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Modeling and Evaluation of the Lumped Flexible-Joint, Rigid-Link Manipulators

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Abstract – In this paper, we propose lumped methods of flexible elements of Flexible-Link manipulator to Flexible-Joint, and compare their performance evaluation to suggest the most suitable modeling method. The first method is to obtain the Equivalent Stiffness through the static analysis of Flexible-Link. The second method is to obtain the natural frequency through the modal analysis of the Flexible-Link System and to derive the Equivalent Stiffness. The final method is to construct an FRF (Frequency Response Function) Model using the input and output signals of the Flexible-Link System and to find Equivalent stiffness through approximation using polynomial and exponential functions. Flexible-Joint and Rigid-Link manipulator is modeled based on Equivalent Stiffness obtained by the above methods, and compared with the existing Flexible-Link model.

Keywords – Lumped Flexible-Joint, Equivalent Stiffness, Modal Analysis, FRF Model Approximation.

1. Introduction

Modeling of Flexible-Link Manipulators has been studied by the academic and industrial communities from the past. The main reason for this research is that mechanical flexibility of robotic manipulators is a major problem in motion control. In many cases, such as manufacturing, high-speed manipulation, large-range operation and space application, the slender, flexible mechanical structure may cause undesirable vibrations [1]. So many robot arms have been rigid more and more in construction. Because rigid elements are necessary for accurate placement and repeatability but it causes higher material costs and increased energy consumption [2]. Therefore, in this paper, we propose methods of lumped flexible elements in Flexible-Joint to improve higher material costs and increased energy consumption, which are disadvantages of robotic manipulators.

The following are the ways to lumped flexible elements of Flexible-Link into Flexible-Joint. The first is to use FEM (Finite Elements Method) static analysis, and the second is a modeling of Lumped Flexible-Joint having an equivalent stiffness with Flexible-Link through Modal Analysis. Finally, the FRF Model of the Flexible-Link System is created using the chirp signal, and the Equivalent Stiffness is modeled by approximating this model to the mechanical MCK model. The same input is given to the models using above ways and the existing Flexible-Link, and the performance is evaluated for each of the above models by comparing the outputs at that time.

The paper is organized as follows: Section 2 introduces the lumped methods of flexible elements from Flexible-Link to the Flexible-Joint. Simulation of each method and the performance evaluation of each model are shown in Section 3. Finally, Section 4 concludes this paper.

2. Modeling of Lumped Flexible-Joint

2.1 Static Analysis

Link deflection of operations is often limited in order to provide integrity and stability of the structure or robot and to prevent cracking of the attached brittle materials. Often, these members are not vibrated or severely deflected to safely support the intended load. However, the bias at a particular point in the link must be determined when analyzing what is statistically uncertain.

In this paper, the integration method is used between various methods to determine the deflection and slope at specific points in the link of operation. The equation of the elastic curve for a link can be expressed mathematically as Eq. (1) [3].

$$\frac{d^2v/dx^2}{[1+\left(\frac{dv}{dx}\right)^2]^{3/2}} = \frac{M}{EI} \tag{1}$$

dv/dx is the slope of the elastic curve, M is the internal moment of the link, E is the Young's modulus, and I is the moment of inertia.

2.2 Modal Analysis

Repetitive natural frequencies are very important for vibration analysis. It occurs more often in complex systems. However, there are few degree of freedom with repeated natural frequencies. In order to adjust the physical parameters of the system, we have assumed a Flexible-Link to the mass-spring system [4]. And we use Modal Analysis to find spring coefficient. The equation between natural frequency and spring coefficient in Modal Analysis is Eq. (2).

$$f_n = 2\pi\sqrt{\frac{K_{eq}}{M_{modal}}} \tag{2}$$

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f_n is natural frequency, K_{eq} is Equivalent Stiffness of Lumped Flexible-Joint, and M_{modal} is modal mass in Modal Analysis.

2.3 FRF Model Approximation

At the industrial field, system design using FRF is more important than any other methods. A fundamental reason for the universal use of frequency response design is that good design is obtained even when faced with uncertainty in the plant model. Another advantage of using FRF is that it is easy to use the experimental information in accordance with the design purpose. In general, design in the frequency domain is not a method of converting the characteristics of the control system into other parameters, it is also an advantage that it satisfies the standard throughout [5].

To take the advantages, FRF Model is created using Flexible-Link I / O data and approximated to mechanical MCK model. At this time, the spring constant K is set to a combination of polynomial and exponential functions to reduce the model uncertainty. The generated MCK model is a Lumped Flexible-Joint Model and the spring constant K is Equivalent Stiffness.

3. Simulations and Evaluation

3.1 Simulations

To verify the proposed methods in Section 2, we use an industrial robot of RAONTEC Inc. in Figure 1. The model is a robot with six degrees of freedom, but we use only one Joint and Link of the robot's center axis in order to compare the Flexible-Link System with the Lumped Flexible-Joint Model.

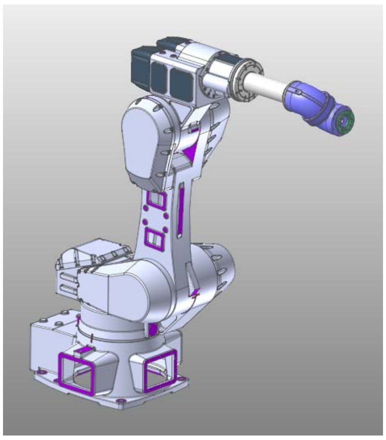

Fig. 1. Simulation Model of Industrial Robot in RAONTEC Inc.

3.2 Evaluation

The same position input is given to industrial robot of RAONTEC Inc. with sinusoidal waveform, and compare the outputs at that time. As shown in Figure 2, the X-axis is time and Y-axis is position data, it shows that the Lumped Flexible-Joint simulates well the Flexible-Link System.

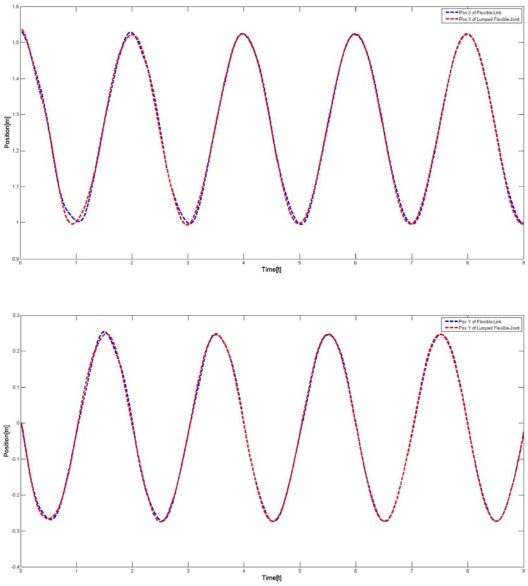

Fig. 2. Position of Flexible-Link and Lumped Flexible-Joint.

4. Conclusion and Future Works

4.1 Conclusion

In this paper, modeling techniques for flexible elements of a manipulator link into a Lumped Flexible-Joint are presented and evaluated using RAONTEC Inc. industrial robot. Simulation results among the modeling methods presented in Section 2, Approximation using FRF Model was evaluated as the best modeling method.

4.2 Future Works

In this study, three modeling methods were used to lumped the flexible elements of the link to the joint, but it would be possible to simulate better if the robot is modeled considering various materials instead of one material. Also, performance evaluation can be one of the Future Works when the degree of freedom is not one degree of freedom in the simulation process.

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