Model-Based Detection of Structural Damage by Means of Vibration Measurement Data

C.-P. Fritzen[*], D. Jennewein[*]

[*]Institute of Mechanics and Automatic Control, University of Siegen, Paul-Bonatz-Str. 9-11, 57068 Siegen, Germany

Abstract:

The paper deals with health monitoring and damage detection of structural systems by means of model based approaches. Starting with the general sensitivity approach it is shown how the localization and quantification of structural damage determination from changes of measured vibration characteristics can be performed. Further, a concept is presented to generate local vibrations in a certain region of the structure while suppressing the motion of the structure by active vibration control at the other locations. When the local deformation coincides with the damage location, this results in a significant deviation of the measured system response and the damage can be diagnosed. The theory is applied to a composite beam with distributed piezoelectric elements. By means of its sensing and actuating capabilities as well as its "computational intelligence", it is shown that this smart system is able to perform a self-diagnosis.

1. Introduction

2. Mathematical Model of the Dynamical System

3. Selective sensitivity

The concept of selective sensitivity was first presented by Ben-Haim [11]. The idea is that parameter reduction can be achieved by designing an excitation vector for a special frequency ω so that the sensitivity $S_j = 0$ for some parameters to be made insensitive and $S_i \neq 0$ for the other parameters..

One of the key aspects of this paper is another idea: to suppress the vibrations of certain members by closed loop control so that the structure remains nearly undeformed in a certain region. Therefore, in this region stiffness sensitivities will be zero. At the same time some of the actuators are not included into the closed loop control but generate a local deformation. In this region $S_i \neq 0$, see. fig. 1. Form this concept a procedure can be developed for sequentially testing different areas of a structure.

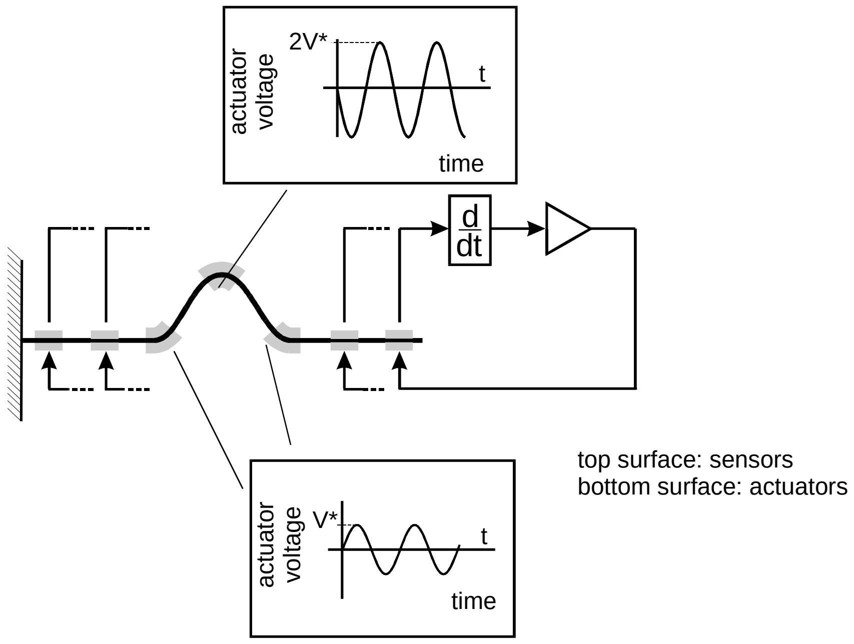

Fig.1: Closed loop design and local deformation for achieving selective sensitivity

4. Damage Diagnosis for Adaptive Structures

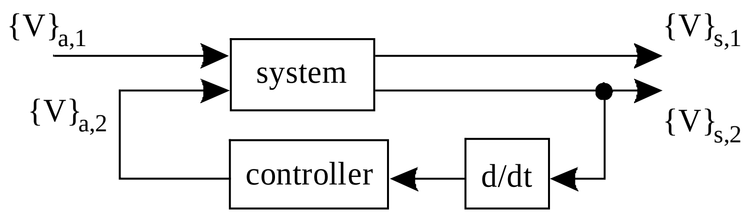

Fig.2: Mixed closed loop and open loop design

Now we can proceed as follows:

1. Assessment of the original state: Test the undamaged structure by generating local vibrations in mixed open/closed loop control subsequently for each possible damage location and store the according measurement data sets (output voltages $\{V_{s,1}\}$), serving as reference data for later comparison.
2. Detection of the damage location: Repeat this procedure after certain time intervals for health-monitoring of the system and to detect a possible change of the structure (caused by a damage). Compare these current output data sets with the reference data from the undamaged case. Due to the selective sensitivity a significant difference will be found only when the local deformation coincides with the damage location.
3. Evaluation of the damage extent: Use the analytical model of the structure including the mixed closed/open loop control and a damage model. Generate the local deformation at the position found in step 2 for the "undamaged model" and store the calculated output data. Then optimize the parameter(s) describing the damage (e.g. stiffness value) for the detected location in that way to obtain the same differences of the model output data between damaged and undamaged state as for the corresponding measured changes obtained from step 2.

5. Example

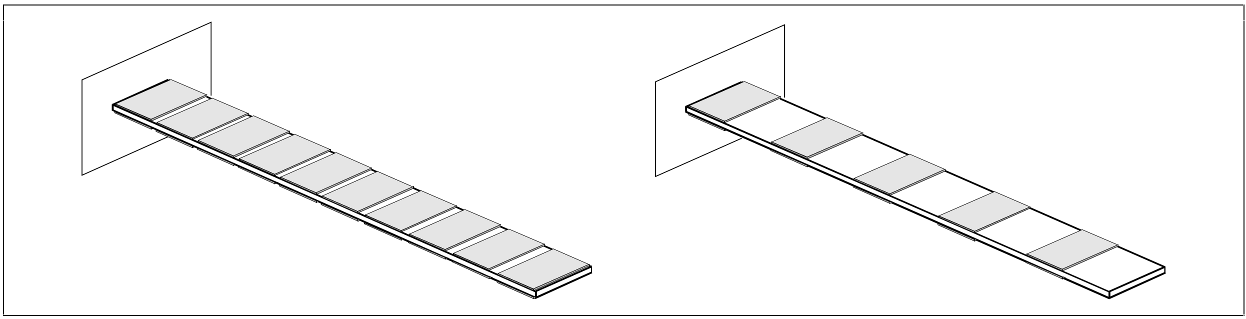

Fig. 3: The two actuator and sensor topologies that were investigated.

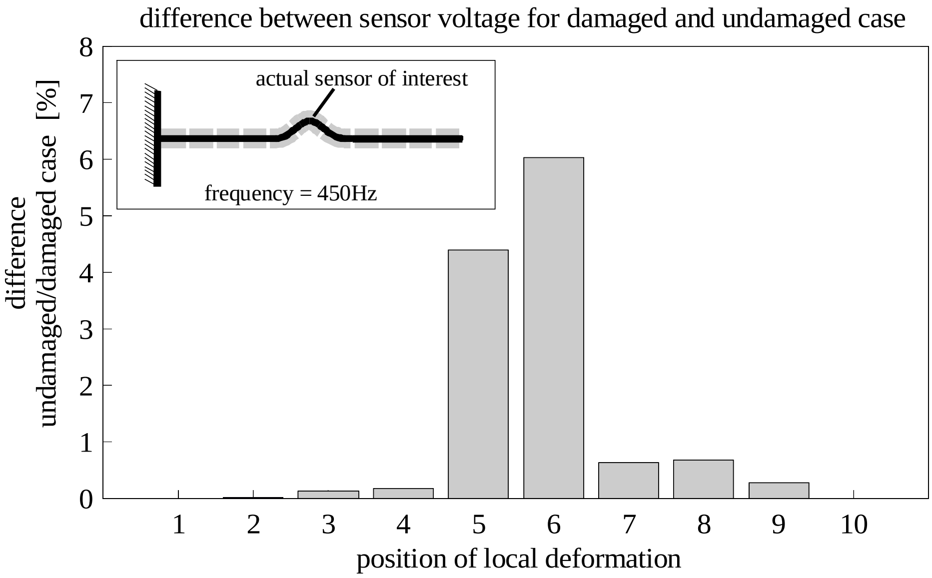

Fig. 4: Identification of the damage location by comparison of the sensor voltage for damaged and undamaged case

6. Conclusion

A concept has been proposed for damage diagnosis of structures using the capabilities of distributed sensors and actuators. The procedure is based on the subsequent generation of local vibrations for different areas using mixed open/closed loop vibration control. The application to a simulated beam structure can be only a preliminary goal and the extension to plates and laboratory experiments should be the next step.