Modeling and Analysis of Articulated Robotic Arm for Material Handling Applications

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Abstract
The Articulated Robotic Arm is gaining huge importance in industries due to its high precision work and ease in carrying out heavy tasks. This paper is related with the modeling and analysis of an articulated robotic arm which can be utilized for material handling tasks. For designing and simulation of the articulated robotic arm with material handling gripper SOLIDWORKS\textsuperscript{®} software is used. In the process of modeling, an analysis such as the study of the finite element method would be very helpful in the early stage of design. The result of the analysis will show the strength and weakness of the design. The finite element analysis was carried out using ANSYS\textsuperscript{®} software workbench to study the model of a robotic arm with different materials and various loading conditions. The results of the analysis are reviewed for selecting the best material and also approving good feasibility of the articulated robotic arm.

Keywords: Articulated Robotic Arm, Material Handling Gripper, Finite Element Analysis.

1. Introduction

Robotics is a remarkable building science that deals with the design, modeling, analysis, and utilization. Today, robots are used everywhere in day to day life. A large family of robots is used in industries and manufacturing processes. Robots are used in supplying the motion required in manufacturing processes such as arc-welding, spray painting, cutting, polishing, milling, drilling, assembly, pick and place, packaging, palletizing, product inspection and testing \cite{1}. Robots that can perform task productively are currently a prerequisite in many industries since they have high accuracy, knowledge and perpetual vitality levels in doing work contrast with human beings. In this way, there are currently expanding the requirement for better robots that can perform different assignments. There are mainly two types of robots one is a service robot and the other is an industrial robot. A service robot is operated fully or semi-autonomously in order to perform intense tasks that ease human and equipment burden. While on the other hand, an industrial robot is fully autonomously controlled, multipurpose manipulator. Industrial robots are robotic arm systems which consist of various links, joints, actuators, sensors, controller and a software/hardware simulator. One end of the arm is connected to robot base while the other free end is equipped with a ‘tool’ that is either a hand or a gripper or an end effector which is similar to human hand \cite{2}.
The robotic arm is a kind of arm also known as manufacturing robot. This typical robotic arm comprised of several metal segments, which are combined at joints. PC controls the robot by turning the individual stepper motors connected to the joints [3]. Fundamentally, a robot is normally an electro-mechanical machine which is guided by the means of PC and electronic programming. The PC which is connected to the robot is programmed to control the motors on the robot joints in a way so that it can perform different tasks [4]. The robotic arm can be designed in various ways, the size and shape of this arm are very crucial to robotic engineering. The arm is the part of the robot that positions the last grabber arm to do their prearranged undertakings. If the structure of the arm is too huge or little, this positioning may not be conceivable [5]. The reason of using a robotic arm is to eliminate errors and human efforts. In the field of robotics, there are five sorts of robot setups that are SCARA, articulated, Cartesian, cylindrical and spherical [6]. SCARA stands for Selective Compliance Assembly Robot Arm [7].

Doing different industrial tasks with the help of robots is nowadays common in most mass production industries. These industries need fast and precise proceedings, which is difficult with the human operator and can be easily accomplished with the robotic system [8]. Mechanical grippers are used on the ends of the robotic arm for pick and place of the object or for material handling operations [9]. One such task is loading and unloading of workpiece like pallets, food items, metal sheets etc. Loading and unloading of heavy materials are done manually in the industries; to do these tedious tasks continuously we can implement a robotic arm [10]. In this paper, our objective is to design an articulated robotic arm with six joints and one mechanical gripper motion and select a suitable material which can sustain the heavy load. The designing of the complete robotic arm will be done on SOLIDWORKS® software. The main task is to perform finite element analysis with selected materials in ANSYS® software workbench to optimize the robotic arm. It will help in deciding the critical parts in the assembly and the best materials for the robotic arm for application in industries. Furthermore, the plan and development of the robotic arm is supported by the results of the analysis.

2. Problem Formulation

After probing varied analysis and literature, it’s been found that learning varied components of the robotic arm is extremely tough and long. Using 3D modelling package, a 3D model of a robotic arm will be simply created with all its geometrical parameters. Before truly making a robotic arm the planning, numerous needs and behaviour of a robotic arm is often studied. It is a cost effective technique because it can alter to make error-free robotic arm. This 3D robotic arm is simply tailored supported the wants or changes provided.

3. Methodology

- Firstly, the necessity of the robotic arm are accumulated and sculptural within the sort of drawing, that is written in a very 2D sketch.
- Then the elaborate assembled 3D solid view will be developed in SOLIDWORKS® with the help of commands and constraints conditions.
- The model will be imported to the ANSYS® software workbench.
- After importing, the materials properties will be given by selecting the proper materials which are well suited for this type of application in industry.
- Now, a mesh will be created and boundary conditions will be applied.
- The structural analysis of the robotic arm will be done at various payload conditions to obtain deformation distribution and stress distribution so that design can be studied.
3.1. CAD Modeling

Computer-aided design (CAD) is defined as any action that includes the effective use of the PC to create, modify or study an engineering design. CAD software is utilized to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD is mostly linked with the use of an interactive computer graphics system, referred to as CAD system [11].

All the parts of the robotic arm are designed in SOLIDWORKS® individually and these parts are then assembled by applying the constraints and conditions. This software SOLIDWORKS® is picked as it is recently being used by many researchers and was able to help reduce robot design and development time, increase the productivity of the designer and improve the speed and nature of robot modeling. The figures 1-8 below show all the different parts of the robotic arm. The assembly of these different parts to form a complete articulated robotic arm is shown in figure 9.
3.2. Structural Analysis

The pressure state of a structure with particular loading is characterized by the FE analysis results. The arm geometry with the FE model, boundary conditions, and loading conditions are the input information for FE analysis. The direction and location of each load input to the component define the loading conditions. The finite element method was adopted to solve various links under stress due to the loading conditions. The component behavior and material properties are assumed to be linearly elastic [12].

FEA is an extraordinary method to be used. The advantage of simulation is less time, cost and easier comparison to experiment method.

SOLIDWORKS® assembly of the robotic arm is converted into STEP or IGS file format so that it can be imported to the software. ANSYS® software uses the static structural toolbox to calculate component stresses and deformation.

3.3. Meshing

Meshing is the process of dividing the whole model into a number of elements so that whenever the load is applied to the model, it distributes the load uniformly. It is typically discretization. The continuum needs to be discretized into a finite number of elements. The nature of the FEA results can be essentially changed with the change number of elements and element size. The fine meshing of the robotic arm is done using triangular elements. Total no. of elements are 46193 and total no. of nodes are 80895. The meshing is shown in the figures 10-11 below.

![Figure 10. Meshing of Robotic Arm](image1)

![Figure 11. Meshing of Gripper](image2)

3.4. Materials

Structural Steel and Aluminum Alloy 356 are assigned as the robotic arm material because of their great strength as they can accommodate large force. Given below table 1 and table 2 shows the properties of both the materials.

| Sr. No. | Properties                  | Values       |
|--------|-----------------------------|--------------|
| 1.     | Tensile Yield Strength      | 2.5×10^8Pa   |
| 2.     | Tensile Ultimate Strength   | 4.6×10^8Pa   |
| 3.     | Compressive Yield Strength  | 2.5×10^8Pa   |
| 4.     | Density                     | 7850Kg/m^3   |
Table 2: Properties of Aluminum Alloy 356

| Sr. No. | Properties                  | Values      |
|---------|-----------------------------|-------------|
| 1.      | Tensile Yield Strength      | 2.05×10^8 Pa |
| 2.      | Tensile Ultimate Strength   | 2.5×10^8 Pa  |
| 3.      | Shear Strength              | 2.05×10^8 Pa |
| 4.      | Density                     | 2680 Kg/m^3 |

4. Results and Discussion

The analysis is done with different forces applied to the end effector or gripper of the robotic arm with two different materials namely Structural Steel and Aluminum Alloy 356. The results of total deformation and total equivalent Stress is carried out for four different loading conditions i.e. 300N, 400N, 500N, and 600N. If the value of maximum stress is greater than the yield stress that means the structure will fail. The figures 12-19 below show the deformation and stress variation on the robotic arm of Structural Steel. The figures 20-27 below show the deformation and stress variation on the robotic arm of Aluminum Alloy 356.

![Figure 12. Deformation at 300N](image1)

![Figure 13. Stress Analysis at 300N](image2)

![Figure 14. Deformation at 400N](image3)

![Figure 15. Stress Analysis at 400N](image4)
Figure 16. Deformation at 500N

Figure 17. Stress Analysis at 500N

Figure 18. Deformation at 600N

Figure 19. Stress Analysis at 600N

Figure 20. Deformation at 300N

Figure 21. Stress Analysis at 300N

Figure 22. Deformation at 400N

Figure 23. Stress Analysis at 400N
Figure 24. Deformation at 500N

Figure 25. Stress Analysis at 500N

Figure 26. Deformation at 600N

Figure 27. Stress Analysis at 600N

Table 3. Results of Analysis for Structural Steel

| Sr. No. | Force (N) | Max Equivalent Stress (MPa) | Max Deformation (mm) |
|---------|-----------|-----------------------------|----------------------|
| 1.      | 300       | 85.286                      | 0.33682              |
| 2.      | 400       | 122.26                      | 0.46126              |
| 3.      | 500       | 128.26                      | 0.54421              |
| 4.      | 600       | 174.59                      | 0.67758              |

Table 4. Results of Analysis for Aluminum Alloy 356

| Sr. No. | Force (N) | Max Equivalent Stress (MPa) | Max Deformation (mm) |
|---------|-----------|-----------------------------|----------------------|
| 1.      | 300       | 93.208                      | 0.96563              |
| 2.      | 400       | 112.12                      | 1.2244               |
| 3.      | 500       | 134.09                      | 1.5121               |
| 4.      | 600       | 174.69                      | 1.8599               |
From table 3 and table 4, we can conclude that all the results for stress distribution are within the permissible limits i.e. they are less than the yield and ultimate stress for both the materials. However Structural Steel Arm is giving better results as compared with the Aluminum Alloy Arm for the same load. There is a slightly greater deformation in case of Aluminum Alloy Arm. Hence for better reliability structural steel robotic arm is best suited. Also both the results show that the structural strength of both the articulated robotic arm met the working requirements and are eligible for further studies.

5. Conclusion

Design and Development of a versatile and low-cost robotic hand similar to the human hand is a need of today’s generation. A 3D CAD software SOLIDWORKS® was utilized to design an explained robotic arm and the designed arm is exported to the ANSYS® for the structural analysis. This robotic arm can be used in industries for various tasks such as pick and place, assembly etc. The structural analysis has been successfully verified. It is observed that the arm is meeting design requirements and is able to carry various payloads. This is suitable for hazardous area in industries and will be helpful in increasing productivity. In the future, simulation can be carried out in the given workspace.

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