IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e- ISSN: 2278-1684, p-ISSN : 2320–334X
PP 42-53
www.iosrjournals.org

DESIGN AND ANALYSIS OF AN ARTICULATED ROBOT ARM FOR VARIOUS INDUSTRIAL APPLICATIONS

S.Pachaiyappan[1] , M.Micheal Balraj[2], T.Sridhar3
[1&2](Assistant Professor , Department of Mechanical Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamil Nadu, India)
[3] (PG Scholar , Department of Mechanical Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamil Nadu, India)
[1]balrajmicheal@gmail.com , [2]pachaisachi@gmail.com, [3]thamusridhar@gmail.com

ABSTRACT: *Nowadays Robots play a vital role in all the activities in human life including industrial needs. In modern industrial manufacturing process consists of precise and fastest proceedings. Human operations are needed to perform a variety of tasks in a robotic system such as set-up, programming, trouble shooting, maintenance and error handling activities. Hazardous conditions exist when human operators intervene into the robotic work zones. Human perception, decision making, and action strategies need to be studied to prevent robot-related accidents. System designers and technology managers are required to consider the limitations of operator perceptual process in design and layout of robotic system. The ultimate object is to save human lives in addition to increasing productivity and quality of high technology work environments. Effective safety training programs for work with industrial robots should be developed. The objective of this project is to design, analysis of a Generic articulated robot Arm. Articulated robot has been noted for application in traversing and performing manipulation in nuclear reactor facilities. Some aspects of the articulated Robot that are anticipated as useful are its small cross section and its projected ability to change elevation and maneuver over obstacle. The small cross section and the loads associated with suspension of the Robot while changing elevation or maneuvering over obstacles require large joint torque to weight rations for joint actuation. A novel joint actions actuation scheme is described and its implementation detailed in this project.*

Keywords*: articulated robot. Manipulation, Novel joint, obstacles, robotic work zones*

1. INTRODUCTION

At present, the main interest is to protect nuclear workers in highly contaminated areas or hostile environments, robots can be used in nuclear power plants to reduce human exposure not only to radiation, but also to hot, humid and oxygen-deficient atmosphere researchers in the field of robotics are proposing a great variety of robots configurations and functional capabilities to be used in nuclear power plants. Wheeled robots and tracked vehicles are the common configurations for mobile robots.

The robotic system is made up of three main sub-systems: sensory head; teleportation and control panel; and mobile robot, vision, sound and temperature cover 90% of all inspections tasks required in BWR nuclear power plants pan-tilt mechanism. So it can be easily plugged into different mechanical robots. Video camera used inspection purpose, stereo vision equipment, produced by stereo Graphics, has been integrated in the tele-operation panel.

This stereo system is of great use in guiding the mechanical robot through cloistered areas. The telepresence is completed with a stereophonic bidirectional audio set, which also provides signals for sound inspection. To carry out close inspection tasks of the vacuum vessel first wall using a long reach robot is called the “Articulated Inspection Arm” (AIA).

Significant stress and high deformations in bending and torsion occur in the structure. The load depends on the articulated structure. The model has to be realistic to have a good knowledge of the end-effectors position.

The model of the complete robot is the assembly of the five elementary models described before. It gives the deformation and position of the structure for any given joint position and loads. The calculation is iterative due to the non-linearities induced by the large displacements and the cumulative effect of the deformations.

2. A BRIEF HISTORY OF ROBOTS

Leonardo da Vinci created many robot-like sketches and designs in the 1500's.The word **robot** first appeared in print in the 1920 play R.U.R. (Rossum's Universal Robots) by **Karl Kapek**, a Czechoslovakian playwright. **Robota** is Czechoslovakian for worker or serf (peasant). Typical of early science fiction, the robots take over and exterminate the human race.

Isaac Asimov popularized the term robotics through many science-fiction novels and short stories. Asimov is a visionary who envisioned in the 1930's the positronic brain for controlling robots; this pre-dated digital computers by a couple of decades. Unlike earlier robots in science fiction, robots do not threaten humans since Asimov invented the three laws of robotics:

1. A robot may not harm a human or, through inaction, allow a human to come to harm.
2. A robot must obey the orders given by human beings, except when such orders conflict with the First Law.
3. A robot must protect its own existence as long as it does not conflict with the First or Second Laws.

Joseph Engleberger and **George Devoe** were the fathers of industrial robots. Their company, animation, built the first industrial robot, the **PUMA** (**P**rogrammable **U**niversal **M**anipulator **A**rm, a later version shown below), in 1961.

2.1 ROBOTIC SYSTEMS

Typically, robots are used to perform jobs that are difficult, hazardous or monotonous for humans. They lift heavy objects, paint, weld, handle chemicals, and perform assembly work for days at a time without suffering from fatigue. Robots are defined by the nature of their movement. This section describes the following,

2.2 CLASSIFICATIONS OF ROBOTS

- Cartesian
- Cylindrical
- Polar
- Articulated
- Scara

2.3 ROBOT PARTS

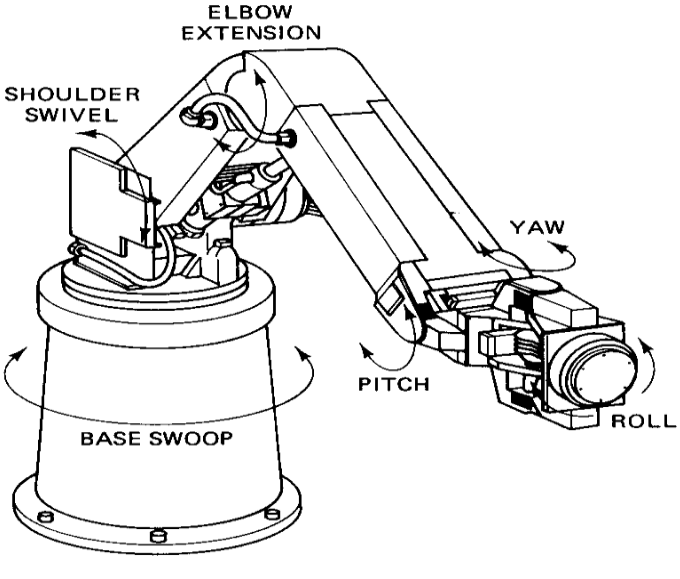


Fig 2.3.1 Parts of Robotic Arm

2.3.1 TECHNICAL ROBOTICS TERMS

SPEED

Speed is the amount of distance per unit time at which the robot can move, usually specified in inches per second or meters per second. The speed is usually specified at a specific load or assuming that the robot is carrying a fixed weight. Actual speed may vary depending upon the weight carried by the robot.

LOAD BEARING CAPACITY

Load bearing capacity is the maximum weight-carrying capacity of the robot. Robots that carry large weights, but must still be precise are expensive.

ACCURACY

Accuracy is the ability of a robot to go to the specified position without making a mistake. It is impossible to position a machine exactly. Accuracy is therefore defined as the ability of the robot to position itself to the desired location with the minimal error (usually 0.001 inch).

REPEATABILITY

Repeatability is the ability of a robot to repeatedly position itself when asked to perform a task multiple times. Accuracy is an absolute concept, repeatability is relative. Note that a robot that is repeatable may not be very accurate. Likewise, an accurate robot may not be repeatable.

WORK ENVELOPE

Work envelope is the maximum robot reach, or volume within which a robot can operate. This is usually specified as a combination of the limits of each of the robot's parts. The figure below shows how a work-envelope of a robot is documented.

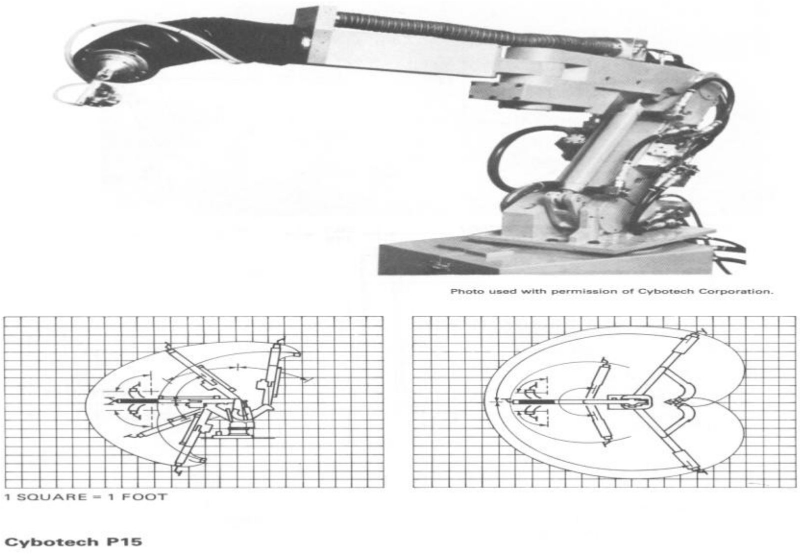


Photo used with permission of Cybotech Corporation.

Fig2.3.2 Work cell Arrangements

WORKCELLS

Robots seldom function in an isolated environment. In order to do useful work, robots must coordinate their movements with other machines and equipment, and possibly with humans. A group of machines/equipment positioned with a robot or robots to do useful work is termed a workcell. For example, a robot doing welding on an automotive assembly line must coordinate with a conveyor that is moving the car-frame and a laser-positioning / inspection robot that uses a laser beam to locate the position of the weld and then inspect the quality of the weld when it is complete.

ROBOTIC SYSTEM COMPONENTS

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

MECHANICAL STRUCTURE

This comprises all of the linkages and joints capable of movement.

ACTUATOR

The mechanism that provides the necessary forces to move the mechanical structure.

CONTROLLER CIRCUIT

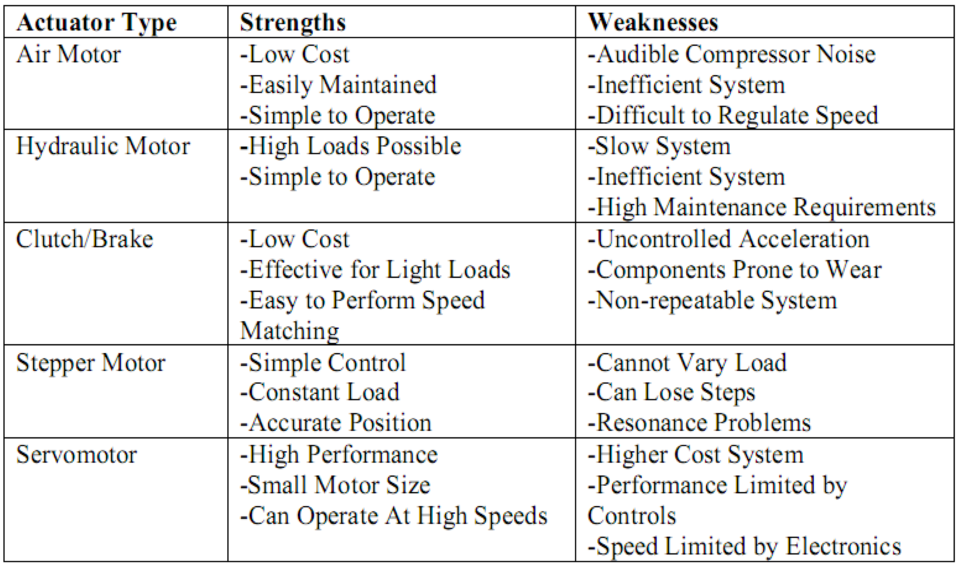
Supplies the actuators with the input required to achieve the desired position, force, speed, etc. The design of the mechanical structure will be discussed in Chapter III. Actuators and controller circuits will be reviewed here.

ACTUATOR TYPES

The proper selection of actuator will dictate how effective 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 Motors
- Clutch/Brake
- Stepper Motors

Table 1: Actuator Comparison



Actuator Type	Strengths	Weaknesses
Air Motor	-Low Cost -Easily Maintained -Simple to Operate	-Audible Compressor Noise -Inefficient System -Difficult to Regulate Speed
Hydraulic Motor	-High Loads Possible -Simple to Operate	-Slow System -Inefficient System -High Maintenance Requirements
Clutch/Brake	-Low Cost -Effective for Light Loads -Easy to Perform Speed Matching	-Uncontrolled Acceleration -Components Prone to Wear -Non-repeatable System
Stepper Motor	-Simple Control -Constant Load -Accurate Position	-Cannot Vary Load -Can Lose Steps -Resonance Problems
Servomotor	-High Performance -Small Motor Size -Can Operate At High Speeds	-Higher Cost System -Performance Limited by Controls -Speed Limited by Electronics

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 specific actuators will be discussed in some detail along with open and closed loop systems.

STEPPER MOTORS

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.

SERVOMOTORS

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 13 diagrams the operation of a typical servo system.

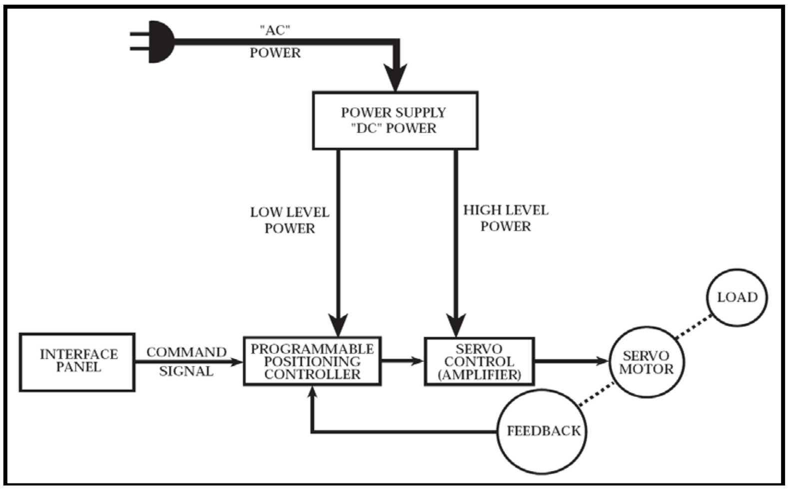


Fig 2.3.4 The Concepts of Servo System

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

- Permanent Magnet DC Motor
- Brushless DC Motor
- Induction AC Motor

Electromagnetic motors operate based on the principle that the magnetic force on an electrical conductor in a magnetic field is perpendicular to that field. This force is defined by,

$$\mathbf{F= qv*B}$$

Where:

F is the vector describing the magnetic force
q is the magnitude of the electrical charge
v is the vector magnitude of the charged particle's velocity
B is the vector describing the magnetic field

However, in the case of an electric motor the force can be quantified as a scalar

$$\mathbf{F=I*L*B}$$

Where:

F is the magnetic force
I is the electric current in the coil
L is the length of the coil contained within the magnetic field
B is the strength of the magnetic field

1.4 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 counterclockwise (figure 14).
Since the motor shaft will rotate freely while an electric current is present, an encoder must be used to provide feedback to a controller.

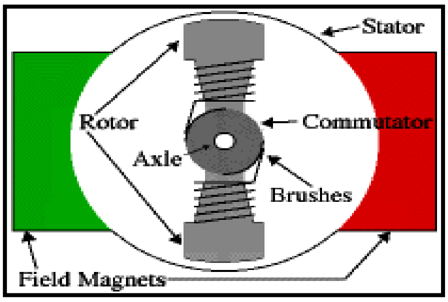


Fig2.4 Permanent Magnet DC Motor

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 commuter. Contact between the two components causes friction and can be disrupted at higher speeds. A brushless DC motor addresses these issues.

1.5 BRUSHLESS DC MOTOR

A brushless DC motor replaces the commutator and brushes with an electronic controller. This controller maintains the proper current in the stationary coils. Figure 15 shows a basic diagram of a brushless DC motor.

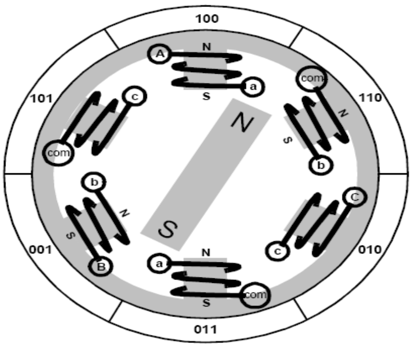


Fig 2.5 Brushless DC Motor

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 Effect 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 justified by the increased performance and elimination of the maintenance needed to replace the brush contacts.

1.6 INDUCTION AC MOTOR

AC induction motors rely on a minimum of two alternating current signals applied out of phase to cause the motor shaft to rotate. Figure 16 shows how the north pole of the motor shaft is attracted to the active south pole of the magnet. Applying the current out of phase (as shown in figure 17) ensures that when one pole is at its peak current, the opposing signal is equal to zero. This is called a rotating magnetic field since in reality the shaft is not rotating but following the shifting magnetic force.

The AC signal regulates the motor speed based on the frequency of the sine wave and the number of stator poles. The maximum speed the motor could theoretically achieve is called the synchronous speed, and is defined as:

$$N_S = 120 * f / P$$

Where:

N is the synchronous speed of the motor
f is the frequency of the AC signal
P is the number of stator poles

However, in order to create torque, the motor must rotate slower than the synchronous speed. The difference between the two speeds is called slip and is represented as a percentage.

$$s = \frac{100(N_S - N_a)}{N_S}$$

3. AIM OF THE PROJECT

1) The main goal of the project is to design and analysis of an articulated robot arm for inspection purpose.
2) To design the robotic arm using analytical calculation
3) To achieve computer aided modeling of this robot arm using solid works software.
4) To perform the Finite Element Analysis of the designed robot arm for the selected dynamic condition using the ANSYS software.

3.1 DESIGN OF ARTICULATED INSPECTION ARM (AIA)

The design calculations are done using basic formulae from strength of materials. The lengths of the AIAs are calculated considering the distance of the control panels from the core, diameter of the core to be inspected and height of the core. This length is considered invariant with respect to the robot designed. The two variants of cross sections considered are hollow square and hollow circular. Since the electrical and control system wiring to the various motors in the robotic assembly are required to pass through the hollow portion of the arm the inner and hence the outer dimensions are first considered.

Calculations:

Volume of the shaft ,V

$V = \pi/4(d_o^2 - d_i^2) \times \text{Length}$
Considering, $k = d_i / d_o = 0.75$
$d_i = 0.75\, d_o$
Volume, $V = \pi/4\, (d_o^2 - 0.5625\, d_o^2) \times 4$
$V = 1.37\, d_o^2\ m^3$ ---------- Eqn. 1

Mass of the shaft, m

Mass $= \text{volume} \times \text{density}$
$= 1.37\, d_o^2 \times 1.1 \times 10^3$ [Considering, density of nylon = $1.1 \times 10^3\ kg/m^3$]
Mass, $m = 1507\, d_o^2$ ----------- Eqn. 2

Force Acting On the Shaft, F

Force, f =mass x acceleration due to gravity
=1507 d_o^2 x 9.81
F = 14783.67 d_o^2 ----------- Eqn.
3

Power of the motor, P

P = (length of the shaft from the motor x speed of the motor x load acting) / 60

P = 4x 10x14783.67 d_o^2/60
P = 9855.78 d_o^2 KW ---------- Eqn.
4

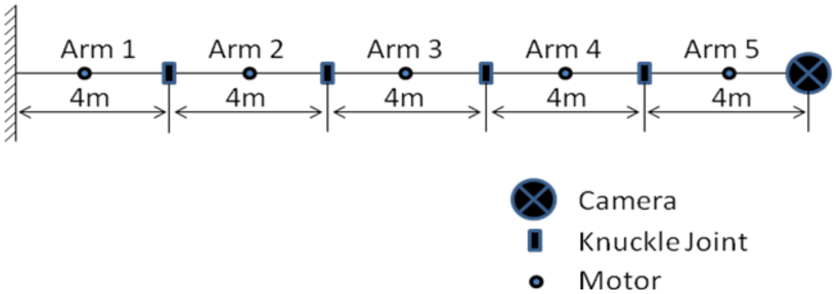


Fig3. 1 Schematic Diagram of the Robotic Arm

Bending moment on the shaft occurs due to

1. Motor
2. Camera
3. Knuckle Joint
4. Weight of the shaft

Bending moment, M =10 x 4(1+2+3+4+5)+(50 x 20)+20X2(1+3+5+7+9)+π/4(d_o^2 - d_i^2) x ρ x 2(1+3+5+7+9)
M = 2600+75350 d_o^2 ----------
Eqn. 5

<u>Calculations based on Torsion:</u>

Equivalent Torsion, Te = $\sqrt{\left[(\text{Km x M}) + \frac{\alpha.\text{F.do}.(1+\text{k}^2)}{8}\right]^2 + (\text{kt x T})^2}$

Radius of gyration, K = $\sqrt{\frac{\text{I}}{\text{A}}} = \sqrt{\frac{\frac{\pi(do^4 - di^4)}{64}}{\frac{\pi(do^2 - di^2)}{4}}} = \sqrt{\frac{0.033\ do^4}{0.343\ do^2}}$

K = 0.31 d_o -----------
Eqn. 6

Column Factor, α = $\frac{1}{1-0.0044\frac{L}{K}}$
= 1 / 1-0.0044(4/.31d_o)
= 0.31d_o/(0.31d_o-0.0176) ------------
Eqn. 7

Torque, T = (P x 60) / (2πN)
= (9855.78 d_o^2 x 60) / 2π x 10

$T = 9411.57\ d_o^2$ KN-m ----------- Eqn. 8

$$T_e = \sqrt{\left[(Km \text{ x } M) + \frac{\alpha.F.do.(1+k^2)}{8}\right]^2 + (kt \text{ x } T)^2}$$

$$= \sqrt{\left[(1.5 \text{ x } (2600 + 75350\ do^2)) + \frac{0.31do \text{ x } 14783.67do^3 \text{ x } 1.5625}{2.48\ do - 0.14}\right]^2 + (1 \text{ x } 9411.57do)^2}$$

------------ Eqn. 9

We also know that,

$T_e = \pi/16 \text{ x } \tau\ d_o^3 \text{ x } (1-k^4)$

$= \pi/16 \text{ x } 7.5\text{x}10^9 \text{ x } d_o^3 \text{ x } 0.68$

$T_e = 1.00138 \text{ x } 10^9 d_o^3$ KN-m ------------- Eqn.10

Equating 9 & 10, we find that,

$d_o = 0.267\text{ m} \approx 0.27\text{ m}$
$di = 0.75 \text{ x } 0.27 = 0.202\text{ m} \approx 0.2\text{ m}$

Calculations based on bending moment :

$$M_e = ½[k_m \text{ x } M + \frac{\alpha.F.do.(1+k^2)}{8} + T_e]$$

$$=1/2[1.5 \text{ x } (2600 + 75350\ d_o^2) + \frac{(0.31\ do \text{ x } 14783.67\ do^3\text{x}1.5625)}{2.48do - 0.14}$$

$$+\sqrt{\left[(1.5 \text{ x } (2600 + 75350\ do^2)) + \frac{0.31do \text{ x } 14783.67do^3 \text{ x } 1.5625}{2.48\ do - 0.14}\right]^2 + (1 \text{ x } 9411.57do)^2}$$

---------- Eqn. 11

And,

$M_e = \frac{\pi}{32} \text{ x } \sigma_b\ (d_o^3)(1-k^4)$

To find σ_b,,

$\frac{T}{J} = \frac{\sigma b}{y}$

$J = \frac{\pi}{32}[d_o^4 - 0.31d_o^4]$

$J = 0.097\ d_o^4\ \ m^4$

Deflection (y) for nylon material would be 0.07 m for every 1 m length

y=0.07 m

$\sigma_b = \frac{T \text{ x } y}{J}$

$= 9411.57\ d_o^2 \text{ x } \frac{0.07}{0.097\ do^4}$

$\sigma_b = 6791.85/\ d_o^2$ KN/m^2

$M_e = \frac{\pi}{32} \text{ x } \frac{6791.85}{do^2} (d_o^3)(0.683)$

$M_e = 455.41\ d_o$ --------- Eqn. 12

Equating 11 & 12, we get

d_o = 0.298 m □ 0.3 m

d_i = 0.75 x d_o = 0.75 x 0.3 = 0.225 m

5) Results and discussion

The maximum displacements of the circular and rectangular sections are 26.638mm and 26.03mm during the first load step i.e., while considering the position of the base arm is at 30 degrees. Considering the 4000mm length of the arm, the deflection is 0.66% in case of circular and 0.65% in case of rectangular section arm. It cumulates to a maximum of 159.83mm in circular and 156.18mm in rectangular section arm. But this is only an elevated estimate since the bending moment and force acting on the arm will also decrease linearly (5-n) with the nth position of the five arms from the base arm. This deflection is negligible and can be controlled while programming the controller for precision. Hence both the models are eligible for further studies.

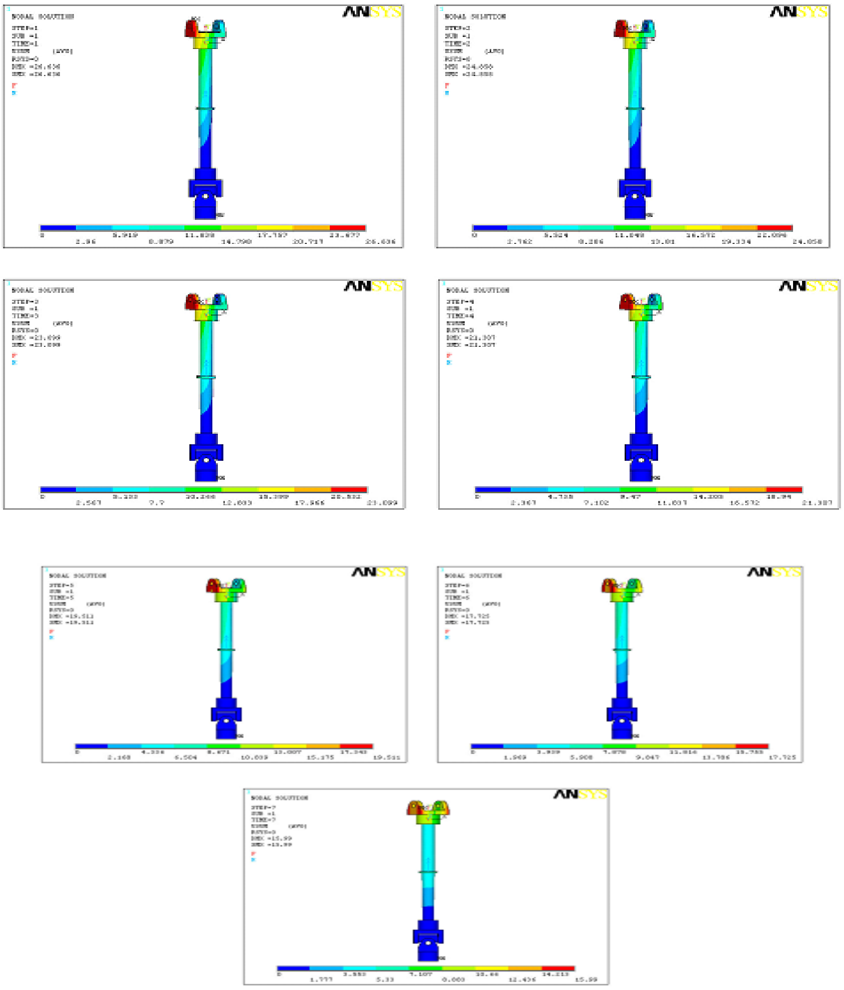


Fig. 4.1 a,b,c,d,e,f,g. Displacement sum of circular cross section AIA considering loads when the arm is at 30, 40, 50, 60, 70, 80 and 90

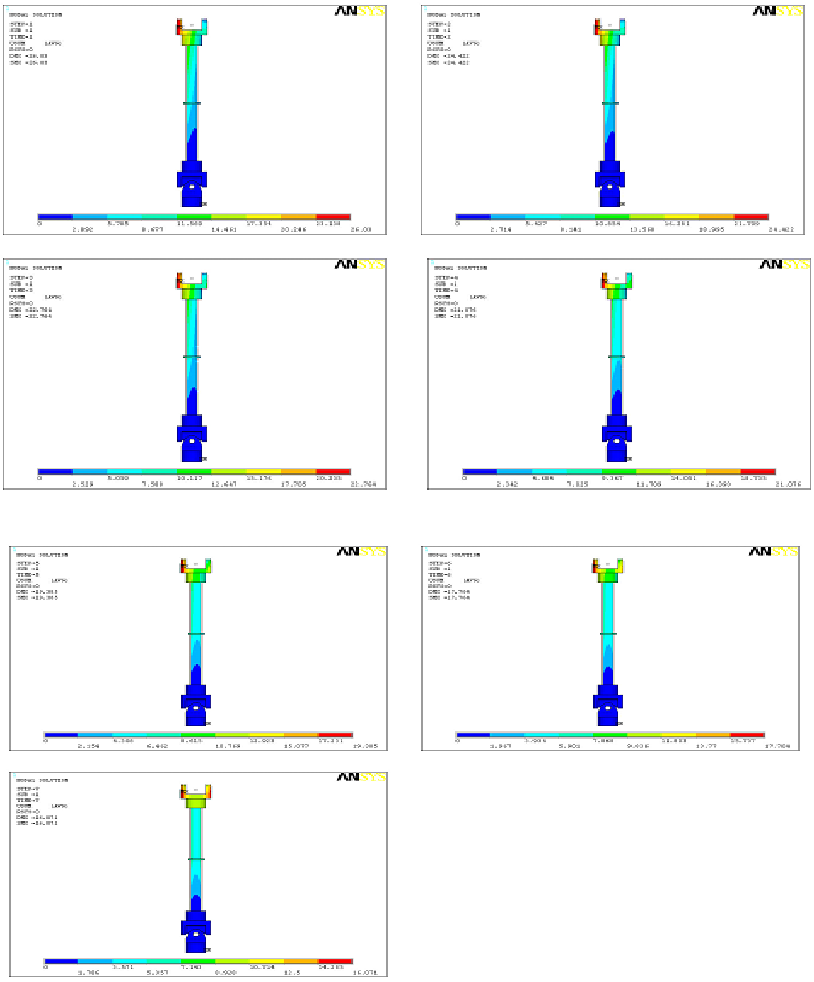
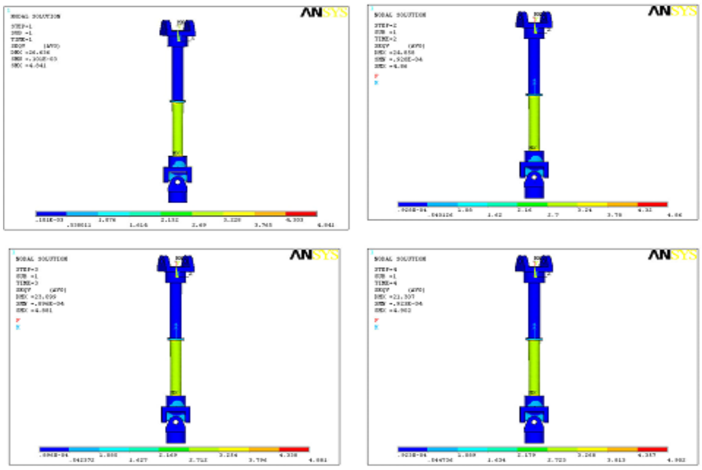


Fig. 4.2 a,b,c,d,e,f,g. Displacement sum of rectangular cross section AIA considering loads when the arm is at 30, 40, 50, 60, 70, 80 and 90



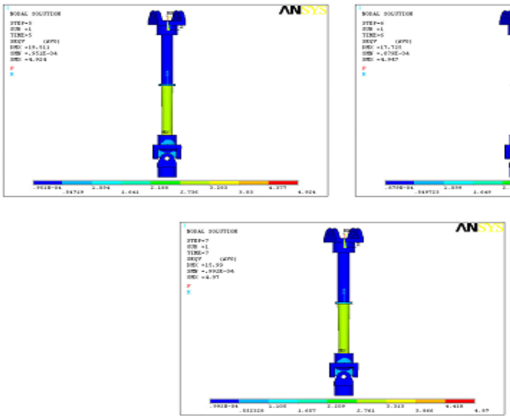


Fig. 4.3 a,b,c,d,e,f,g. Von Mises stress of circular cross section AIA considering loads when the arm is at 30, 40, 50, 60, 70, 80 and 90

4. CONCLUSION

The AIA is designed using basic formulae from strength of materials. Two possible hollow cross sections, considering the electrical, control and feedback wiring to pass through, is modelled using commercially available 3D modelling tool, SolidWorks, for further study and comparison.

The Model is used for analysis using a commercially available analysis tool, ANSYS, taking into account the various critical loads acting on the base arm alone. Since the base arm is the major component in which maximum magnitude of the critical loads considered occur, it is enough to analyze the base arm alone.

Considering the shapes, sizes, deflections during working and stresses occurring, both the AIAs are workable comparatively. Considering the manufacturability, ease of transport, assembly, and weight, the circular section AIAs are preferred over the rectangular section AIAs.

REFERENCE

[1] D. Arthur, Y. Perrot, C. Bidard et al. ITER Articulated Inspection Arm (AIA), Geometric Calibration Issues of a long –reach flexible robot. Fusion Engineering and Design75-79(2005) 543-546.

[2] J.V.Miro, A.S.White, Modeling and industrial manipulator a case study, Simulation practice and theory, 9(2002) 293-319.

[3] Leoncio Briones, Paul Bustmante, Miguel A.Serna, A Wall Climbing pneumatic robot for inspection in nuclear power plants, Robotics and computer integrated manufacturing, 0736-5845(95)00005-4.

[4] O.A.Barbian, W.Kappes, R.Neumann, H.K.Stanger, apparative developments for in-service inspection of reactor pressure vessels, Nuclear engineering and design 102(1987)341-355.

[5] Ernst G.Schlechtendahl, CAD Supported Remote Handling Systems For Fusion Reactors, Nuclear Engineering And Design 100(1987)461-474.

[6] Baldev Raj.D, D.K.Bhatacharya, P.Rodriguez, Development Of In-Service Inspection Techniques For Nuclear Power Plant In India, International Journal Of Pressure Vessel And Piping 56(1993)183-211.

[7] Joseph S.Byrd, John.J.Fisher, William R Mallet, Expert Robots For Process Environments, Automation In Construction 1(1992)55-69.

[8] Guido La Rosa, Michele Messina, Giovanni Muscato, T.Sinatra, A Low Cost Light Weight Climbing Robot For The Inspection Of Vertical Surface, Mechatronics 12(2002)71-96.

[9] Debu Majumdar, Artificial Intelligence Applications In The Nuclear Industry And International View, Nuclear Engineering And Design, 113(1989)181-193.