DESIGN AND ANALYSIS OF 3-AXIS SCARA ROBOT TO SUSTAIN 60 N-m TORQUE BY NUTRUNNER

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Abstract – *This paper focuses on design and analysis of 3-Axis SCARA Manipulator to sustain 60 N-m Torque Tooling. Nowadays the use of robots on production lines has increased to reduce the production time and increase the productivity. As we go for more specialized robotic machining operations, the cost of robot increases. The basic objective is to design low cost and compact robotic arm which will handle Electric Nutrunner imposing 60 N-m torque during operation. The SCARA robot can be used in various tooling applications like screw driver, Nutrunner, riveting machines etc. The main advantage is that the robot is designed to operate by Servo motors so it is light weight as compared to hydraulic and pneumatic actuation.*

Key Words: **SCARA ROBOT, KINEMATICS OF SCARA ROBOT, INVERSE KINEMATICS, STRUCTURAL ANALYSIS.**

1. INTRODUCTION

The robotic arms used for assembly and production operations help to reduce errors and human effort with more production rate. The main feature of SCARA configuration is high speed, less maintenance, high repeatability and robust in design. SCARA ROBOTS are mostly used for pick and place operations but we have designed it for machining operations. SCARA stands for Selective Compliance Assembly Robot Arm which has 3-Dof with one linear motion and two rotational motions. This case study is concern with design of SCARA Robot which is servo motor driven. Configuration used for SCARA Robot is PRR configuration. It is difficult to provide prismatic joint for tooling as tool is very heavy for linear motion in vertical direction .Hence ball screw is used to provide vertical motion. The desired height for operation can be achieved with the help of ball screw for nut running operation. The servo motor with reducer controls the linear and rotational motion of the robot. Ball screw is used to achieve the linear motion. This paper also describes the calculations of link lengths and forces on joints of robotic arm. The structural analysis is performed on the links to validate and improve the design.

2. LITERATURE REVIEW

1. Design, Manufacturing and analysis of Robotic Arm with SCARA Configuration by Kaushik Phasale, Praveen Kumar, Akshay Raut, Ravi ranjan Singh, Amit Nichat.

This paper deals with design of 4-Axis SCARA Robot. The analysis is also performed in Ansys. For experimental setup, the robot with cardboard material is made by author. The experimental model is used to analyze the location of motors, length of links and its movements. The designing of robotic arm is done in creo software. The animation is done with various constraints in the software. This research study also includes the manufacturing and assembly processes of robot.

2. Modeling, Simulation And Analysis of SCARA Robot for Deburring of circular components by PVS Subhashini, N.V.S Raju and G. Venkata Rao.

This research study describes the study of SCARA Robot for deburring operation of circular profiles. The SCARA Robot with four degrees of freedom is modeled in CAD Software. The Kinematics of Robot is also explained in simplest way. The results of joint positions and joint velocities calculated from CAD Software are compared with results obtained from MATLAB. The mathematical modeling and its results in MATLAB is best explained through this paper.

3. Design and Fabrication of SCARA Robot with 5 Degrees of Freedom by Banoth Bhadru, D. Narendar, B. Kiran.

This paper deals with design and fabrication of SCARA Robot of 5 degrees of Freedom which is driven by stepper motor and servo motor. The author has developed a new way to give motions in 5- Axis with the help of stepper and servo motors. Arm motion is achieved using servo motors while the inverse kinematics algorithm is implemented by using stepper motors for position control. Author has given details of fabrication of robot in this paper. The paper also describes the programming of robot with the help of microcontroller.

4. Modelling and Analysis of Robotic Arm using Ansys by Jeevan, Dr. Amar Nageshwar Rao.

This paper deals with study of different cross-sections of robotic arm and its analysis in ansys. The cross-sections considered are hollow square, Solid Square, hollow circular and solid circular. All four different cross-sections are designed in CAD software. The results of stress and deformation are compared and conclusion is derived. The deformation is less in hollow square link cross-section and the stresses are less in hollow circular cross-section.

5. Kinematic Analysis of Various Robot Configurations by Game R.U. , Davkhare A.A. , Pakhale S.S. , Ekhande S.B. , Shinde V.B.

This paper deals with study of forward and inverse kinematics of robot manipulators. Various models such as 2R, 3R, 3R-1P, 5R, 6R are used by author to study D-H parameters of direct and inverse kinematics. The author used roboanalyzer and MATLAB software to obtain results of inverse and direct kinematics. The author compared the results obtained from roboanalyzer and MATLAB along with

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algebraic method. This research study concludes that inverse kinematic analysis is complex and challenging as compared to forward kinematics. Forward kinematic analysis of any robot configuration is easy to calculate joint angles along with positions. The study aims to analyze the results of inverse kinematics in roboanalyzer, MATLAB and algebraic method.

3. PROBLEM STATEMENT

To design 3-Dof SCARA Robot for workspace dimensions of 1200×500 mm. The objective is to design a robotic arm which will sustain 60 N-m tooling torque at the end of gripper.

4. METHODOLOGY

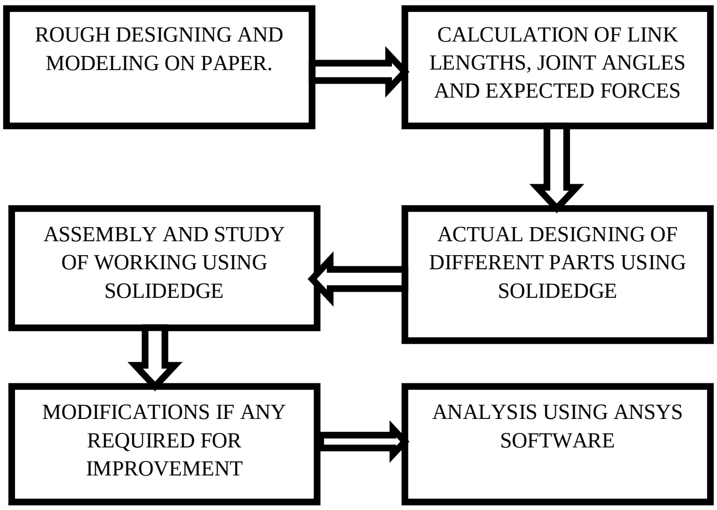

Fig-1: Methodology Flow for design and analysis

5. ANALYTICAL CALCULATIONS

5.1 WORKSPACE DEFINITION OF SCARA ROBOT

The SCARA Robot is designed for 1200×500 mm workspace dimension. The assumptions made are: SCARA Robot is placed between center of workspace and it is kept away by 100 mm distance from the workspace.

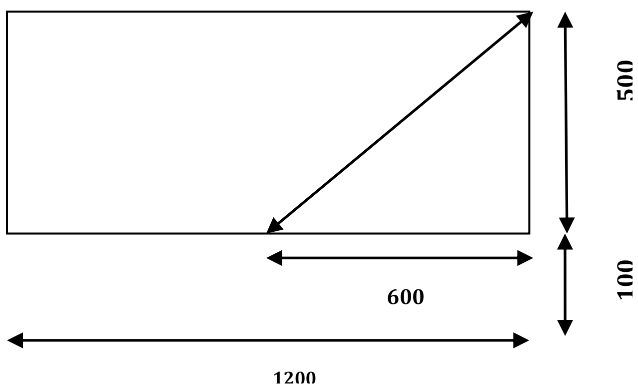

Fig-2: Predefined workspace for SCARA robot

First of all the lengths of the links are optimized by drawing a line diagram analytically and tracing it over the workspace for maximum and minimum distance coverage. The length of links 2 and 3 should be such that tool covers every point on the work-piece.

By using this method the when second and third links are fully outstretched, the total length of links can also be calculated analytically using Pythagoras Theorem,
i.e.: addition of lengths of 2 links outstretched
$(600^2 + 600^2)^{1/2} = 848.5281$ mm

6. KINEMATICS OF SCARA ROBOT

Denavit and Hartenberg (DH) proposed a systematic notation for assigning right handed orthogonal frames, one to each link in an open kinematic chain of links. Once the link is attached coordinate frames are assigned, transformations between adjacent coordinate frames that can be represented by 4X4 homogeneous transformation matrix.Following is the description of DH parameters of SCARA Robot:

Arm Parameter	Symbol	Revolute Joint	Prismatic joint
Joint Angle	Θ	Variable	Fixed
Joint Distance	D	Fixed	Variable
Link Length	A	Fixed	Fixed
Link Twist Angle	α	Fixed	Fixed

Table-1: Description parameters of DH Method

Link	α_i	a_i	d_i	θ_i
1	0	l_1	q_1	0
2	π	l_2	0	q_2
3	π	l_3	0	q_3

Table-2: DH Parameter Table for SCARA Robot

There are two types of Kinematics methods:

1. Forward Kinematics
2. Inverse Kinematics

As we know the workspace dimensions i.e. we know the end effector positions. Hence we know the link lengths but not joint angles. To determine the joint angles we have used Inverse Kinematics method.

6.1. INVERSE KINEMATICS

- Inverse Kinematics means using kinematics equations of robot for determining the joint angles from known values of end effector positions. For determining the joint angles consider the motion of two links with revolute joint from given below diagram.

- Initially the position of link is assumed at (0,600) : (x, y). The joint angles at this position are:

  L1= Link 1 and L2= Link 2
  x=0 and y= 600 (all dimensions are in mm)
  θ_1= joint angle moved by link 1
  θ_2= joint angle moved by link 2

$\cos\theta_2 = (x^2+y^2-L1^2-L2^2) / (2*L1*L2)$
$\tan\theta_1=[y(L1+L2*\cos\theta_2)- x*L2*\sin\theta_2]/[x (L1+L2*\cos\theta_2) + y*L2*\sin\theta_2]$

Calculations lead us to the initial angular positions of links as,

$\theta_1 = 44.9^0$ and $\theta_2 = 90.198^0$

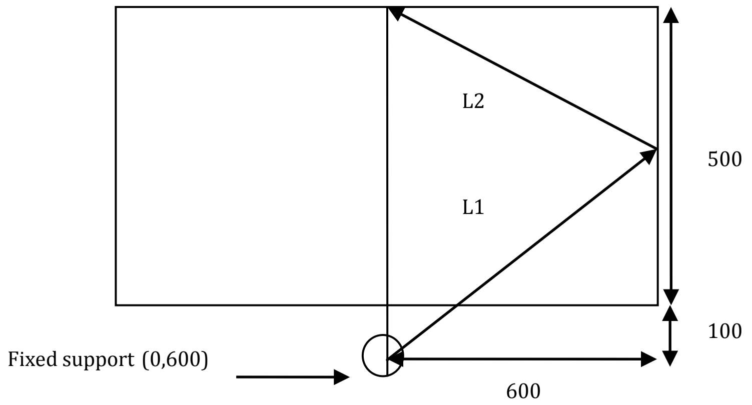

Fig-3: Initial Position of Link 2 and Link3

7. Selection of cross-section of links:

Mostly for SCARA Robots, links with rectangular cross section are considered. With reference of previous research papers and analyzed data the rectangular cross section for links of SCARA Robot is considered. Section Modulus is also considered for selecting the cross section. Basically section modulus is the property which indicates strength of beams based on their cross section.'S=I/y' where, 'I' is the moment of inertia and 'y' is the distance from the neutral axis .Hence, rectangular cross section is considered for obtaining high strength as compared to other cross sections.

8. Selection of Ball Screw:

Ball screw is used to convert the rotary motion into linear motion. Considering the travel of 300 mm and other parameters such as mounting of motors and mounting of supports, the length of screw shaft is considered. The shaft length of 800 mm is considered from standard catalogue. The ball screw is selected by referring to standard catalogue. The lead of screw shaft indicates the linear distance travelled by nut per one revolution of screw. From the possible combinations of shaft length, diameter of screw shaft and lead, the ball screw of 5mm lead with 20 mm diameter is selected.

9. Selection of Motors:

The link has to trace circular path while achieving the desired position. The torque is very high, hence motor with reducer is considered. Reducer reduces the rpm and increases the torque so that the weight of the links can be moved using this high torque.The maximum time considered for movement of π radian is 0.5 sec. So,
$\omega = \pi/0.5 = 2\pi$

Ratio	50
Backlash	5 arc-min
Allowable nominal torque	75 N-m
Allowable maximum torque	125 N-m
Allowable average input speed	3000 rpm
Allowable maximum input speed	6000 rpm
Allowable radial load (Applied to the output shaft center)	2100 N

Thus, $N=(\omega\times60)/(2\pi)= 60$ rpm.
From standard motors, a motor with reducer is selected. Following are the characteristics of motors:

Reducer Specifications:

Motor Specifications:

Capacity	0.4 kW
Nominal torque	1.3 N-m
Maximum torque	3.8 N-m
Nominal speed	3000 rpm
Maximum speed	4500 rpm

10. CALCULATIONS OF FORCES:

The forces are calculated on each link. The free body diagram of each link is considered to calculate the forces. Initially the robot links move to reach the desired position and when the nutrunner is in operation the links are stationary. The nutrunner imposes 60 N-m torque on the gripper of link3 and then it is transmitted to previous links. The following is figure of Link 3 along with gripper. The weight of standard Nutrunner is 4kg. So it exerts 40 N force vertically downward. The nutrunner is considered to be clamped 60 mm above from its lowest point. So force imposed due to 60 N-m torque is, F=60/0.15 where 0.15 is the radius of nut runner where it is to be clamped.

F=400N

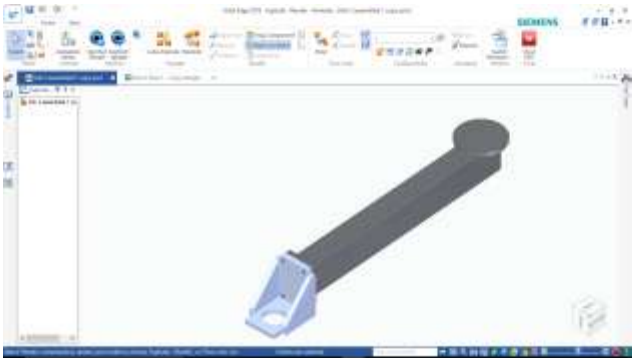

Fig-4: Design of Link 3 with gripper attached in solid edge

The links impose their self-weight on previous links. For Link2, the weight of link3 along with nutrunner weight is considered. The weight of Link 3 is obtained by assigning material in solid edge and calculating its value.
So total force acting on the link2 is,
F=40+75+80=195N

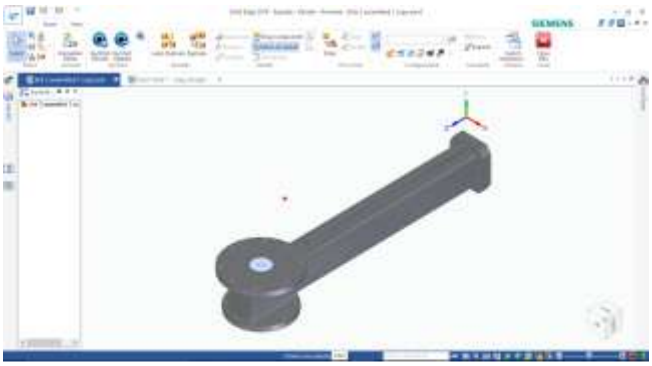

Fig-5: Design of Link2 in Solid Edge

Due to link2 and link3 bending moments are imposed on the vertical link. Hence supports are designed for ball screw to sustain such large bending moments. A block is designed for mounting of Link2 and Link3 on the ball screw. The nut of ball screw is assembled inside the block. As the nut moves it provides linear motion to the whole assembly with travel of 300 mm.

Fig-6: Design of vertical link in solid edge

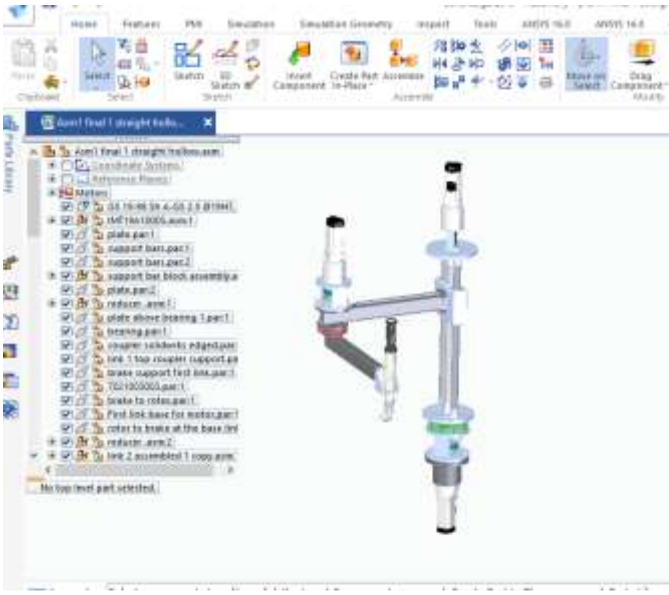

Fig-7: Assembly of SCARA ROBOT in Solid Edge

11. STRUCTURAL ANALYSIS OF SCARA ROBOT:

Finite Element Analysis is used to optimize the design by performing analysis. The above calculated forces are applied on the each link and analysis is performed in Ansys software. Without loss of generality, the material considered for whole assembly is structural steel. For analysis two conditions were considered:

Case1: When the nut runner is in operation and links are stationary.
Case2: When the links are moving to desired position carrying the nut runner.

11.1 Case 1:

During this case it is considered that links are stationary and Nut runner is in operation. The analysis is performed to obtain results of Von-mises stresses (equivalent stresses) and Total deformation. The analysis is performed by fixing one end of link and applying calculated forces.

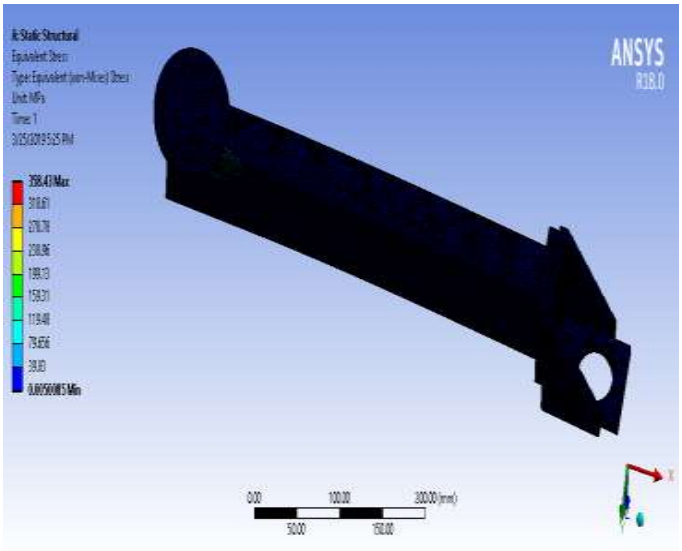

Fig-8: Von-Mises Stress Analysis of Link 3

The above analysis results show that link is safe to sustain stresses imposed due to nut running operation.

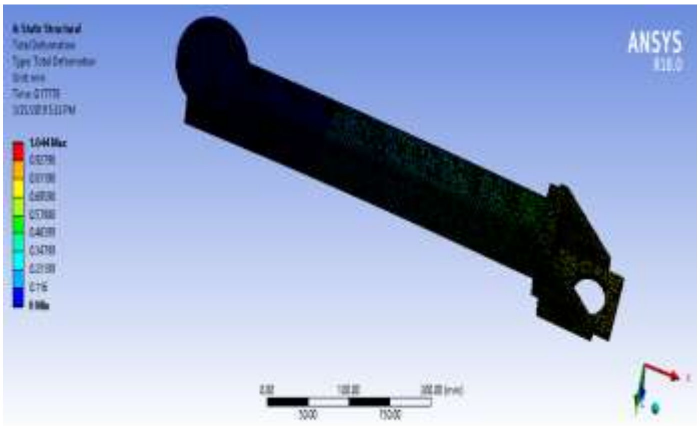

Fig-9: Deformation analysis of Link3

The above deformation results show that link is safe in deformation. The critical area is gripper to which nut runner is clamped. The deformation is negligible and link can sustain high forces due to nut runner operation.

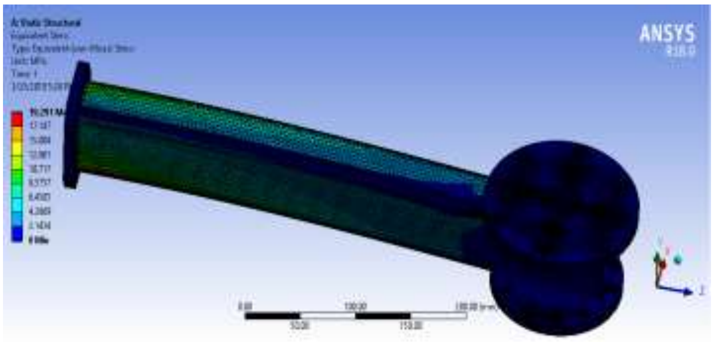

Fig-10: Von-Mises Stress Analysis of Link2

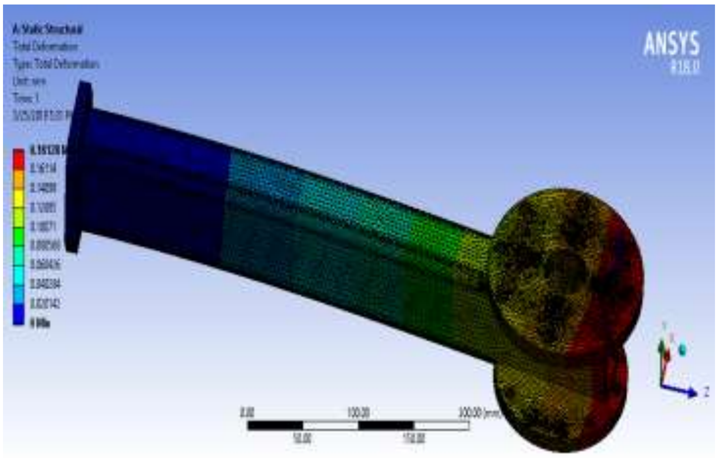

Fig-11: Deformation Analysis of Link2

The above results of stress and deformation analysis of link2 show that link2 is safe and can sustain forces transmitted from link3 during nut running operation.

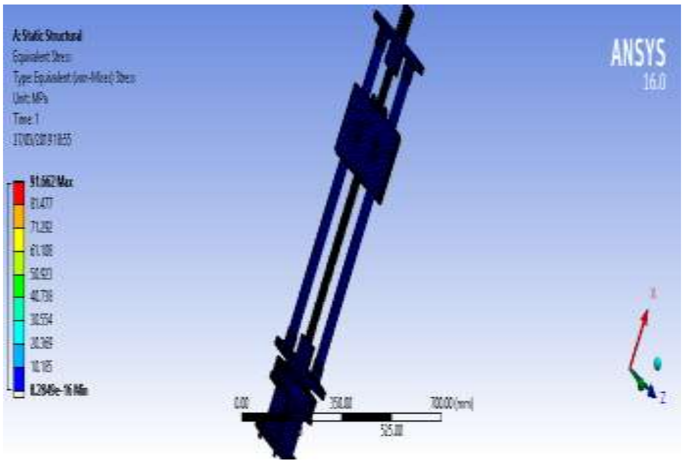

Fig-12: Von-Mises Stress Analysis of Link1

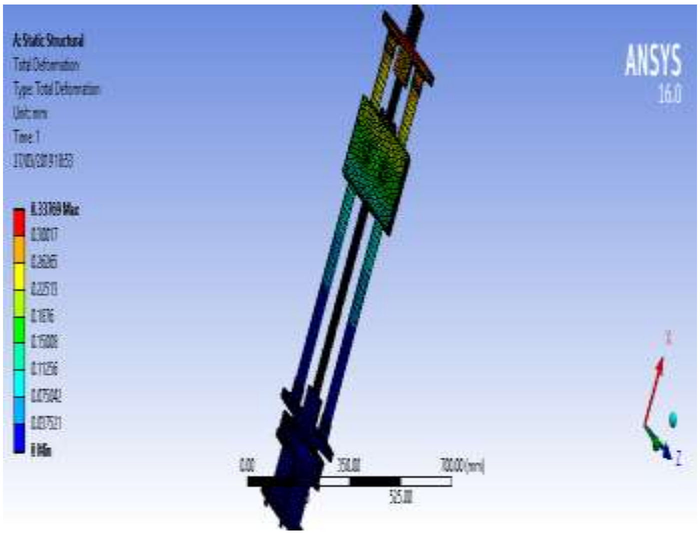

Fig-13: Deformation Analysis of Link1

The above results of analysis for vertical link shows that the link is safe against the bending moments imposed due to link2 and link3.
The following result table shows the results for each link with maximum and minimum deformation and stresses.

Link no.	Von-Mises Stress(MPa)		Deformation(mm)	
	Max	Min	Max	Min
1	91.62	8.28×10^{-16}	0.337	0
2	19.29	0	0.18	0
3	358.43	0.005	1.04	0

Table-3: Result Table for Case 1

11.2 Case 2

During this case, the robot motion is considered to reach to desired position. Servo motor is considered to drive the mechanism. Hence, while tracing the points of workspace various radial forces and joint torques are considered. The analysis of full robot assembly is performed in ansys. The results are obtained for deformation and equivalent stresses. There are chances of buckling of ball screw while achieving the desired position. Hence analysis is performed to improve the design and optimize the material.

The following figure shows analysis results for stresses on full model.

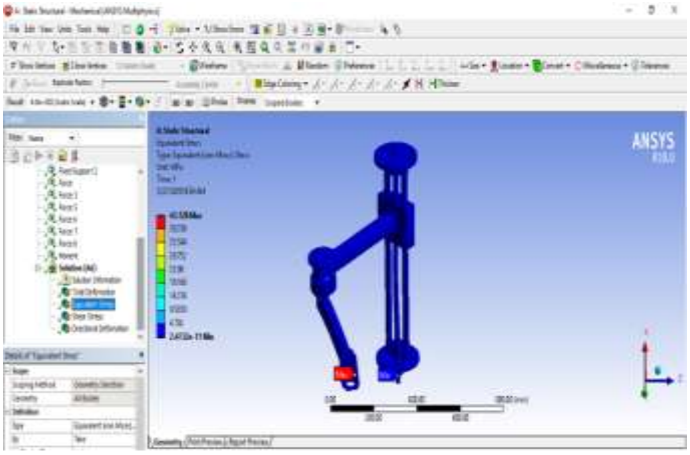

Fig-14: Von-Mises Stress Analysis on full model

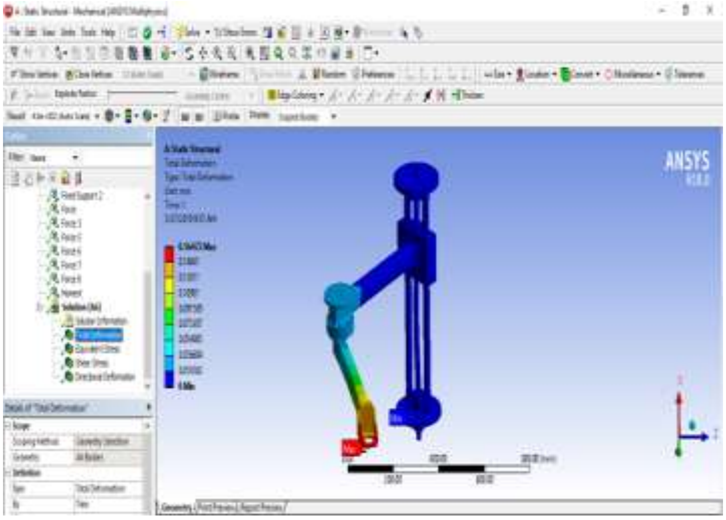

Fig-15: Deformation Analysis of full model

The following result table shows the results for the robot with maximum and minimum deformation and stresses.

Von-Mises Stress(MPa)		Deformation(mm)	
Max	Min	Max	Min
41.52	2.47×10^{-11}	0.167	0

Table4: Result Table for Case 2

11. CONCLUSION

Thus, from analysis results we can conclude that the designed configuration of SCARA Robot for Nut tightening and loosening application is perfect for manufacturing. The motion study performed in solid edge shows that the robot satisfies locus of all points present on the workspace. Results obtained from analysis on Ansys software, we can conclude that the links of the robotic arm can sustain the forces imposed on it due to Nut running operation. The robot designed is of PRR configuration which is a new development for this type of robot in nutrunner application. A small workspace is considered in this design of robotic arm. Similarly this robotic arm can be designed for larger workspace and can be manufactured.

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