DESIGN, ANALYSIS AND OPTIMIZATION OF 6 DOF ROBOTIC ARM

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ABSTRACT

The main objective of this paper is to design, analyse and optimize a stationary 6-axis pick and place robotic arm. Motive here is to reduce the risk factor involved physically in pick and place operations. An available 4 axis robotic arm is taken as reference and is modified to six axis robotic arm with an intention to increase the flexibility and to reduce cost by shape optimization. The model of robot is established using the solid works software and finite element analysis is done. Payloads and gravity are applied for analysis and the strains, stresses and deformations are calculated.

Modifications are made to lower arm which has more weight compared to others, with an intention to reduce the weight. The weight of the robotic arm is reduced by 12% without compromising its functionality.

KEYWORDS: Robotic Arm & Optimization

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1. INTRODUCTION

In the highly developing society time and man power are critical constrains for completion of task in large scales. The automation is playing important role to save human efforts in most of the regular and frequently carried works. One of the major and most commonly performed works in industry is picking and placing of jobs from source to destination.

Present day industry is increasingly turning towards computer-based automation mainly due to the need for increased productivity and delivery of end products with uniform quality. The inflexibility and generally high cost of hard-automation systems, which have been used for automated manufacturing tasks in the past, have led to a broad based interest in the use of mechanical arm capable of performing a variety of manufacturing functions in a flexible environment and at lower costs. The use of industrial mechanical arm characterizes some of contemporary trends in automation of the manufacturing process. However, present day industrial mechanical arm also exhibit a monolithic mechanical structure and closed-system software architecture. They are concentrated on simple repetitive tasks, which tend not to require high precision.

For the last few decades, robotics have played a very important role in process automation, with robot manipulators assuming a leading role in the development of several productive areas. Nowadays, industrial robots are used for the automation of a variety of tasks such as assembling, transfer of materials, all kinds of welding, precision cutting of materials, palletizing, painting, remote surgical procedures, among many possible applications [1,7]. In general, industrial robots are employed to carry out repetitive jobs and/or those that require precision and speeds difficult to achieve by human beings. This has made it possible to improve the quality of products and the efficiency of their manufacturing [2, 3]. Therefore, industrial robots are increasingly used in modern and automated production processes, as well as in hazardous applications, in which their use is clearly justified. On the other hand,

industrial robots can perform tasks during many hours per day without getting tired or losing precision or effectiveness, because they are currently highly developed and robust devices that practically do not fail. Thus, to know, study, improve, reprogram, and adequate these systems to different scenarios becomes necessary, so users can profit as much as possible from them [4, 5]. The present work arises from the compelling need of having less weight robots which can perform quickly as applied to pick and place operations.

2. PROBLEM STATEMENT

To solve the problems of pick and place of the cylindrical object having 6 cm diameter and 0.2 gram mass from one conveyor to another at room temperature in order to reduce human effort and efficient material handling. The distance between two conveyers is 50 cm, and robotic arm should be suitable to work with six degree of freedom.

2.1 Objectives

The objectives in the current paper are design and analysis of six axes robotic arm. Modeling of the robotic arm and static analysis is carried out in Solid Works 17 software [6]. The stress and strain analysis is carried out to see that the links are safe with regard to load carrying. Finally topology optimization is done to reduce the weight of the robotic arm.

2.2 Design Parameters

Many times it is difficult to judge the actual working co-ordinates including the degree of freedom, work-space coordinates of the prototype in the design stage. Following parameters are useful in modeling the robotic arm. Pay-load is **0.2kg**, maximum horizontal reach of **0.4m** and the length of the longest link as 0.215m. The material for the arm is chosen as aluminum **1060** alloy having density 2700kg/m^3 , tensile strength 69Mpa, yield strength 28Mpa and modulus of elasticity 69GPa. This material is chosen keeping in view the strength and light weight. Electrical actuators DC servo are chosen instead of hydraulic and pneumatic actuators because of the little power requirement and its light weight which is suitable for this purpose. The torque is fully balanced by the electric motors.

3. MODELING

The various parts of the robotic arm are modeled as shown in figure 1. The assembled robotic arm is as shown in figure 2. table 1, table 2 and table 3 present specifications of articulated robotic arm, links and hybrid stepper motors respectively.

Base of the robot

Robotic arm rotary head.

Figure 1: Parts of Robotic ARM.

Figure 2: Assembly of Robotic Arm.

Table 1: The Specifications of Articulated Robotic Arm

Specifications	Value
Number of axis	6
Number of motors used	7 stepper motors
Max payload mass	200gm
Max reach	410 mm
Material	Aluminium 1060
Total mass	2149 grams

Table 2: Link Length, Mass and Angle of Rotation of Robotic Arm

Link	Length (Meters)	Maximum Operating Range in (Degrees)	Mass(kg)
Base	0.031	270 to -270	0.682
Rotaty head	0.063	180 to -180	0.513
Lower arm	0.215	155 to -105	0.430
Upper arm	0.137	270 to -270	0.445
Wrist	0.038	145 to -145	0.031
Gripper	0.035	270 to -270	0.039

Accordingly torques coming onto the different joints is calculated and stepper motors are selected. Following table indicates the details of the stepper motors.

Table 3: Specification of Hybrid Stepper Motors

Stepper Motors	Size (mm)	Mass(kg)	Torque (n-m)	Quantity
Nema 08	20 x20	0.0091	0.036	2
Nema 11	28x28	0.0250	0.180	1
Nema 17	43x43	0.0350	0.440	1
Nema 23	57x57	0.1000	1.870	2
Nema 24	60x60	0.1900	4.000	1

4. RESULTS AND DISCUSSIONS

The robotic arm has five joints and 6 degrees of freedom. Every joint has only one degree of freedom except upper arm has two degree of freedom (two rotations). To do this, we must specify an axis for each joint to rotate around it. Any other kinds of movement are constrained. In this area, we discuss about the behaviour of the joints under loads and boundary conditions. Base is fixed as shown in figure 2 and external loads like gravity 9.81 and force of 20N are applied.

The meshing of the designed articulated arm robot is accomplished very cautiously to achieve good amount of stress distributions. By default, meshing provided by solid works is adopted and the part is simulated, from which a stress distribution patterns are obtained. The initial size of the mesh is 0.1 and the average element size is 0.2. The local area mesh option in solid works is used to mesh high stress areas and element size is changed to 0.01 minimum and average element size is kept 0.02. The local mesh control gives us the option to edit the density of the mesh at chosen area. The mesh adjusts itself according to the shape of the geometry. The shape of the element is tetrahedral and during the final stages of simulation, it is made sure that every geometry has at least 2 lakh elements. The meshed finite element model is shown in figure 3. The maximum stress obtained at the end Effector is 27Mpa as shown in figure 4 and the maximum strain is 0.0026 as shown in figure 5. The deformation occurred is as presented in figure 6. The maximum deformation as evidenced is 2mm at the end Effector.

Figure 3: Meshed Model of Robotic Arm.

Figure 4: Von-Mises Stress Distribution.

Figure 5: Von-Mises Strain Distribution.

Figure 6: Deformation Distribution.

5. OPTIMIZATION

Servomotors are used in industrial robots because of their precise positioning control and stable structures and the cost of those motors increases in proportion with their torque. A robot with a lifting capacity between 5 and 7 kg has about 300 kg

average weights. Especially the second axis motor carries 70–75% of the robot's total weight. Considering the high acceleration of robot arms, it will be better to use a more powerful motor. Therefore, it is important to select a different material with same strength or to change the geometric structure of the same material to get a reduced motor load. When the articulated robots extend their arms in full and horizontally, the torque caused by robot's own weight is extremely high. In addition to that, when the robot is loaded at its maximum capacity, the stress on the second axis arm is increasing and it is growing closer to the rotation axis. Since it would heterogeneously increase the amount of deformation, concentration of stress on a narrow region is an undesired situation. If those loads could be dispersed by a geometrical change, particularly on the second axis arm, deformation at the tip of the robot will be decreased. The lower arm which constitute a major portion of the weight is modified to make is light weight. The optimized lower arm is as shown in fig 5, where stress is distributed to higher areas making a link almost of uniform strength.

Figure 5: Modified Lower Arm.

The modified link specifications are as presented in table 4. Net of 0.257kg mass has come down for the whole configuration.

Table 4: Comparison of Masses of Links before and after Modifications

	Mass(kg) (Initially)	Mass(kg) (Modified)	Change in Mass(Kg)
Base	0.682	0.640	-0.042
Rotary head	0.513	0.403	-0.11
Lower arm	0.430	0.325	-0.105
Upper arm	0.445	0.445	--
Wrist	0.031	0.040	+0.009
Gripper	0.039	0.039	--

6. CONCLUSIONS

In this paper, a 6axis robotic arm has been successfully designed and is analyzed for strength to avoid failure. A four axis robotic arm is taken as reference which is available in industry used for pick and place operations. Two additional axes are created to increase the flexibility and reach of the existing four axis robot. The material used for the links of the robotic arm is Al 1060 alloy. The robotic arm is modelled in Solid works 17, knowing link lengths and material. The total mass of robotic arm turned out to be 2149 grams. FE analysis is done by using solid works simulation tool. Static analysis is performed to calculate the stresses by considering the forces. From the results it is concluded that the maximum von-Mises stress occurred is 27 Mpa, which is well below the yield strength of the material. Shape optimization is done to lower arm, which constitute most of the weight, with an intention to reduce the weight and increase the efficiency of stepper motor. The percentage of weigh reduction as obtained from the results is 12%.

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