INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 5, Issue - 6, June – 2019
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Scientific Journal Impact Factor: 6.497
Received on : 21/06/2019 Accepted on : 29/06/2019 Publication Date: 30/06/2019

Implementation of 5-dofs automatic screwing robotic arm (prototype)

[1] Ei Ei Wai, [2] Mon Mon Aye

[1] Ei Ei Wai, University of Technology (Yatanarpon Cyber City), Pyin Oo Lwin, Myanmar
[2] Mon Mon Aye, University of Technology (Yatanarpon Cyber City), Pyin Oo Lwin, Myanmar
Email - [1]eieiwai.mech@gmail.com , [2]monmonaye.mech@gmail.com

Abstract: *The main focus of this paper is the design consideration and implementation of automatic screwing robot arm for prototyping in factory automation. 5DOFs (base linear movement, vertical arm link, horizontal arm link, pitch joint & roll joint, and the rotating tool of spindle) articulated robot arm is designed for screwing operation with 15mm (~0.5in) thread length screw on (3D-Plane) XY, XZ, and YZ planes. Spindle is considered as the end effector. For articulation, suitable selection of motor for each joint of rotation of robot arm is one part of the design considerations of implementation. Servo motors are used as the actuator for each joint and stepper motor is used for base movement. Steel hollow bar was used to build the robot frame and acrylic board was used to build the robot arm links. The task of this robotic arm was to perform the repetitive and complex job to be automated for more precise, reliable and accuracy. Necessary conditions for the precise positioning of an articulated robotic arm are determined.*

Key Words: *Articulated Robot Arm, Servo Motor, End Effector, Screwing, 3D-Plane.*

1. INTRODUCTION:

Robots in automation technology have become important over a wide range of applications from manufacturing to surgery for the handling of hazardous materials. Emerging application areas, such as safe robotics greatly enable the extension of robot automation to new application process in different industry segments. Successful realization of industrial robotic structure that is adopted for the design.

A robot is a machine constructed as an assemblage of joined links so that they can be articulated into desired position by a programmable controller precision actuators to perform a variety of tasks. Robot range from simple devices to very complex and intelligent systems by virtue of added sensors, computers and special features.

This paper approaches the robotic technology for the design consideration of automatic screwing robotic arm used in factory automation.

2. EDUCATIONAL GOALS:

- To develop an evaluation method, which can be applied in the early stages of the design process, for selecting the most suitable robot structure for executing new processes in emerging application areas,
- To familiarize the students with the design process- from brainstorming, initial design, prototyping, testing, revising, to final production and competition.
- To allow students to experience the perilous designer/builder interface.
- To spark student's interest in Science and Technology.
- To improve the manufacturing processes' speed, efficiency, quality, productivity by purchasing a automation system with robotic arm.

3. APPLICATION AREA:

This research can be applied for the manufacturing lines in factories, picked & placed operation, material transfer, automated assembly, metal cutting, welding, taping, machining, welding, painting & adhesive operations. It can be easily fitted with almost any tool, including a hand-like clamp, a welding torch, a camera, or other sensors that can be relayed to computer and allows to perform a large variety of tasks.

4. METHODOLOGY:

This research adopts through the design as a research methodology, which is based on the action-reflection approach in an experimentation setting. The experiential knowledge is gained on how to evaluate for the robot structures based on various requirements. This is done by carrying out simulation-based evaluation tasks on serial and parallelogram linkage articulated structures.

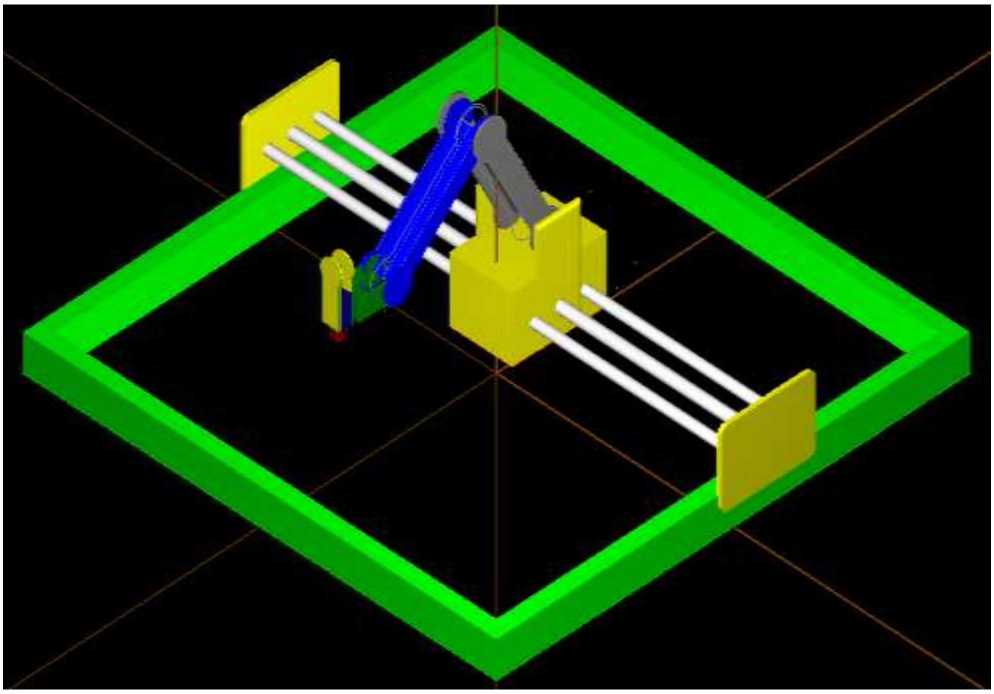


Figure:1 Modeling of 5DOFs Articulated Robotic Arm

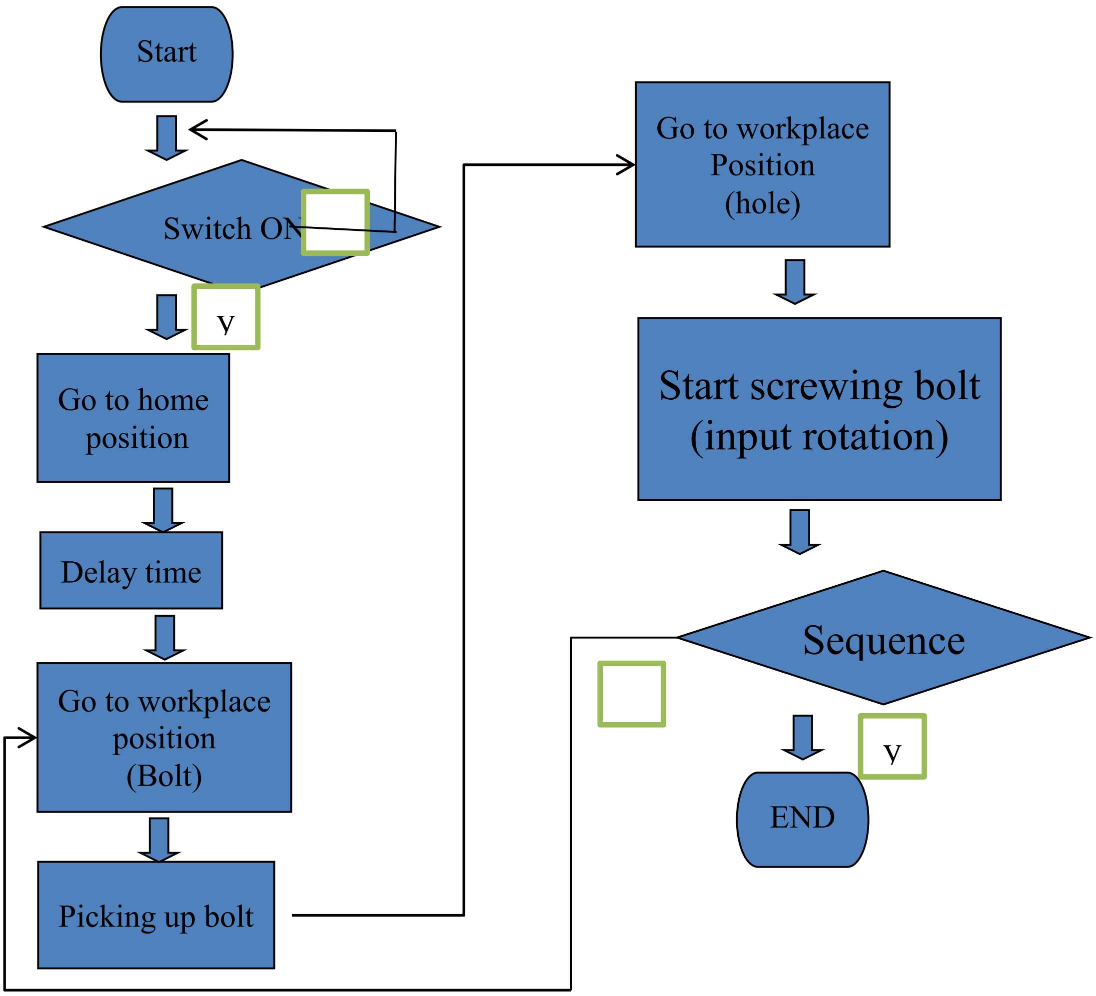


Figure:2 Flow Chart of Overall Diagram

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 5, Issue - 6, June – 2019
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Scientific Journal Impact Factor: 6.497
Received on : 21/06/2019 Accepted on : 29/06/2019 Publication Date: 30/06/2019

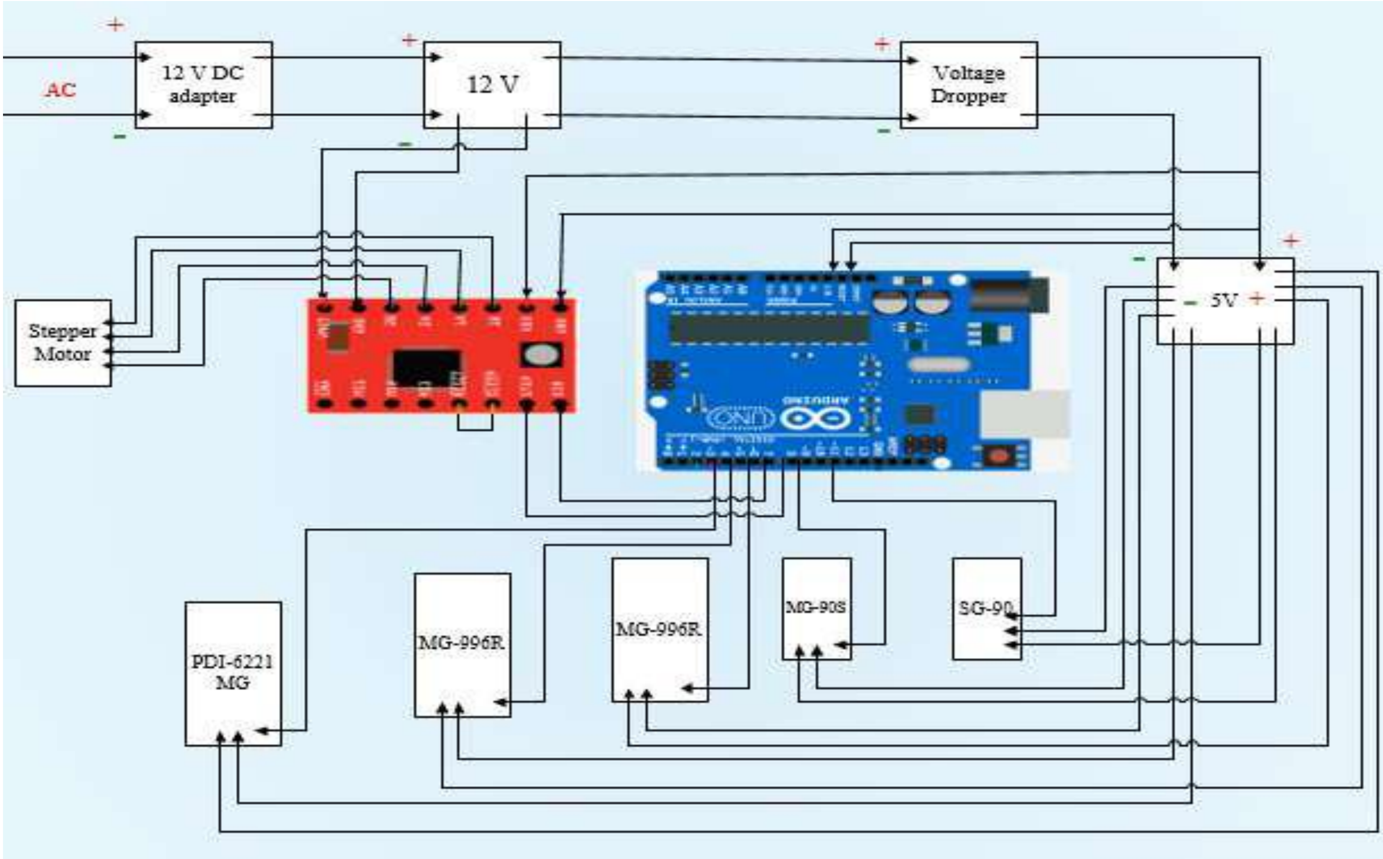
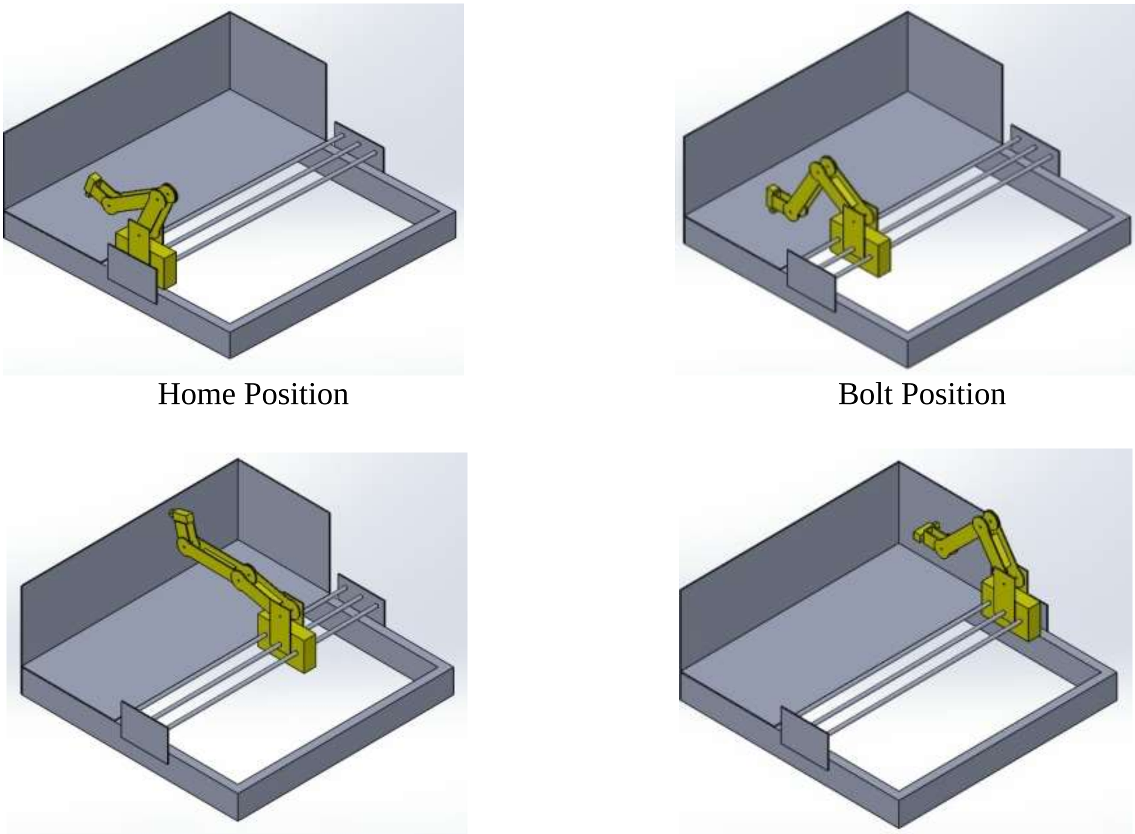


Figure:3 Overall Circuit Diagram



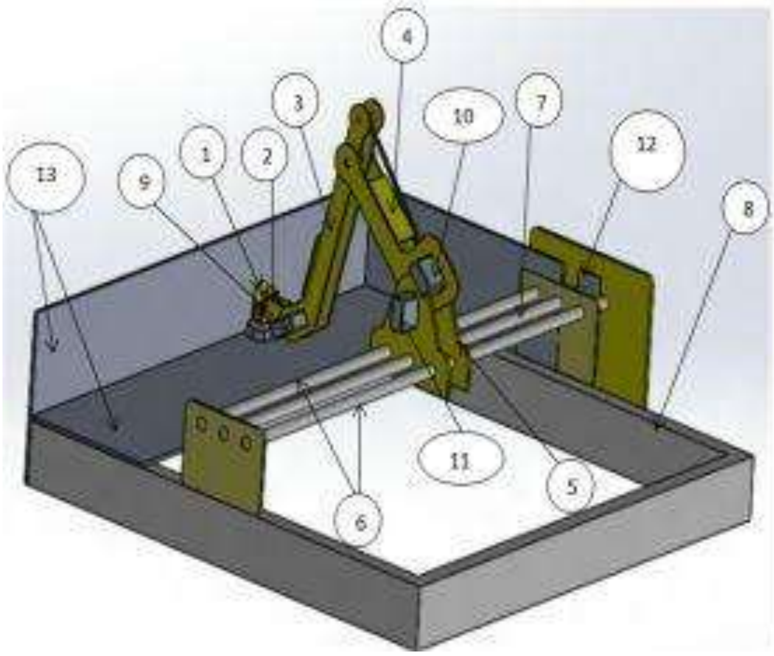
Home Position

Bolt Position

Workplace Position

Workplace Position

Figure: 4 Working Steps of Robot Arm



No.	Description	QTY
1	End Effector (Spindle)	1
2	Wrist Link	1
3	Horizontal Arm	1
4	Vertical Arm	1
5	Base Link	1
6	Linear Shaft	2
7	Lead screw	1
8	Base Frame (Square)	1
9	MG 90S Servo	2
10	MG 996R Servo	1
11	PDI-6221MG Servo	1
12	Nema 17 Stepper Motor	1
13	Planes	2

Figure: 5 Components of Automatic Screwing Robotic Arm

5. MATERIAL SELECTION FOR ROBOT ARM:

Robot arm need to have lower density and high fatigue strength. Acrylic is chosen because it offers a high strength-to-weight ratio. Acrylics has high rigidity and relevant yield strength and ultimate strength. Acrylics is an amorphous thermoplastic which is unaffected by moisture, aqueous solutions of most laboratory chemicals. Acrylics are easily sawed, drilled, milled, engraved, and cut surfaces may be readily sanded and polished. They are available in extruded, sheet, rod and tube forms as well as custom profiles. However, acrylics are not recommended for use with chlorinated or aromatic hydrocarbons, or esters.

6. SPECIFICATIONS FOR IMPLEMENTATION:

The structure of robot arm is constructed using arcylic which is lightweight and the robot arm design is the articulated robot which is most common type of industrial robot. Depending on the robot structure, the detail specifications of the robot are described as follows:

Degree of freedom	**5 DOF**
Material	**Acrylic**
Actuator	**Servos and stepper**
Controller	**Arduino**
Workpiece screw weight	**10 g**
Workpiece screw diameter	**6 mm**
Workpiece screw length	**15 mm**
Twisted torque of spindle	**0.196 Nm**
Spindle RPM	**83 rpm**
Vertical arm rotation angle	**70 degree(max.)**
Horizontal arm rotation angle	**65 degree(max.)**
Wrist pitch rotation angle	**150 degree(max.)**
Wrist roll rotation angle	**150 degree(max.)**
Base Translational movement	**580 mm (max.)**
Length of first link	**48 mm**
Length of second link	**200 mm**
Length of third link	**180 mm**
max. horizontal reach	**377 mm**
mini. horizontal reach	**158 mm**
max. vertical reach	**333 mm**
mini. vertical reach	**0 mm**

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 5, Issue - 6, June – 2019
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Scientific Journal Impact Factor: 6.497
Received on : 21/06/2019 Accepted on : 29/06/2019 Publication Date: 30/06/2019

Table.1 Mechanical Properties of Acrylic

Properties	Metric
Yield strength	64-83 MPa
Ultimate strength	40-110 MPa
Shear strength	25-62 MPa
Density	1180kg/cm^3
Modulus of elasticity	2.76-3.30 GPa
Thermal conductivity	0.187-0.209 W/m-K
Poisson's ratio	0.37
Coefficient of Friction	0.45-0.80
Melt Temperature	130°C (266°F)
Factor of safety	8

7. DESIGN CALCULATION FOR ARM LINKS:

Weight Calculation for End Effector,

Material = Acrylic

Thickness = 3 mm

Density, ρ = 1.18 g/cm3

Volume, V = 2.639 cm3

Mass, m = ρV = 1.18 × 2.639 = 3.11 g

Weight, W = mg = 3.11× 9.81 = 0.03 N

Weight of servo = 9 × 9.81 = 0.088 N

Weight of Hex. Head = 3.32 × 9.81 = 0.033 N

Weight of End Effector = 0.224 N

Roll joint servo motor torque = 2 kg.cm = 0.196 Nm

The torque due to spindle = (0.088 + 0.033) × 30 + 0.06 ×30×8.69 = 0.00544 Nm

Motor torque > Exerted torque

So, MG 90S servo motor is satisfied for roll joint in this design.

Table.2 Results of Calculation for Links & Motor Selection

Description	Arm Link	Wrist Link	Horizontal Arm	Base Link	Vertical Arm
Volume (V)	2.639 cm^3	5.013 cm^3	25.051 cm^3	56.762 cm^3	33.224 cm^3
Weight (W)	0.03 N	0.059 N	0.294 N	0.657 N	0.385 N
Thickness (t)	3 mm	3 mm	3 mm	6 mm	6 mm
Torque (T)	0.005 Nm	1.021 Nm	1.021 Nm	0.058 Nm	1.942 Nm
Motor	MG 90S Servo Motor	MG 996R Servo Motor	MG 996R Servo Motor	Stepper Motor	PDI 6221MG Servo Motor

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 5, Issue - 6, June – 2019
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Scientific Journal Impact Factor: 6.497
Received on : 21/06/2019 Accepted on : 29/06/2019 Publication Date: 30/06/2019

8. CALCULATION OF TORQUE FOR LEAD SCREW:

D_o **= 8 mm,** D_c**= 6 mm**

$$D_m = \frac{D_o + D_c}{2} = 7\text{mm}$$

r_m **= 3.5 mm**

The loaded weight on screw = 5.091 N

$$D_m = D_o - \frac{p}{2} \;,$$

$$7 = 8 - \frac{p}{2}$$

p = 2 mm

For four start screw,lead = 4 × 2 = 8 mm

$$\tan\alpha = \frac{\text{lead}}{\pi d} = \frac{8}{7\pi} = 0.364$$

The coefficient of friction of steel, μ = 0.53

tan θ = 0.53

The coefficient of friction at collar, μis negligible.

$$P = W\tan(\alpha+\theta) = W\left(\frac{\tan\alpha + \tan\theta}{1 - \tan\alpha\tan\theta}\right) = 5.091 \times \frac{0.364 + 0.53}{1 - 0.364 \times 0.53} = 5.639\text{ N}$$

$$T = P \times \frac{d}{2} + \mu WR = 5.639 \times 3.5 + 5.091 \times \frac{12+3}{2} = 58\text{ Nmm} = 0.058\text{ Nm}$$

Stepper motor torque = 0.196 Nm

Stepper motor torque is greater than the required torque. So, this type of power screw is satisfied.

9. TORQUE CALCULATION FOR WORKPIECE SCREW:

D_o**= 6.5 mm,** D_c**= 5 mm**

$$D_m = \frac{D_o + D_c}{2} = 5.75\text{mm}$$

r_m**= 2.875 mm**

The loaded weight on screw = 0.05 N

$$D_m = D_o - \frac{p}{2}$$

$$5.75 = 6.5 - \frac{p}{2}$$

P=1.5 mm

For single start screw,

lead = p = 1.5 mm

$$\tan\alpha = \frac{\text{lead}}{\pi d} = \frac{1.5}{5.75\pi} = 0.083$$

The coefficient of friction of steel, μ = 0.4

tan θ = 0.4

The coefficient of friction at collar, μis negligible.

$$P = W\tan(\alpha+\theta) = W\left(\frac{\tan\alpha + \tan\theta}{1 - \tan\alpha\tan\theta}\right) = 0.05 \times \frac{0.083 + 0.4}{1 - 0.083 \times 0.4} = 0.25\text{ N}$$

$$T = P \times \frac{d}{2} + \mu WR = 0.25 \times 2.875 + 0.05 \times \frac{7+3}{2} = 0.968\text{ Nmm} = 9.68 \times 10^{-4}\text{ Nm}$$

Spindle motor torque = 0.196 Nm

Spindle motor torque is greater than the required torque.

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 5, Issue - 6, June – 2019
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Scientific Journal Impact Factor: 6.497
Received on : 21/06/2019 Accepted on : 29/06/2019 Publication Date: 30/06/2019

So, the spindle motor can drive the workpiece screw.

10. BENDING MOMENT CALCULATION FOR SHAFT:

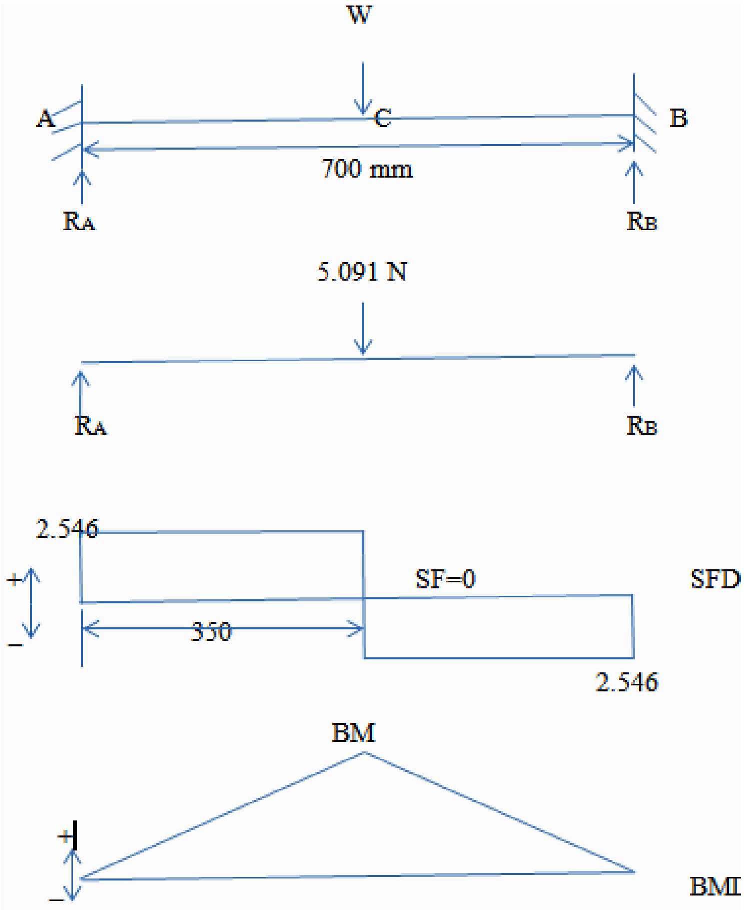


Figure.6 Bending Moment Diagram

Span AC (0< x < 350)

$F_{xx} = +\frac{W}{2}$ **(constant)**

$M_{xx} = +\frac{W}{2} \times x$

$x = 0, \; M_A = 0$

$x = 350, M_c = \frac{W}{2} \times 350 = 891$ **Nmm**

Span BC (0<x<350)

$F_{xx} = -\frac{W}{2}$ **(constant)**

$M_{xx} = \frac{W}{2} \times x$

$x = 0, \; M_A = 0$

$x = 350, M_c = \frac{W}{2} \times 350 = 891$ **Nmm**

$\Sigma M_A = 0$ **(clockwise+)**

$5.091 \times 350 - R_B \times 700 = 0$

$R_B = 2.546$ **N**

$\Sigma F_y = 0$ **(^ +)**

$R_A + R_B - 5.091 = 0$

$R_A = 2.546$ **N**

Yield strength of steel = 250 MN/m^2

Allowable bending stress, $\sigma_{allow} = \frac{\text{yieldstress}}{\text{safetyfactor}} = \frac{250}{4} = 62.5\frac{MN}{m^2} = 62.5\frac{N}{mm^2}$

Maximum bending moment, M = 891 Nmm

$$I = \frac{\pi}{64d^3}$$

Bending Theory, $\frac{M}{I} = \frac{\sigma}{y}$

$$\frac{891}{\frac{\pi}{64d^3}} = \frac{62.5}{\frac{d}{2}}$$

d = 5.25 mm

If d = 8 mm,
Maximum bending stress, $\sigma_{max} = 17.726\ N/mm^2$
Allowable bending stress, $\sigma_{allow} = 62.5\ N/mm^2$
Since $\sigma_{max} < \sigma_{allow}$ **,**
Dimensions of shaft are satisfied.

11. FABRICATION OF ROBOTIC ARM:

The dimensions of each link parameters must be decided and calculated for the design of robot arm. The structure of the robot arm is built with acrylic sheets in order to decrease the overall weight of the robot. The arm is attached to a base steel frame which is the most bottom part of the robot. It is important to mention that the base ought to have considerably heavy weight in order to maintain the general balance of the robot in case of grabbing an object. The developed robot in this research is a translation articulated 5DOFs robot arm with prismatic and revolute joints. The acrylic sheets can be made the necessary holes and cut in order to connect the parts to each other and to keep the actuators tightly. All the parts are cut and drilled according to the Master CAM application software. And then, all parts are assembled. The fabrications of 5DOFs robot model are shown in figure.

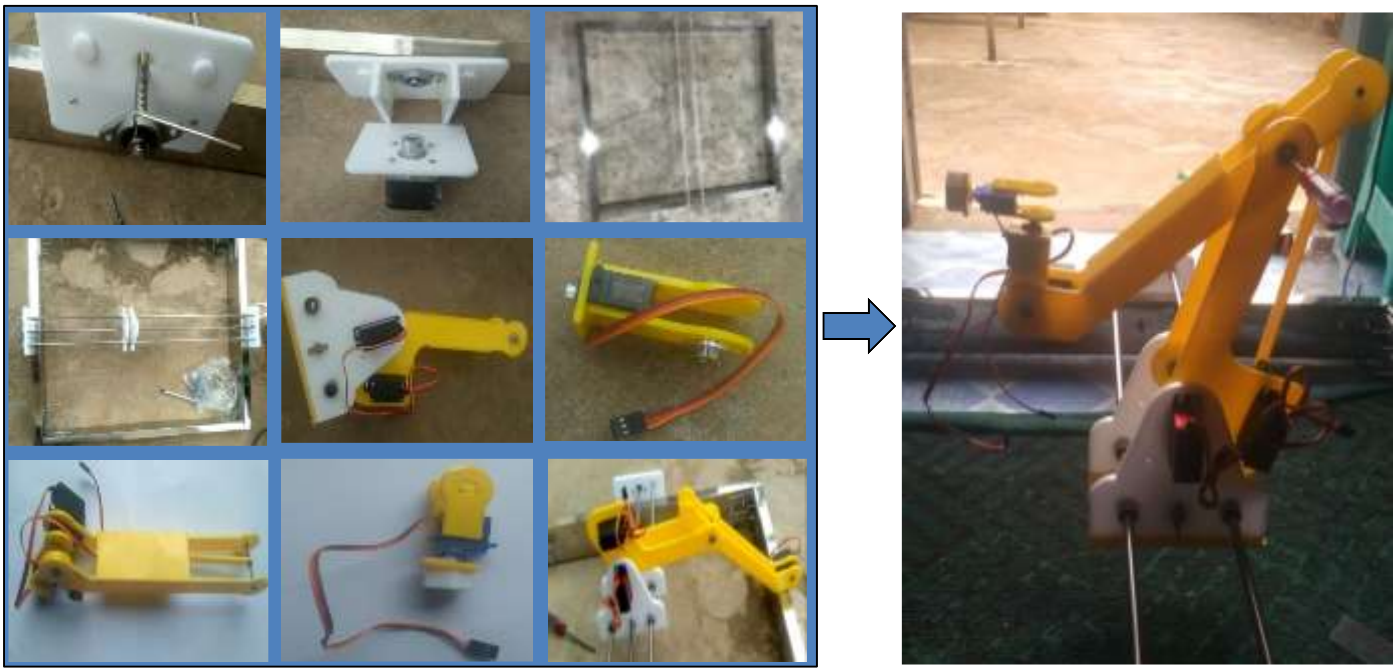


Figure.7 Experimental Test Run

12. SOFTWARE IMPLEMENTATION:

The Automatic Screwing Robot Arm is controlled by commending the Arduino MEGA. According to the working pocedure, the control of servo motors (for robot arm) and the stepper motor (for linear translation) of the robot arm is programmed by using the results from kinematics calculations.

Firstly, The servo motors are installed by adjusting the default angles to 0 degree. Secondly, the calculated degree (35) is put for moving the robot arm to the next position. The speed limit of servo motor can be adjusted by microsecond.

The direction pin and step pin are defined at the start of the program. The NEMA-17 hybrid stepping motor is used as a unipolar stepping motor and has a 1.8º step angle (200 steps per revolution). The thread lead angle of the shaft is 8mm per one revolution. So the value 6250 can be calculated for the distance of 250 mm.The direction of the motor can be reversed by setting the step pin from LOW to HIGH.

The attach and detach function is used for enabling the spindle rotation ON and OFF. The direction can be reversed by setting the value over 2000 in Microseconds function.

13. RESULTS OF PERFORMANCE TASK :

The working procedure of the robot arm is shown in figure. The robot arm is at home position when the program is started. The robot arm go to the bolt position and pick up bolt. The robot arm go to the workplace(hole) position and start screwing with input rotation. And then, The robot arm go back to bolt position and pick up and go to the workplace(hole) position on another plane for screwing. After the working procedure is finished, the robot arm go back to home position and stop.

The operation and circuit diagram of the complete system is expressed. The implementations of the hardware and software control system have been described. Experimental results of the system are described.

At home position **At bolt position** **At picking up a bolt** **At workplace position**

Figure.8 Experimental Test Run

14. BENEFITS :

This articulated robot arm can perform many tasks in manufacturing processes, like welding, painting, product inspection, product testing, and more, depending on what the end effecter is. It reduces the man power and might have a good effect on production rate.

15. CONCLUSION & DISCUSSION:

In this paper, design consideration and fabrication of automatic screwing robot arm is described. The mechanical robot arm is designed as a prototype of the robot arms. Robotic arm with 5 DOFs (degree of freedom) is designed for desired work option. Five Servo motors are used as the actuator for each joint of the robot arm. One stepper motor is used for base linear movement. Steel hollow bar is used to build the robot frame and acrylic board is used to build the robot arm links. For articulated robot arm, selection of material and selection of motor are described by calculating the applied torque on this robot arm. The torques at the actuator will result by using the object's weight and the density of robotic body's material, and length. Suitable motor can be chosen by these torques. Arduino is used as a main controller. Weight and diameter of work-piece screw are 10 g and 6.5 mm. It is 15 mm long in thread length. Twisted torque of spindle is 0.196 Nm and spindle RPM is 83 revolution per minute. The vertical and horizontal links of robot arm can rotate 100 degree(max.). Wrist pitch and roll of robot arm can rotate 150 degree(max.). The robot arm can travel linearly by 580 mm (max.). Lengths of first, second and third links are 48 mm, 200 mm and 180 mm respectively. Maximum and minimum horizontal reach of robot arm are 377 mm and 158 mm. Maximum and minimum vertical reach of robot arm are 333 mm and 0 mm respectively. The performance of a robot arm with respect to control accuracy and mechanical efficiency is based on the effects of manipulator gravity. During the work cycle, a manipulator must accelerate, move at constant speed and decelerate. This time varying torque is applied at the joints to balance the internal and external force. This paper is emphasized theoretical aspects of design and construction system of robot arm. Servo motors, stepper motor, lead screw, steel solid shaft, steel hollow bar, acrylic sheet, A4988 motor driver are implemented in this research. PDI 6221 MG servo motor, MG 996R servo motors and NEMA 17 stepper motor can be used for this design safety. The screwing processes can be done by controlling the servo and stepper motor using Arduino. Motor control is also important for the robot's moving direction because it has precision of position for the robot. This design can be applied in the area of factory automation where the assembly process cannot be done by human power. Moreover, it can be applied in the non-stop manufacturing factories such as automobile industries.

The robot arm can be made more flexible by using different link lengths. Spindle rotation can be modified by using sensors or can be limited between allowable torque. By changing the control system and the end effector, the robot arm can operate more processes like pick and place operation. Therefore, this design is not fixed option for the whole system. In the future, it can be changed according to the need for industrial processes. In designing the robot components, design calculation of each links, finger and actuator is all under satisfied level but test should be carried out by using software for more accurate result. By changing acrylic to the aluminum, the design will be more satisfied and the required ultimate strength and yield strength are not changed too much by changing material. One more joint is set up at base as a rotation joint, the robot can approach the object with greater approach angles and more work envelope.

REFERENCES:

1. A.N.W.Qi, K.L.Voon, M.A.Ismail, N.Mustaffa, M.H.Ismail (2015), Faculty of Mechanical Engineering, Universitiy Malaysia Pahang, "Design and Development of a Mechanism of Robotic Arm for Lifting".
2. F.C.Park and K.M.Lynch, (2016) "Introduction to Robotics Mechanics, Planning, and Control" Frank L.
3. Lewis, Darren M. Dawson, and Chaouki T. Abdallah (2004), "Robot Manipulator Control: Theory and Practice(Second Edition, Revised and Expanded)".
4. James M. Gere and Professor Emeritus (2004), Stanford University, "Mechanics of Materials (sixth edition)".
5. John.J.Craig(2005), "Introduction to Robotics Mechanics and Control (third edition)".
6. R.S. KHURMI and J.K. GUPTA, (2005)"A Textbook of Machine Design (fourteenth edition)".
7. https://www.RobotShop Distribution Inc.com/History of Robotics Timeline
8. https://www.Engineering ToolBox.com