PROBABILISTIC EVALUATION OF A VIBRATIONAL NDE DAMAGE DETECTION AND RELIABILITY ASSESSMENT METHOD FOR AEROSPACE STRUCTURES

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ABSTRACT

The topic of detecting damage on space structures using changes in measurements of the vibrational characteristics is considered. A general theory of damage detection from changes in resonant frequencies is presented. The solution algorithm is modified to account for uncertainties in the frequency measurements. The effects of experimental uncertainties on the damage predictions are examined by simulating a number of NDE inspections on a hypothetical cantilever beam subjected to a single damage at several locations using Monte Carlo techniques. The statistics of the final damage predictions are obtained through the simulation results. The probability of detecting various levels of damage along the beam is examined by defining successful detection based on a combination of several damage detection events.

An entire space structure is modeled as a free-free beam. The free-free end conditions are simulated in the laboratory by suspending a beam vertically. The nature of the uncertainties on the experimental measurements is determined by repetition of the impact testing on an undamaged beam. Monte Carlo techniques are used to determine the probability of detecting damage on the model structure using the statistical parameters for each frequency measurement. Damage experiments are conducted for separate damage cases by taking several sets of frequency measurements before and after inflicting damage to the beam.

A method of estimating the reliability of the structure directly from the damage

predictions is formulated. A limit state function is derived in which the statistics of the damage predictions from the experimental NDE inspections are substituted for the damage variable. The reliability method is tested by using the experimental damage predictions, and these results are verified utilizing Monte Carlo simulation techniques.

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CHAPTER 1

INTRODUCTION

1.1 Background of Damage and Damage Detection

Structural systems which are subjected to large and uncertain loading conditions must be routinely inspected for any possible damage. Damage may be defined as any deviation in the structure's geometric or material properties which cause undesirable displacements or vibrations in the structure. These deviations may be due to cracks, loose bolts, broken welds, corrosion, fatigue, and so on. If a structure has sustained a damage, and the damage remains undetected, the damage could progressively increase until the structure ultimately fails. Therefore, early detection, analysis, and repair of a damaged structure, if necessary, is vital for the safe performance of the structure.

There are currently a number of non-destructive techniques available for damage detection and assessment, such as X-ray radiography, infrared thermography, ultrasonic spectroscopy, acoustic holography, etc. These methods have been well developed, can be used on a variety of structures and materials, and give very accurate information on the type and extent of any damage. The major drawback with these methods is that they are all local in nature; that is, a defect is detected by placing the respective measurement equipment relatively close to the location of the damage. The time required to inspect a large structure completely using any of these methods is quite lengthy, and the costs

associated with such an inspection make them impractical as a global detection technique.

Recently a global damage detection scheme has been suggested which includes the possibility of utilizing the vibrational characteristics of a structure in order to determine the location and magnitude of damage [1]. This technique is based on the fact that damage of any structure is characterized by a decrease in the stiffness of the structure. These stiffness changes are then reflected in the dynamic response of the structure as changes in the natural resonant frequencies (eigenvalues) and the corresponding modes of vibration (eigenvectors). The vibrational properties are obtained by taking transducer measurements at various locations of the structure. Changes in the vibrational signatures, extracted before and after the infliction of damage, may be used to estimate the location and extent of damage. Then, any local inspection method can be employed to ascertain the exact nature and scope of the damage, and structural reliability concepts can be used to determine the safety of the structure given that damage. From these results, a decision can be made as to whether immediate repair of the structure is warranted.

Orbiting aerospace structures are subject to potentially damaging events, such as impacts from micrometeoroids, collisions with space debris, booster engine firings, docking, thermal cycles, and so on. It is important to identify and analyze damage to these types of structures early, since the expense of replacing a failed space structure can be enormous. In the case of manned space systems, this need is critical. Since an emergency evacuation of a space structure which is on the verge of failure is almost impossible, such a failure would result in loss of life as well as loss of the structure.

Any of the inspection techniques currently available for inspection of ground based structures could, theoretically, be used on aerospace structures. However, due to the large costs associated with planning and implementing a mission to inspect a space structure by one of the local methods, and the inherent danger to the crew involved in executing the mission, it is not feasible to use these methods, even to verify a known damage. Therefore, it is highly desirable to develop a global inspection system which not only can correctly locate damage, but also accurately estimate the overall safety of the structure given this damage.

1.2 Vibrational Methods

Various researchers [2-11] have demonstrated that different types of damage result in measurable changes in the vibrational characteristics of a structure, which can then be used to locate the damage. Cole [4] developed the Random Decrement method, which consists of averaging time history measurements of the dynamic response due to random excitations. This technique was applied to offshore structures by Yang, Dagalakis, and co-workers [5,6]. Adams and co-workers [9] showed that damage could be detected by a reduction in stiffness whether the damage was localized as in a single crack, or distributed throughout the structure as many micro-cracks. Cawley and Adams [11] determined that measurement of dynamic characteristics, natural frequencies, and damping ratios is potentially a very attractive technique for non-destructive evaluation, since these properties can be measured at a single point on the structure, and are