# Chapter 6
# Design Optimization Application for a Flexible Robot Manipulator

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## ABSTRACT

*In this chapter, design optimization is performed for a single-link flexible manipulator driven by a standard trapezoidal velocity input. The mass of the original manipulator is reduced by a quarter by design optimization without changing the payload. The finite element model, which is one of the non-rigid models, and topology optimization were utilized for the application. Dynamic stress and natural frequencies of the system are utilized as optimization objectives. The results were compared with the original manipulator in terms of both safety factor and vibration modes. In addition, the system parameters were compared with the tapered beam, and beam with reduced width, which was prepared to have the same mass as the optimized designs. As a result, although the mass of the original manipulator was reduced by one-fourth with the proposed design, it was observed that the dynamic stresses decreased. The study is expected to have significant implications in terms of improving the benefits of flexible robots and providing a contribution to the attenuation of vibrations and stresses.*

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## INTRODUCTION

The preference of links with low stiffness in the manufacture of robot manipulators improves various aspects of the robot. The difference in link mass, for example, can be exploited to work with higher payloads as the smaller link mass decreases the load on the actuators and joints. Likewise, as the robot's flexibility improves, so does its ability to work in human-populated environments. Furthermore, lightness improves energy efficiency by lowering energy usage. Moreover, because the robot can travel at higher speeds, shorter cycle durations can be achieved in applications.

Lightness in robot linkages can be achieved in a variety of ways. The utilization of new technological materials is one of these ways. Composite materials such as carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) are now often employed. Among the composite materials, it can be said that the carbon fiber reinforced polymer material stands out from the rest. The reason for this is that it is lighter than aluminum, which is one of the lightest metal materials but has higher stability even than steel. Because of its low density, high elasticity modulus, and the optimum ratio these create, it has a high natural frequency. In fact, a robot manipulator with a link composed of carbon fiber reinforced polymer composite was proven in a study to be capable of carrying 16 times its own weight. In addition, cutting-edge additives such as modified (carboxylic acid (COOH) functionalized, fluorinated, or similar) multi-walled carbon nanotubes can be employed to improve composite material characteristics such as natural frequencies and damping ratios. Mechanical parameters such as modulus of elasticity and maximum tensile strength can also be improved using these additions. Despite this, demanding and intricate manufacturing methods, as well as expensive costs, make choosing composite materials over typical metal links difficult.

Aside from all of these benefits, it's important to remember the drawbacks of having flexible links in robot manipulators. As a result of the increased flexibility of the links, the natural frequency of the body decreases, resulting in low frequency and high amplitude oscillations. Furthermore, because the damping ratio is reduced, the vibrations persist for a longer amount of time. A few robot manipulator applications provide an example of the detrimental implications of this circumstance. In a pick-and-place application, for example, it will be essential to wait a lengthy period for the robot to cease vibrating before releasing the workpiece. Because the sensitivity criterion will not be met otherwise. According to studies, residual vibration after 2-3 seconds of movement can easily reach one minute. In this case, the increase in the cycle time by about 30 times makes the flexible robot useless. In addition, the studies focused on the height of vibrations during motion. In this instance, it will be impossible to discuss the effectiveness of robots used for tasks like welding or observation, which require a predetermined path to be followed. The stresses that

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