

Design of Tool Loading Robotic Arm

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ABSTRACT: Robot manipulator is an essential motion subsystem component of robotic system for positioning, orientating object so that robot can perform useful task. In the field of robotics, there are five types of robot configurations that are SCARA, articulated, cartesian, cylindrical and spherical. The shoulder uses two large-scale servo motors, working together to provide the torque needed to lift the rest of the arm, as well as any object that it may be grasping. Attached to the shoulder piece is an elbow that can move through 180 degrees, also powered by a large-scale servo. The wrist is made up of one standard servo and can rotate the gripper clockwise and counter clockwise. The revolute geometry allows the robot arm to reach any point within a half-cylinder. The radius of the half-cylinder is the length of the arm when its shoulder, elbow, and wrist are straightened out.

KEYWORDS: Manipulator, Robotics, Servo Motors, Harmonic Drive, Al Extrusion Profiles.

I. INTRODUCTION

Robot is an integral part in automating the flexible manufacturing system that is greatly in demand these days. Robots are now more than a machine, as robots have become the solution of the future as cost labor wages and customers' demand. Even though the cost of acquiring robotic system is quite expensive but as today's rapid development and a very high demand in quality, humans are no longer capable of such demands. Research and development of future robots is moving at a very rapid pace due to the constantly improving and upgrading of the quality standards of products. Robot and automation is employed in order to replace human to perform those tasks that are routine, dangerous, dull, and in a hazardous area. In a world of advanced technology today, automation greatly increases production capability; improve product quality and lower production cost. It takes just a few people to program or monitor the computer and carry out routine maintenance.

An industrial robot is defined by ISO 8373 as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes. The field of robotics may be more practically defined as the study, design and use of robot systems for manufacturing (a top-level definition relying on the prior definition of robot). Typical applications of robots include welding, painting, assembly, pick and place (such as packaging, palletizing), product inspection, and testing; all accomplished with high endurance, speed, and precision.

II. LITERATURE WORK

A. ROBOT CONFIGURATIONS

Depending on the configuration and size of the links and wrist joints, robots can reach a collection of points called as Workspace or Work Envelope. Different configurations and types of robots are required for different kinds of operations. Work environment and space considerations play an important role in the selection of robot configuration. There are two types of joints or motions along the axes are possible: Linear and rotational. Robots can be classified on the basis of these coordinate systems, which directly affect the shape of workspace. The different coordinate axes configurations and their workspaces are as following:

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1. Cartesian configuration: This configuration has three linear axes as, X, Y and Z axes. The Work Envelope for this arrangement is rectangular in shape. It has three linear joints and do not have any radial joints. These types of robots have greater accuracy and repeatability than other types, especially at heavier loads.
2. Cylindrical configuration: This has one rotary and two linear axes. The Work envelope of this configuration is cylindrical. The horizontal arm has a sliding carriage which allows arm to extend and retract as shown in the figure. The whole unit is mounted on a column which can rotate in horizontal plane.
3. Spherical or Polar configuration: It has two rotary and one linear axes motion. Linear motion is provided by the telescopic arm. This arm has a limited tilting movement. At the same time, the arm can swivel like the turret of a tank. This results in spherical Workspace.
4. Articulated configuration: This type of robot performs actions like human arm. There are two arms, namely forearm and upper arm. All three joints in this configuration are rotational. Therefore, these are also called as revolute robots.
5. SCARA configuration: SCARA stands for 'Selective Compliance Assembly Robotic Arm'. In this arrangement, the shoulder and elbow rotational axes are vertical. This allows high rigidity in vertical plane and is suitable for operations where it is expected to perform insertion tasks. This robot has cylindrical configuration.

Many times, according to the job requirement, these configurations are modified for special purposes. For example, in SCARA configuration, there is no vertical movement possible at the rotating joint of column. If there is a special requirement, vertical motion can be added by accommodating linear motion guide ways. Modification in configuration also adds extra degrees of freedom, thereby increasing the productivity of a robot. Therefore, these types of configurations are termed as, modified SCARA, modified polar, etc. [1]

B. MATERIALS

6061-T6 is an alloy used in the production of extrusions, long constant cross-section structural shapes produced by pushing metal through a shaped die. This material can be purchased from market in extrusion form. The most important advantage is that, no extra machining is required on these extrusions. They can be easily assembled or dismantled, as only nuts and bolts are required to join them. Therefore, Al extrusion profiles are being widely used for arms of industrial robots. As shown in the figure, these profiles have slotted geometry. So, it is easy to join multiple profiles together. Moreover, strength is further increased due to this structure. There is space provision in the middle of the profile, which can be used for internal wiring of the robot. [2]

C. HARMONIC DRIVE

Harmonic Drive is a strain wave gear which can improve certain characteristics compared to traditional gearing systems. Harmonic Drive is trademarked by the Harmonic Drive Company. The strain wave gear was invented in 1957 by C.W. Musser. The advantages include: no backlash, compactness and light weight, high gear ratios, reconfigurable ratios within a standard housing, good resolution and excellent repeatability (linear representation) when repositioning inertial loads, high torque capability, and coaxial input and output shafts. High gear reduction ratios are possible in a small volume (a ratio from 30:1 up to 320:1 is possible in the same space in which planetary gears typically only produce a 10:1 ratio). They are typically used in industrial motion control, machine tool, printing machine, robotics and aerospace, for gear reduction but may also be used to increase rotational speed, or for differential gearing. [3]

D. BALL SCREW

A ball screw is a mechanical linear actuator that translates rotational motion to linear motion with little friction. A threaded shaft provides a helical raceway for ball bearings which act as a precision screw. As well as being able to apply or withstand high thrust loads, they can do so with minimum internal friction. They are made to close tolerances and are therefore suitable for use in situations in which high precision is necessary. The ball assembly acts as the nut while the threaded shaft is the screw. In contrast to conventional lead screws, ball screws tend to be rather bulky, due to the need to have a mechanism to re-circulate the balls. [6]

III. ROBOT DESIGN

A. METHODOLOGY OF MACHINE DESIGN

The basic procedure of machine design consists of a step by step approach from given specifications about the functional requirements of a product to the complete description in the form of drawings of the final product. A Logical sequence of steps, usually common to all design projects, is illustrated in the flowchart below. These steps are interrelated and interdependent, each reflecting and affecting all other steps. The following steps are involved in the process of machine design. [14]

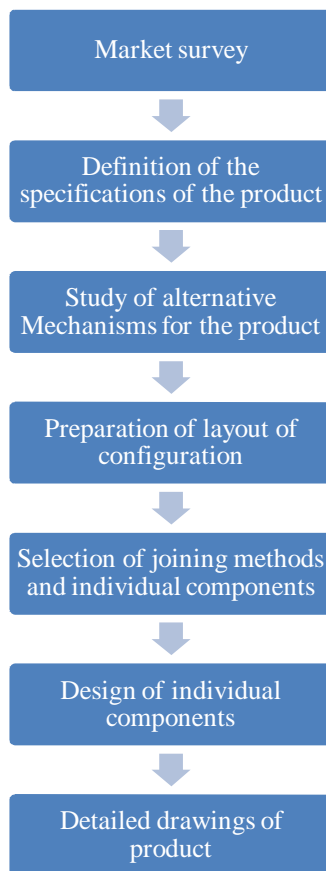


Fig. 1 Design procedure and methodology of the robot

B. ARM CALCULATIONS

Payload = 30 Kg

Mass of the gripper = 25 Kg

Mass of bearing, gearbox and servo motor = 15 Kg

Total mass at free end = 70 Kg

Factor of safety = 1.5

Force acting at the free end = P = Total mass × F.O.S × g = 70 × 1.5 × 9.81 = 1030.05N=W

Self-weight=W_s=g/m × length of arm × 9.81

$$\text{Deflection} = y = \frac{P}{3EI} L^3 + \left[\frac{W_1}{3EI} a^3 + \frac{W_1}{2EI} a^2(L - a) \right]$$

F-100x100 (from ‘Rose Krieger’ catalogue) was selected for arm-1 as it has permissible deflection (0.7203mm). As the deflection reduces the arm gives higher accuracy, also deflection is inversely proportional to strength. As deflection

goes on decreasing the strength of arm increases. Profile type F-100x100 is selected as it will give permissible accuracy and will have less self-weight. Similarly, Profile type F-120x120 (from 'Rose Krieger' catalogue) (0.4642mm) is selected for arm-2 as it will give maximum accuracy and give better resistance to induced bending stress.

IV. MOTOR CALCULATIONS

Required speed of arm = 90° in 3 seconds

Therefore, required speed = 30°/sec

Hence, arm will travel 360° in 12 seconds i.e. 1 revolution in 12 seconds.

Therefore, N = 5rpm.

$$T = I \times \alpha$$

$$\alpha = \omega / t$$

$$\alpha = 2\pi N / 60t$$

$$I = m \times k^2$$

Where, t is the time required for the acceleration of the arm. 't' is assumed to be 0.5 seconds. The smaller the value of 't' greater will be the acceleration of the arm. For Servo motor at first rotational joint

$$\alpha = (2\pi \times 5) / (60 \times 0.5)$$

$$\alpha = 1.047 \text{ radian/seconds}^2$$

Now, m = 88 kg

For safe design, considering the factor of safety as 1.5.

Hence, calculating for m = 132 kg

$$I = m \times k^2 = 132 \times 1.5 \times 1.5 = 297 \text{ kgm}^2$$

$$T = I \times \alpha = 297 \times 1.047 = 311 \text{ Nm}$$

Hence, the servo motor model SHA32A with gearing ratio of 81 was selected for arm-2 from the catalogue of 'Harmonic Drive Systems Ltd.'. Similarly, the servo motor model SHA20A with gearing ratio of 51 was selected for arm-1 from the catalogue of 'Harmonic Drive Systems Ltd.'

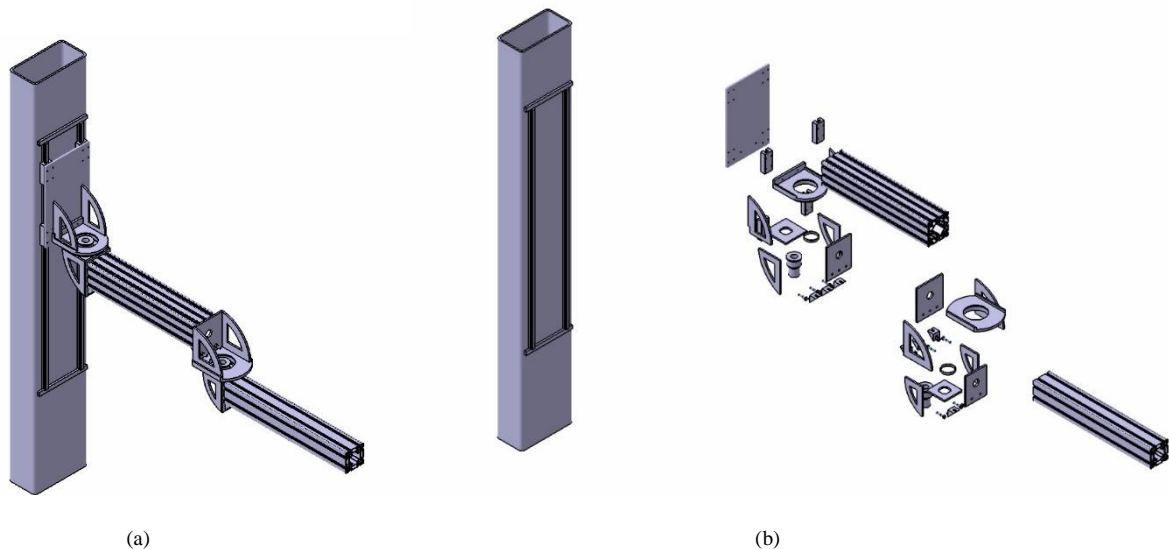


Fig. 2 CAD model the robot modelled in Catia (a) Full assembly (b) Exploded view

V. RESULTS

A. TOTAL DEFORMATION

Total Deformation at the tip of the arm was found out 5.2964mm, which is well below the constraints. Duty cycle for Aluminum is 10mm. Aluminum starts to deform permanently after around 10000 cycles if the deflection is greater than 10mm. Possibility of plastic deformation is eliminated which was one of the main objectives of design.

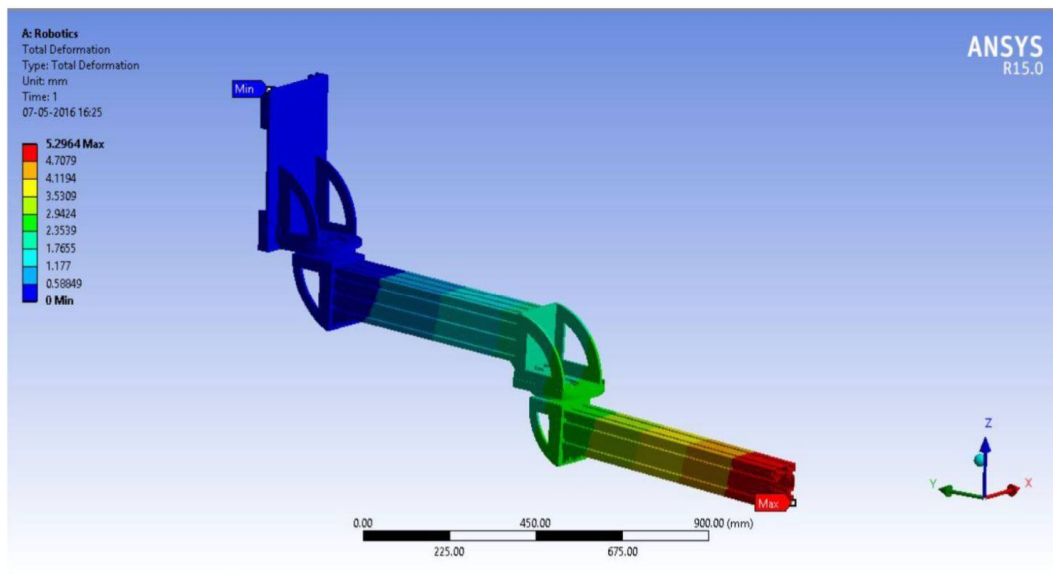


Fig. 3 Analysis for total deformation of robot assembly done in Ansys

B. EQUIVALENT STRESS

Maximum Equivalent stress was found to be 502.36 MPa, which is within limits.

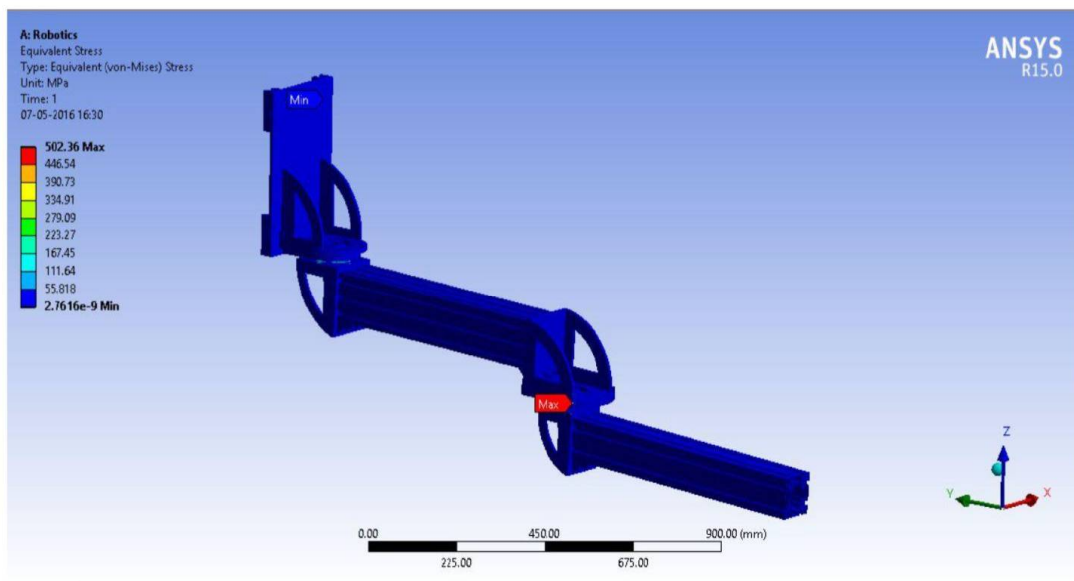


Fig. 4 Analysis for equivalent stress of robot assembly done in Ansys

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Weight of the robot = 105 kg
Payload capacity = 30 kg
Degrees of freedom = 4
Maximum deformation = 5.2964 mm
Factor of safety = 15 (max.), 5 (min.)

VI. CONCLUSION

Different types of robot configurations, like Cartesian, SCARA, Polar, etc. were studied. Lesser known, but superior to conventional drives, that is Harmonic Drive technology was studied and implemented. Degrees of freedom were increased from 3 to 4, using modified SCARA configuration. Weight of the entire robot was minimized to 105 kg and payload capacity of 30 kg was achieved by incorporating Aluminum Extrusion Profiles. By coupling Harmonic Drives with Servo Motors, precision and accuracy of the robot is very high. Moreover, the robot is made compact by the use of Harmonic Drives.

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