \tag{4.12}$$

$$a = \frac{32 + 80}{2}$$

$$a = 56mm$$

Helix Angle :

$$tan\gamma = \frac{Z_1}{q} \tag{4.13}$$

$$tan\gamma = \frac{2}{8}$$

$$\gamma = 14^o$$

Servo Motor :

From the standard rating of motor here, a motor of following specification is taken,

M_t= 0.303 *N-m* and 5000 *rpm*

Tangential Force on Worm wheel $(P_1)_t$:

$$(P_1)_t = \frac{2M_t}{2d_1} \tag{4.14}$$

$$(P_1)_t = \frac{2 \times 303}{32}$$

$$(P_1)_t = 18.93N$$

Axial Force on Worm $(P_1)_a$:

$$(P_1)_a = (P_1)_t \frac{(cos\alpha cos\gamma - \mu sin\gamma)}{(cos\alpha sin\gamma + \mu cos\gamma)} \tag{4.15}$$

$$(P_1)_a = 18.93 \frac{(cos20^o cos14^o - \mu sin14^o)}{(cos20^o sin14^o + \mu cos14^o)}$$

$$(P_1)_a = 52.08N > 40N$$

hence the required weight of 2 *kg* can be lifted with this arrangment.

4.3 Diameter of Shaft :

Torque on the Shaft is M_t=303*N-mm*

And bending moment,

$M_b = (P_1)_t \times L$,

where, $(P_1)_t$ is a downward force on gear.

M_b =18.9 ×22.5=425.25 *N-mm*

Now, equivalent torsional movement ,

$$d^3 = \frac{16\sqrt{(M_b)^2 + (M_t)}}{\pi \times \tau_{max}}$$

Diameter of the shaft is,

$$d = 27mm$$

4.4 Selecting the proper Vacuum Cup

Selecting the type of vacuum cup, material, and size suitable for an application is important to the overall vacuum system. Calculating the forces involved for each application is recommended to determine the vacuum cup size. It should be noted that these calculations are basic theoretical guidelines and each application must be tested for actual results. With all vacuum applications, certain practical assumptions concerning cup materials, environmental conditions, and product characteristics to name a few, may not be consistent with the performance. Again, the user should determine the eciency, performance, and safety factor of the cup selection.

4.5 Calculating the pad diameter and forces

4.5.1 Mass

The easiest way to determine the mass of an object is to measure the weight with a scale within the earth's gravitational field (a_g = 9.81 m/sec^2).

4.5.2 Forces

For vacuum applications, force is a vector quantity in a dened direction either horizontal or vertical. The standard international unit of force is measured in Newton (N) which is the equivalent of (kg-m/sec^2). The force can be calculated by measuring the eect of a change in acceleration on a mass. Newton's Law:

F(N) = mass(*kg*) x $a_g(m/sec^2)$

4.5.3 Acceleration

Acceleration is the change in velocity of a moving object. Acceleration is a vector, a directional quantity expressed in units of meters per second squared (m/sec^2) and symbolized as "a". a = (Velocity /Time)

4.5.4 Lifting forces

When calculating lifting forces, safety factors of 2 for horizontal lifts and 4 for vertical lifts are minimum values. Applications with irregular shapes, dicult surfaces, and awkward motions will require increased safety factors.

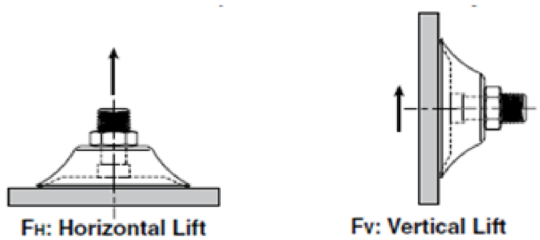

Figure 4.4: Lifting forcess

Horizontal lifting force :
F_H(N) = mass(kg) x (a_g+ a) x S_H

Vertical lifting force :
F_V (N) = mass(kg) x (a_g+ a) x S_V

4.6 Calculating the diameter of the cup

$$(D) = 35.7\sqrt{\frac{m(a_g + a) \times S}{P_v \times n}} \tag{4.16}$$

where,

D = Diameter of cup
m = Mass
a_g = Acceleration due to gravity
a = Motion acceleration
S = Safety factor
P_v = Operating vacuum pressure

n = Number of cups

Now, taking the values:
m =10 kg
a_g = 9.81 m/sec^2
a = 3 m/sec^2
s = 4
P_v = 61 kPa
n = 2
D = 32.719 mm

4.7 Design of vacuum cup

The fixture for the vacuum gripping of the glass plate is conceptualized as shown in figure.

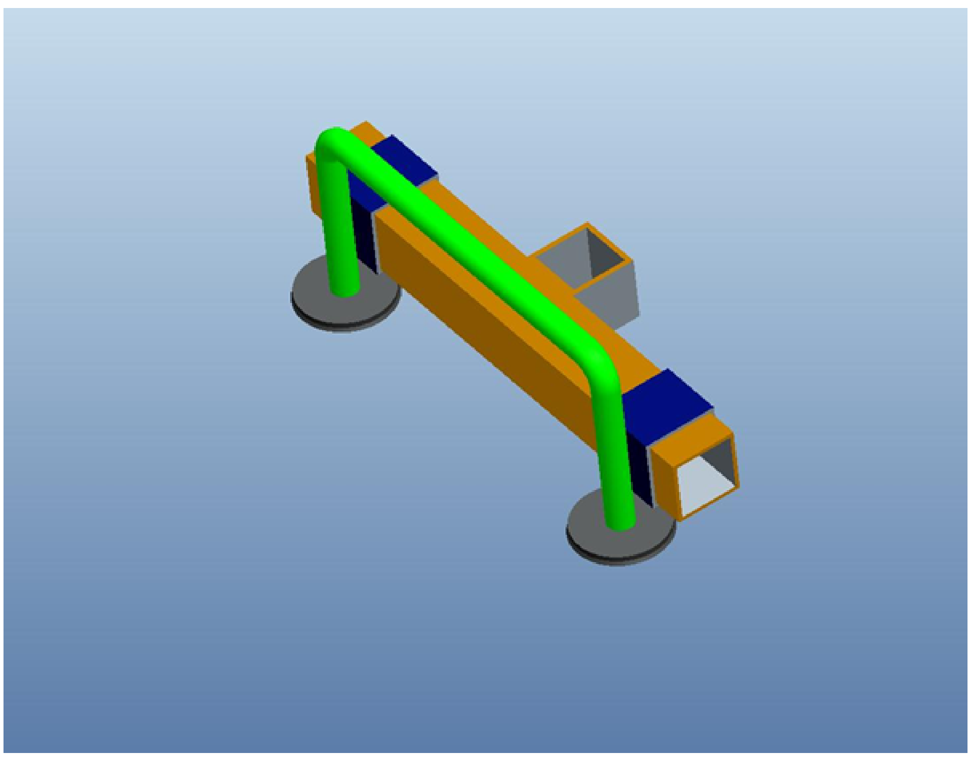

Figure 4.5: Design of Vacuum Cup in PRO-E

Chapter 5

Analysis of Robot Arm

The need for accurate and computationally efficient manipulator dynamics has been extensively emphasized in recent years. Modeling and analysis of robot systems by using various program softwares has facilitated the process of designing, constructing and inspecting the robots in the real world. Analysis is important for robot programmers to evaluate, predict the behavior of robot, in addition to verify and optimize the path planning of the process. Moreover, this will save time and money and play important role in the evaluation of manufacturing automation. It opens a wide range of options for solving many problems creatively. One can investigate, design, visualize, and test an object or even if it does not exists.

5.1 Model of Robot

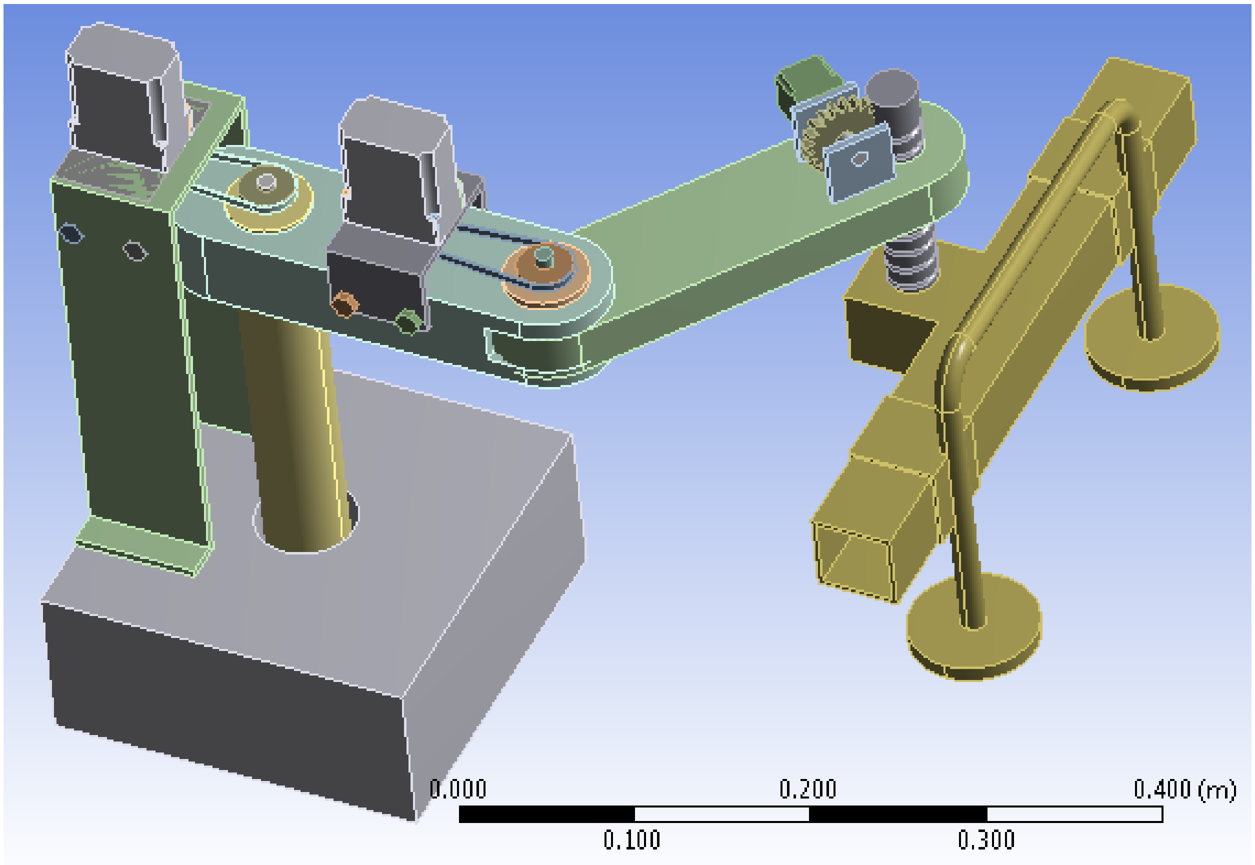

Figure 5.1: Model of Robot

5.1.1 Meshing

Meshing of the model is done in work bench by default parameter.

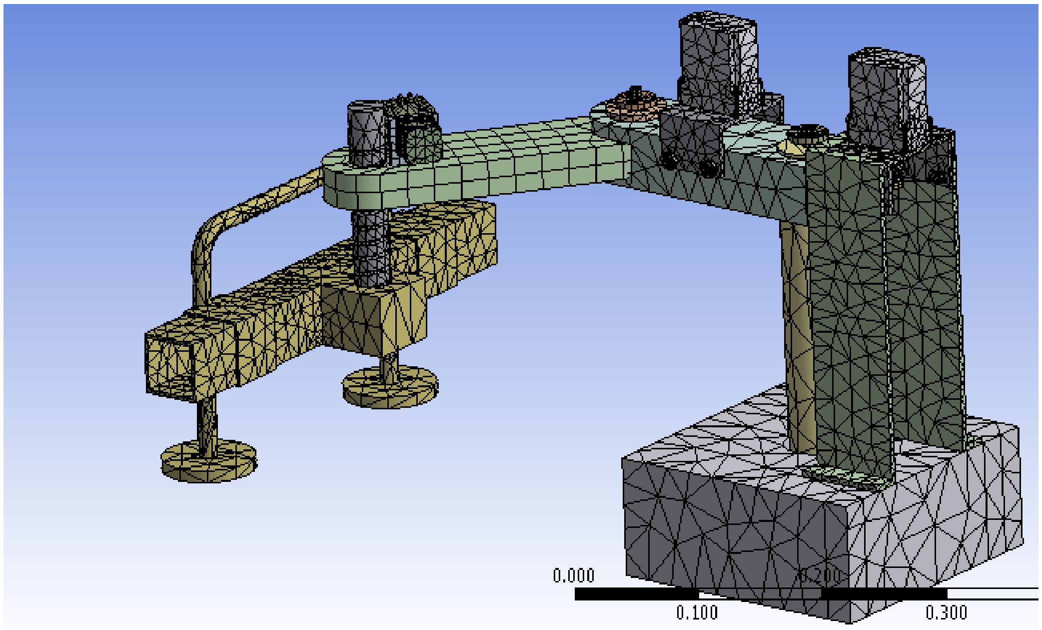

Figure 5.2: Meshing

Parameter	**Value**
Element Type	Solid187
Young's Modulus	69 GPa
Poisson's Ratio	0.33

Table 5.1: Meshing Parameter

5.1.2 Boundary Conditions

Boundary Conditions	**Value**
Downward Force on End Effector	20 N
Fixed from Base	-

Table 5.2: Boundary Conditions

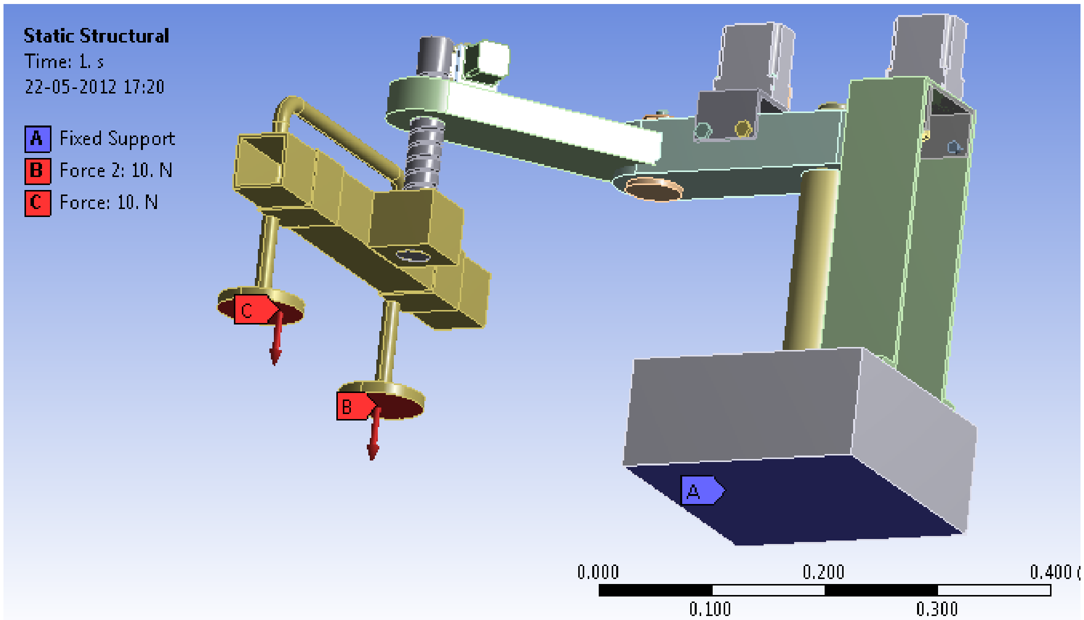

Figure 5.3: Boundary Conditions

5.1.3 FE Results

5.1.3.1 Von-Mises stress in Gripper Assembly

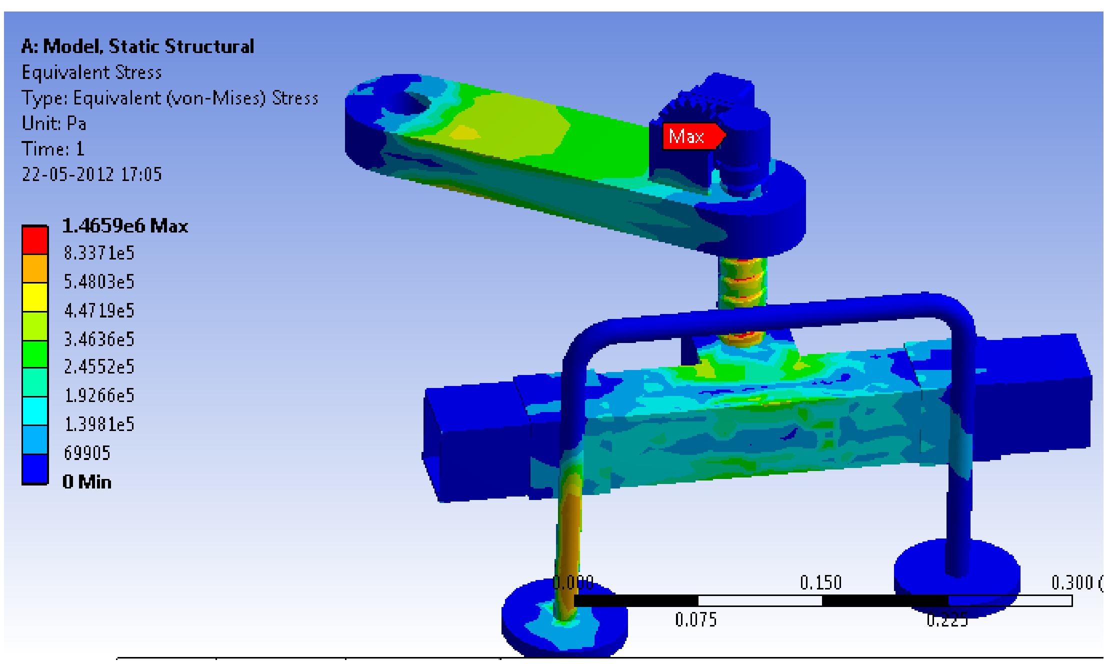

Figure 5.4: Von-mises stress in Gripper Assembly

In whole structure maximum stress generation is found near the tooth of worm wheel, where it contacts with the worm gear.

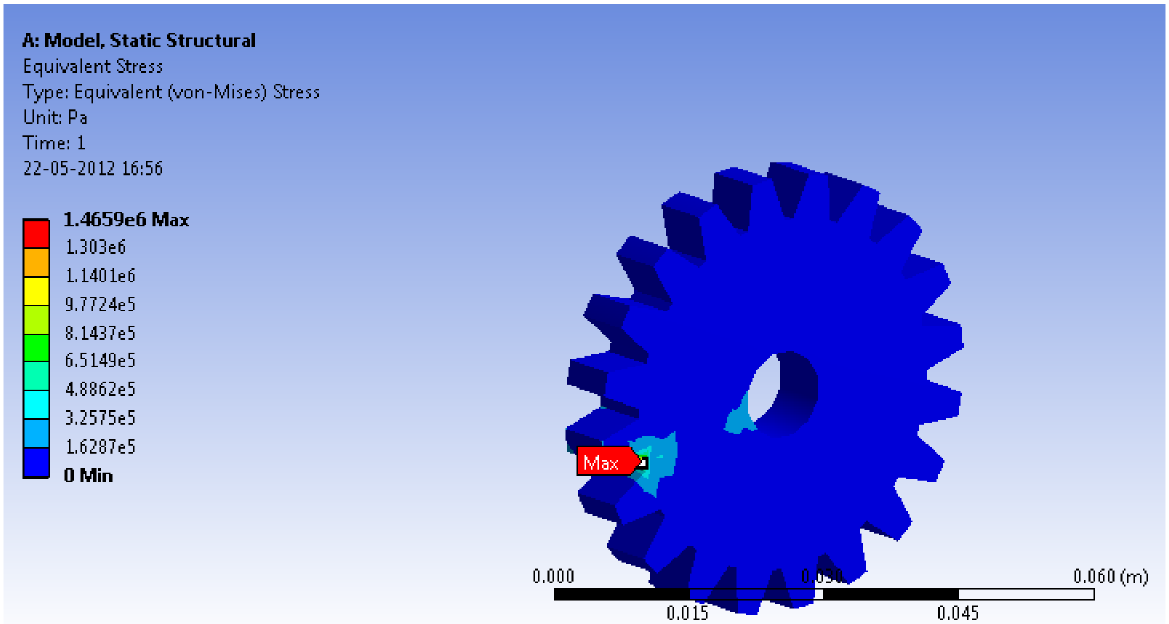

Figure 5.5: Detaild view of Von-mises stress in worm gear

5.1.3.2 Deflection in Gripper Assembly

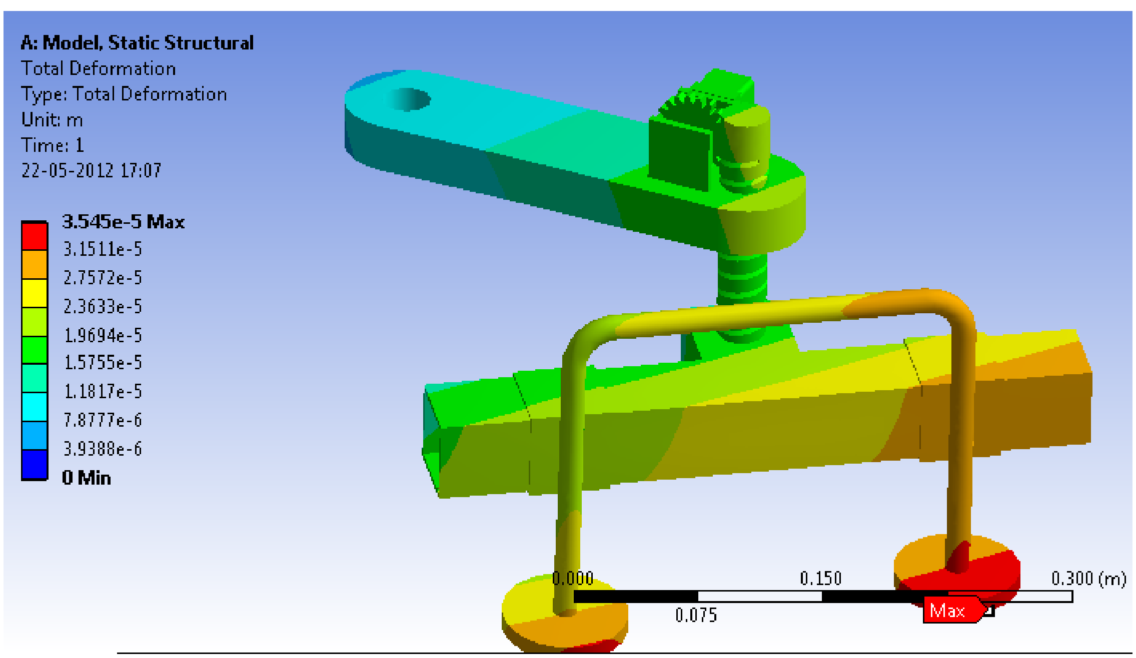

Figure 5.6: Deflection in gripper assembly

5.1.3.3 Von-Mises stress in Worm Gear

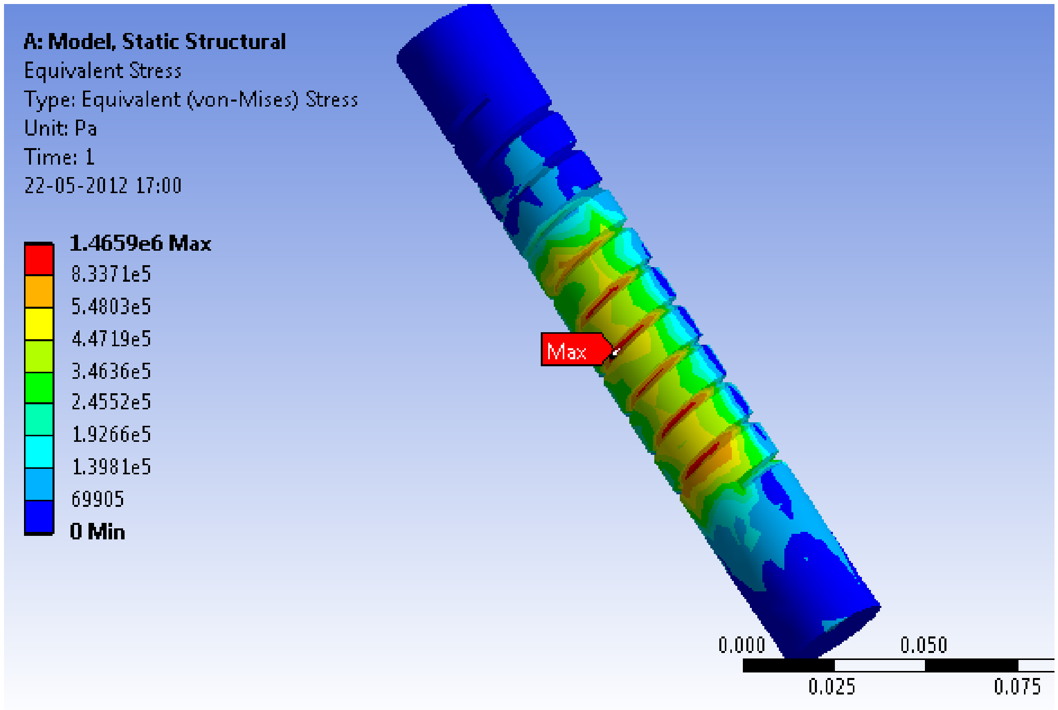

Figure 5.7: Deflection of worm gear

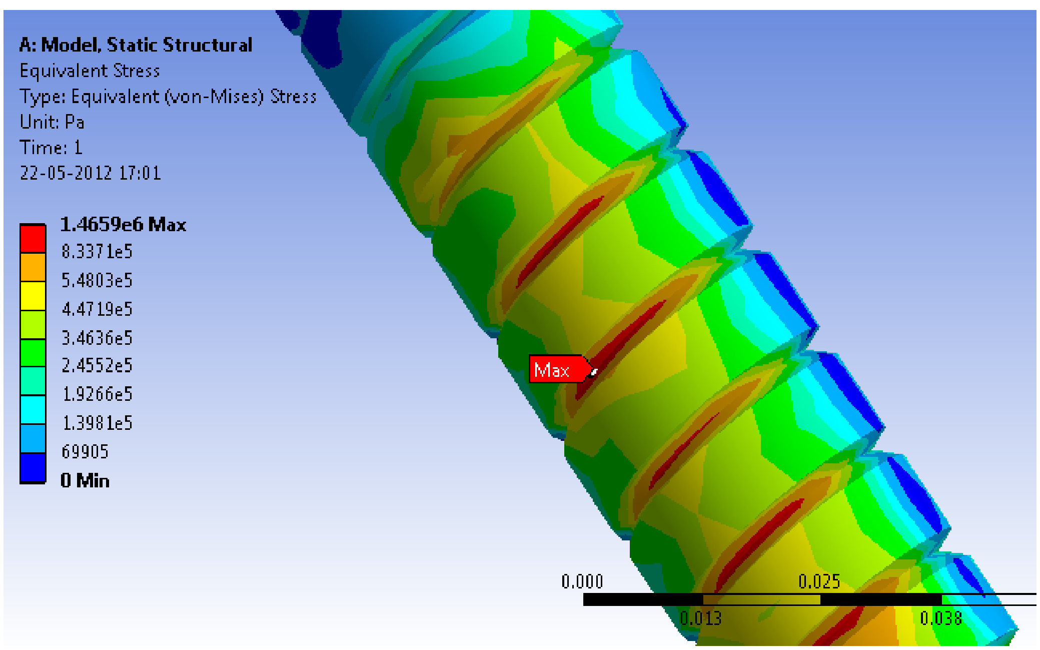

Figure 5.8: Detailed view of deflection of worm

Chapter 6

Summary and Future Work

6.1 Summary

- Vacuum gripper is designed to lift a glass plate of 2 kg weight.
- To meet the assembly requirements SCARA robot model with 4 degree of freedom is conceptualized and designed .
- The model is analysed using ANSYS software. Deflection and stresses generated in various components are well within the permissible limits.

6.2 Future Scope

- Optimization of the structural components to minimize the weight.
- Fabrication of the model.

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