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FLEXURAL SENSING USING PIEZOELECTRIC TRANSDUCERS

M. R. Kermani, R. V. Patel and M. Moallem
Department of Electrical and Computer Engineering
University of Western Ontario, London, Ontario

ABSTRACT

Abstract: In this paper the application of piezoelectric transducers for flexural measurements in simple flexible structure as well as multibody systems is presented. A multibody system as part of a large-scale robotic manipulator is considered and a sensor arrangement for measuring its modal components is presented.

1. INTRODUCTION

In modal identification, feedback control, condition monitoring and damage detection, vibration measurement is an essential part of the process (Hung and Ko (2002), Jackson (1962)). In fact, the first step of almost any vibration control problem is the modal measurement of the system. It is only then that design engineers start to build a model or evaluate their mathematical model of the system and make a decision towards control design. In this regard, piezoelectric materials, due to their large bandwidth are promising candidates. The main idea behind using a piezoceramic as a sensor is to expose it to the strain of the vibrating structure. This can be achieved either by direct bonding of the piezoceramic to the structure as will be explained later on or indirect transferring of the motion to the piezoceramic using an extra mass (Scheeper et al. (1996)).

The direct piezoelectric effect can be utilized for measuring strain in a mechanical structure. The idea is to bond a piezoceramic to the structure such that the amount of strain developed along the sensor is equal to the strain of the structure. This contains all the information about vibration in a flexible structure. Each vibration mode of the system can be measured in time domain, should a single sensor be dedicated to that particular mode.

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In the frequency domain, on the other hand, the information of each state can be extracted from the original signal using a bandpass filter. This is due to the fact that the output signal of a piezoelectric sensor measures a weighted sum of all states (vibration modes) of the system. Thus, using appropriate filters whose central frequencies are set to the frequencies of the desired states, all states of the model can be theoretically measured from the signal of a single sensor. In order to illustrate this method for measuring the states of a model, Figure 1 shows the original signal (power spectral density) of a piezoelectric sensor bonded to a flexible beam as well as the output signals of three bandpass filters designed to extract the first three states of the system. The filters used here are

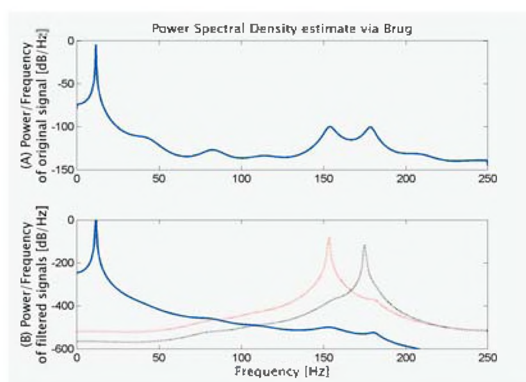

Fig. 1. The state measurement in frequency domain.

relatively low order, yet the distinctiveness of the states allows each filter to extract the information of one particular state for which the filter has been designed. In multibody systems, the frequencies of the high-order states may happen to be close to each other. Hence, the separation of such states in the frequency domain requires high order filters with sharp slopes which are not always practical in real-time control applications.

2. MULTIBODY FLEXURAL SENSING

In order to measure the flexural modes of a system with high modal density, dedicating a separate sensors to each mode is a more suitable method. Additionally, using a specific electrode profile (sensor shape) or sensor arrangement, it is possible to make some of the modal components unobservable. The placement of sensors for the first-time testing of a large and complex structure is not an easy task by any means. See, for example, (DeLorenzo (1990), Lim (1992), Lindberg, Jr. and Longman (1984)). In a large structure with a large number of possible locations for sensors, the number of possible combinations is overwhelming. In practice, engineering judgment is combined with heuristic investigations to determine sensor locations. In most cases, a trial and error approach is used to obtain acceptable results. In this regard, Finite Element Method (FEM) can be utilized to classify the mode shapes and hence, to conjecture a possible sensor arrangement. Such information about mode shapes also facilitates the selection of sensor type in a complex structure. For instance, if an accelerometer is used as a sensor, the best location of the sensor to measure a particular mode would be where the mode shape is maximum. On the other hand, if a strain-based measurement device, such as piezoceramics or strain gages are used as sensors, the best location of the sensor for a particular mode would be where the curvature of the corresponding mode shape is maximum. To illustrate this, let us consider the first four mode shapes (Figure 2) of a multibody structure as part of a more complex robotic manipulator known as macro manipulator. As seen, the first mode shape is a pure bending mode. The second and third mode shapes are torsional modes which involve twisting of the manipulator links. The fourth mode is a mixture of bending and torsional motions. It is clear that if pizeocermaics are used as sensors, for the first mode, they should be placed near the base. For the torsional mode, the strain is measured by the angle of rotation of a link cross-section. Thus, to have the best measurement for the second mode, the sensors should be placed near the base but in the middle of each link. Now, if the sensors are symmetrically placed off the middle, then their measurements for the second mode will be out of phase. In this way, one can obtain the information of the first mode by adding the two signals from each sensor and similarly the information of the second mode by subtracting the two sensors signals, assuming that the higher modes are negligible. It is worth noting that, with regard to the second mode, the further the sensors are placed from the middle of the link, the weaker their measurements become. The third mode is also a torsional mode. However, inspecting the mode shapes of the system shows that the most effective location for this mode is on the sides of the links rather than on the top or bottom surface. Nevertheless, if the sensors are placed on the link's top surface but off its middle, the third mode will still produce a net strain and as a result the third mode is still can be observed in output signal of the sensors used for the first and second modes. In this case, this mode also creates out of phase signals on two sensors. The best locations for the sensors for the first three mode shapes of the structure are indicated in Figures 2(A) ,2(B) ,2(C) using arrows.

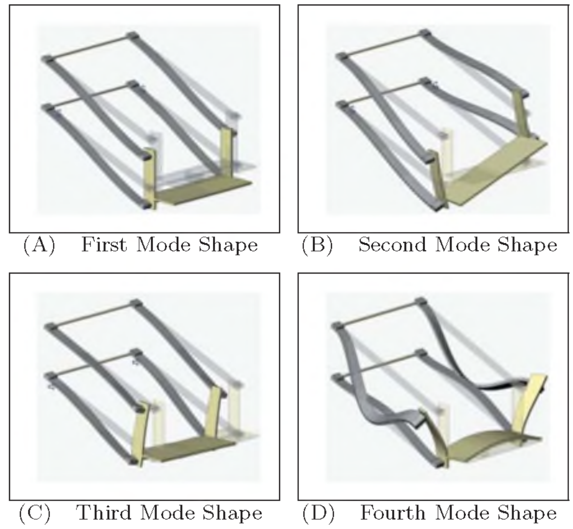

Fig. 2. The first four mode shapes of a multibody system.

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