Characterization of Structural Response for Systems with Loose Joints

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Abstract

This paper describes a technique to locate and characterize 100SC joints in a large truss structure to generate an accurate structural model. The joint looseness is modeled as a gap in the member that closes and opens depending on the loading. Arbitrarily placed actuators are used to prestress the structure to first linearize the response, Next the actuator displacements are systematically reduced while monitoring the displacement response. The gap locations are determined by comparing the measured displacements with sets of calculated displacements and the sizes are estimated by monitoring the gap member length changes using the appropriate linear force-displacement relationship for the load level. The effect of measurement error in the truss displacements and the actuator length changes are investigated,

Introduction

Adaptive structures are an attractive concept for support structures which are required to maintain a precise configuration when subject to various disturbances[1,2,3]. An example of this type of structure is the support structure for a segmented reflector which is intended for space based applications. The panels in the reflector will function as a single reflector with equivalent overall diameter when they are accurately aligned. Active members can be used to maintain an accurate surface configuration for the reflector panel mounts as well as provide vibration suppression to ensure the panels remain within the specified tolerances. However controlling the structure, whether statical] y or dynamically, requires an accurate model.

Joint looseness in a precision structure becomes a real problem for structures intended for orbit because of assembly in space or because of the change to a gravity free environment. In either case, the linear structural model is invalid and joint

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looseness becomes a significant issue for the level of precision required in an operational configuration.

Approach

Many researchers have addressed system identification problems[4,5,6] and frequently modal information is used to determine accurate structural properties or the location of damaged members. In this paper, the location of loose joints are detected using a static approach. The joint looseness in a truss structure is modeled as a gap; if the member associated with the gap is free of loading, the gap is considered open and the member stiffness is zeroed. When the structure is loaded such that the relative displacement between the gap member endpoints exceeds the gap size, the gap is considered closed and the member stiffness is included in the system stiffness matrix. The procedure was tested using a numerical simulation of the response of a structure with arbitrarily placed gaps.

The approach taken here is to first completely prestress the structure, enforcing closure of all existing gaps. Once the structure is prestressed, the structure is then slowly unloaded reducing the gap detection problem to that of locating one gap at a time. In the prestressing and subsequent unloading of the structure, a set of actuators at preassigned locations is used and the nodal displacements at a number of degrees of freedom and the actuator length changes are monitored.

The response of the structure during the unloading sequence is piecewise linear. Within each linear region, the nodal displacements, actuator length changes, and gap member length changes can be calculated using relationships derived from the standard set of equations from the displacement method of analysis.

When the structure has unloaded sufficiently to allow the first gap to open, there will be a break in linearity in the displacement response. The actuator displacements and the gap member length changes are recorded at this break. The unloading continues in this manner and each break indicates the presence of another gap. At the conclusion of this process, the number of gaps is known but the locations and sizes are yet to be determined.

To determine gap locations, the structure is again prestressed to the same state and unloaded to a region where it has been determined the first gap has opened. At this load level, a perturbation is applied with one actuator and the displacement response to the perturbation is recorded. Then ***npgap*** displacement responses to the perturbation are calculated and assembled as columns of S where ***npgap*** refers to the number of possible gap locations. Each set of displacements in S represents the response when one member of the structure in a possible gap location has been removed. An error measure, e_j, is calculated for the measured and each response pair as follows:

$$e_j = \sum_{i=1}^{nd} (x_i - S_{ij})^2, \quad j=1,2,3,\ldots, npgap \qquad (1)$$

displacement measurements. For an error free system, e_j will be zero when j is at the correct gap location. This process is repeated for subsequent gap openings until all locations are determined.

Because the number of displacement measurements is typically much less than the number of degrees of freedom in the structure, the columns of S are typically not unique and the possibility of calculating $e_j=0$ at multiple locations exists. The location detection process can be refined by using different actuators for the perturbation or by altering the unloading pattern until a unique match is found.

After locating all gaps, the sizes can be estimated by reviewing the gap member length changes at the breaks in linearity.

Numerical Examples

A modified version of a support structure for a space-based segmented reflector was used as the basic structure in the numerical examples (Figure 1). This structure consists of 72 members and 63 degrees of freedom with member sizes which range from 0,77 m to 0.92 m in length. The gap sizes were all set at 100pm although uniformity in size is not necessary for the procedure. The displacement measurements are 12 out of plane displacements at the surface. In each case, the gap locations and the actuator locations were selected at random.

In several cases, ideal conditions are assumed and the procedure successfully identified the location and sizes of gaps for various configurations with up to 4 actuators and 5 gaps. One case resulted in a non-unique match between the measured and calculated response. The ambiguity was resolved by simply altering the unloading pattern.

The next set of test cases incorporate measurement error into the nodal displacement measurements and the actuator displacement measurements. The nodal

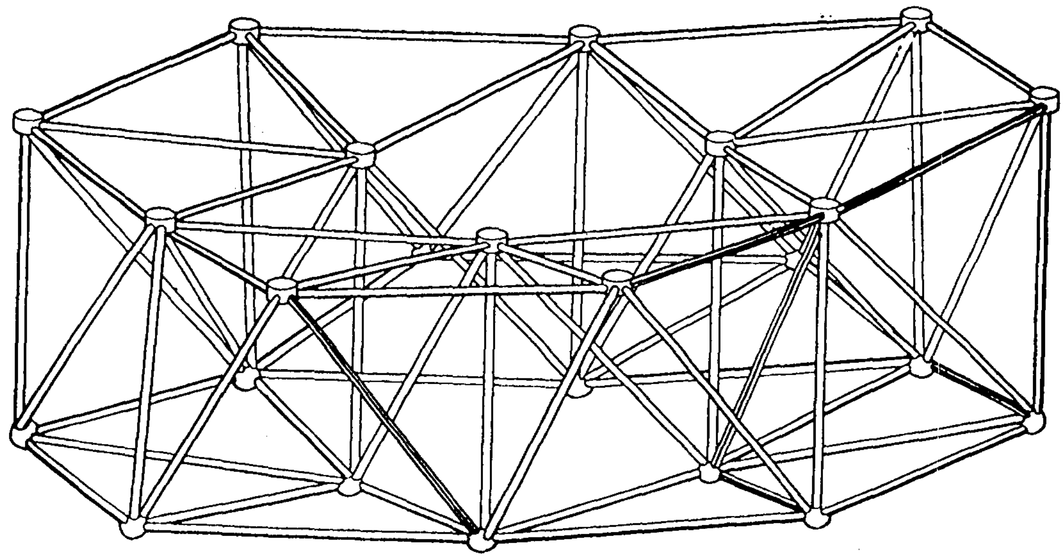

Figure 1, Truss Structure for Numerical Simulations displacement measurements are used for locating the gaps and the procedure remains successful when the maximum error value is 5 percent. The actuator displacement determines the gap size and an error vector with a maximum value of 5 percent generates on average a 5 percent error in the size of the gaps.

Conclusions

It is important to know the gap locations and sizes in order to provide an accurate model for subsequent shape adjustments. The locations and sizes of the gaps were accurately detected using an actuator driven loading and unloading static procedure. There are three key features in this procedure. The first is that a minimal number of actuators and sensors are used which is a significant feature for space applications to minimize weight and power consumption. Second, the actuator and sensor locations were not critical which suggests the possibility of getting dual use from instrumentation installed for performing shape control or other functions, An ideal situation would be perhaps using the same set of actuators and sensors to first determine the true structural model and then correcting for disturbances. The last feature about this method is it does not fail when measurement error is included. This is critical since under operating conditions, there will undoubtedly be some corruption of measured data.

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The research described in this paper was carried out by the Jet Propulsion Laboratory, California institute of Technology, under a contract with the National Aeronautics and Space Administration