OPTIMIZING CROSS-SECTION OF LINKS FOR TWO LEVEL DESIGN OF RR PICK AND PLACE ROBOT ARM

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Abstract—The mechanical structure of a robot manipulator, which consists of rigid cantilever beams connected by hinged joints forming spatial mechanism, is inherently poor in stiffness, accuracy and load carrying capacity. The errors accumulate because joints are in a serial sequence. These difficulties are overcome by advanced design and control techniques. Performance of the robot manipulator actually depends upon many control parameters i.e. kinematic and dynamic parameters. The kinematic and dynamic complexities create unique design of a robot manipulator a very challenging and critical issue. The main areas of thrust are the shape, material and design optimization of robot arm. The shape optimization requires to test the arm links for different standard shaped cross-sections for minimum stress conditions and selecting best of them. This paper attempts to find out the set of cross-sections to optimize the design of two degree of freedom pick and place robot arm with revolute joints (RR). In this paper, a number of cross-sections are considered, modeled in Pro-E and experimented in Pro-Mechanica and analyzed using Finite Element Methods (FEM) i.e. ANSYS. The design optimization of the robot arm at two levels is carried out for minimizing the weight of the same for the given loading condition. From our analysis it is found that, the optimized modal of robot arm with hollow rectangular cross-section is best suited for the pick and place robot and is proposed as the most efficient one for carrying out its function.

Key Words: Shape optimization, cross-section, Finite Element Methods (FEM)

I. INTRODUCTION

In the modern design practice, optimization has become a vital part of the computer-aided design. In many industrial design activities, optimization is achieved by comparing a few chosen design solutions and accepting the best solution. This simplistic approach never guarantees an optimal solution (Deb, 1996). Design optimization provides tremendous flexibility in the types of problems that can be handled and permits virtually any aspect of design, not just the cost or weight. Applications are almost boundless and can include optimization of volume, stress, natural frequency, temperature etc. The designer can derive maximum benefit by using optimization analysis in conjunction with finite element analysis and hence it becomes a versatile tool to build rational designs of machine components. A robot is a reprogrammable multifunction manipulator designed to move material, parts, tool through a variable programmed motions for the performance of a variety of tasks (Rivine, 1988). The most significant part of robot is its arm, which does the main function of pick and places the objects at specified location. Even though it is a mechanical component, when coupled with robots programmable capacity, it becomes an extremely versatile element (Clafter, 1989) Therefore we have considered this component of robot for analysis with an objective of making it more versatile and simple in carrying its functions. The actual robot arm has three degrees of freedom (up and down motion, forward and backward motion left and right motion). The wrist attached to the arm also has three degrees of freedom and hand has one degree of freedom. Altogether robot arm has seven degrees of freedom. Additional degrees of freedom are required if the robot body must move on a plane. The end connectors of the arm should fulfill these requirements. Therefore the design of end connectors is crucial in the whole design process of robot arm. The stresses induced in these connectors are also significant because of the degrees of freedom allowed for the element. Keeping this in mind, a best shape was chosen for the end connector and the optimization procedure is adopted to get its accurate dimensions.

II. TWO DEGREE OF FREEDOM RR PICK AND PLACE ROBOT ARM

The mechanical structure of a robot manipulator that consists of rigid bodies connected by means of articulations is segmented into an arm that ensures mobility and reachability, a wrist that confers orientation and an end effector (EE) that performs the required task. Most manipulators are mounted on a base fastened to the floor or on the mobile platform of an autonomous guided vehicle. The arrangement of base, arm, links, joints and end-effector for two degree of freedom robot manipulator with two revolute joints (RR) is shown in the Figure 1.

A point at the distal end of the manipulator is considered as EE in present work. The manipulator act as pick and place robot manipulator and weight of object to be picked is replaced by equivalent payload of one kilogram at the end point, see Figure 1.
III. TWO LEVEL DESIGN OPTIMIZATION AND DEFINING THE DESIGN PARAMETERS

Optimum design of the robot arm means determining the best system architecture, optimum setting of control factors and tolerances. Developing the optimal robot design by planning experiments requires hundreds of runs and several weeks and months of time. Several design methodologies i.e. design of experiments, robust design method [9], analysis of variance (ANOVA), neural networks etc. and computer aided design (CAD) tools are available for analyzing and simulation of robot manipulator. Design of experiment methodology also plays an important role in exploratory studies to determine which parameters are important. The effect of a parameter is defined to be change in response produced by change in the levels of a parameter. Here the levels of a test parameter refer to how many test values of the parameter are to be analyzed. Commonly one of these levels is taken to be the initial operating condition. These levels should be taken sufficiently far apart so that the chance is increased for capturing any non-linearity of the relationship between the control parameters. The difference in response between the levels of one parameter is not the same at all the levels of other parameters. When this occurs there is interaction between the parameters.

Design of experiments involves first determining the more important parameters while taking into account the number of parameters that can be dealt with feasibly. Next the desirable levels of the selected parameters are identified. Finally it may be of interest to find the relationship between the parameter levels, the corresponding responses, and the physical economic constraints that are imposed. Although different kind of designs can be used at each of these stages, multi-parameter experiments are usually employed. One such multi-parameter experiment used in exploratory stage is the $2^k$ factorial experiments which involves $K$ parameters, each at two levels. So the total number of experiments is $2^K$. Three parameters for each member of robot manipulator are involved in the kinematic analysis; link length and link twist angle are two of them [2, 3]. For revolute joints, the joint offset is the third parameter and has significant effect on the performance of robot manipulator [4]. For the planar robot manipulator with revolute joints link offset and link twist is zero. The only parameter remains to be decided in present work is link length. Identifying the parameters for the analysis also plays an important part in optimizing the design of manipulator [5].

Dynamics relates forces and torque to positions, velocities and accelerations. During the work cycle a manipulator must accelerate, move at constant speed and decelerate. Time varying torque is applied to joints to move the end effector with particular velocity and acceleration. This applied torque balance out the internal forces i.e. inertial, Coriolis and frictional forces as well as forces exerted by the environment i.e. applied load, gravitational forces etc. [2,3]. Each of this dynamic parameter has different and significant effect on the optimization of manipulator mechanism [6, 7, and 8]. In the present work torques are assumed to be acting on the joints ignoring the effect of mass distribution, non linear forces, couplings and inertia on the robot manipulator.

As discussed above first determine the more important parameters while taking into account the number of parameters that can be dealt with feasibly. Based on previous work, the work in this paper is limited to few factors that have much influence on the performance [9]. These are:
- Length of Link-1 ($L_1$)
- Mass of Link-1 ($M_1$)
- Length of Link-2 ($L_2$)
- Mass of Link-2 ($M_2$)
- Torque acting on the joint-1 ($T_1$)
- Torque acting on the joint-2 ($T_2$)
- X-component of velocity ($V_X$)
- Y-component of velocity ($V_Y$)

Next step is to identify out the desirable levels of these selected parameters. Levels chosen for the experiment should be realistic and should be able to predict any nonlinearity of the relationship between parameters. Levels for above said parameters are given below in the table-1 [9].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower Level</th>
<th>Higher Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1$ (m)</td>
<td>0.3</td>
<td>0.42</td>
</tr>
<tr>
<td>$L_2$ (m)</td>
<td>0.25</td>
<td>0.35</td>
</tr>
<tr>
<td>$M_1$ (kg)</td>
<td>4.5</td>
<td>6.3</td>
</tr>
<tr>
<td>$M_2$ (kg)</td>
<td>3.75</td>
<td>5.25</td>
</tr>
<tr>
<td>$V_X$ (m/s)</td>
<td>0.35</td>
<td>0.4</td>
</tr>
<tr>
<td>$V_Y$ (m/s)</td>
<td>0.25</td>
<td>0.28</td>
</tr>
<tr>
<td>$T_1$ (Nm)</td>
<td>50.00</td>
<td>75.00</td>
</tr>
</tbody>
</table>
Table 1: Level of parameters

<table>
<thead>
<tr>
<th>T2 (Nm)</th>
<th>15.00</th>
<th>25.00</th>
</tr>
</thead>
</table>

Table 2: Results of motion and structure analysis

<table>
<thead>
<tr>
<th>Positional Accuracy</th>
<th>Maximum Stress (N/m²)</th>
<th>Maximum Strain</th>
<th>Transverse Displacement (m)</th>
<th>Rotational Displacement (Radians)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X=0.40425m, Y=0.29938m</td>
<td>8.72E+09</td>
<td>6.050E-03</td>
<td>4.89E-03</td>
<td>3.37E-01</td>
</tr>
</tbody>
</table>

Figure 2: Selected cross-sections robot arm

Figure 3(a): Assembled geometric model of robot arm and Figure 3(b): Meshed model of hollow rectangular section link

V. RESULTS AND CONCLUSION

The robot arm is for a number of cross-sections considered, modeled in Pro-E and experimented in Pro-Mechanica and analyzed using Finite Element Methods (FEM) i.e. ANSYS. Finally based on the analysis the rectangular hollow section emerged as the best one. The assembled geometric model of robot arm for hollow rectangular section is shown in Figure 3(a). The motion analysis in Pro-Mechanica assures the maximum positional accuracy for hollow rectangular section. The meshed model of hollow rectangular section is shown with Figure 3(b).

Finally, the finite element analysis is done for various cross-sections and it is found that stresses and strain are minimum in case of hollow rectangular section. Although the displacement values are higher for hollow rectangular section but the same can be ignored in view of best positional accuracy.

Thus, shape optimization results show that out of various cross-sections, rectangular hollow section gave the best results for given positional accuracy and minimum values of the stress, strain and displacement as given in Table 2.


Figure 4: Structure analysis of hollow rectangular cross-section

REFERENCES


[17] “ANSYS 7.0 Analysis Guide, Structural Analysis”, ANSYS Inc. USA


