FIELD EXPERIENCE IN USING LASER ACOUSTIC SENSING FOR INSPECTION

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INTRODUCTION

Research being performed to develop a viable noncontacting NDE technique for measuring the extent of bonding has led to the development of a laser sensor field system. The noncontacting laser sensor has been used to collect data from diffuse surfaces, such as the Thermal Protection System (TPS) tile on the space shuttle orbiter. The bonded material gently excited with an acoustic signal, and the displacement is detected and related to the degree of bond.

Controlled experiments in the laboratory have provided useful information on the dynamic response of TPS tiles. It has been shown that several candidate signatures are common to all the "pedigree tiles." This degree of consistency in the tile-SIP (strain isolation pad) dynamic response proves that an unbond can be detected for a known tile and establishes the basis for extending the analysis capability to arbitrary tiles for which there is no historical data.

The field tests of the noncontacting laser acoustic sensor system, conducted at Kennedy Space Center (KSC), investigated the vibrational environment of the Orbiter Processing Facility (OPF) and its effect on the measurement and analysis techniques being developed. The data collected showed that for orbiter locations, such as the body flap and elevon, the data analysis scheme, and/or the sensor, will require modification to accommodate the ambient motion. Several methods have been identified for accomplishing this, and a solution is seen as readily achievable. It was established that the tile response was similar to that observed in the laboratory [1]. Of most importance, however, is that the field environment will not affect the physics of the dynamic response that is related to bond condition. All of this information is fundamental to any future design and development of a prototype system.

DEVELOPMENT OF ACOUSTO-OPTIC TECHNIQUES

During the past year, important progress was made in the area of sensor development. There is now a much better understanding of the sensor's capabilities and limitations. The sensor response has been modeled and verified with experiments using the piezo pusher. In addition, a long focal length lens has been incorporated that allows data collection at up to 10 m away [2].
The laser cavity response to light scattered from vibrating surfaces has been successfully modeled. This tool is being used to study improved methods for extracting the vibration signal. The model has also been used to explain several characteristics of the signal that arise when the vibration amplitude exceeds half the light wavelength [2]. If the model's criteria are violated, then nonlinear effects are predicted. These nonlinear effects have been observed. Frequency doubling occurs when the vibration displacement approaches the magnitude of a wavelength of laser light. Signal attenuation and frequency doubling are observed when the "at rest" distance to the sample violates nonlinearity. This understanding will result in improved performance with the existing hardware and possibly development of an improved servo scheme that will allow the sensor to accommodate large amplitude vibrations, such as the ambient vibrations encountered in the OPF.

FIELD TESTS

The field tests conducted in July of 1988 verified that tile resonances were detectable in the Orbiter Processing Facility environment. The field tests established that the vibration isolation of the sensor system, the long focal length optics, and the excitation methods could function in a field environment. There was no difficulty in obtaining an adequate reflection from the normal tile surfaces, and the pneumatic tires on the laser's cart provided sufficient vibration isolation for the system. However, the measurements, which were made on the Orbiter Columbia, also showed that the sensor response was complicated by ambient motion of the orbiter. While small (–10 μm at 20 Hz), these motions were detected by the sensor and frequently masked the induced excitation. Figure 1 shows TPS data collected near the external tank doors. The data in the two unaveraged data sets in Figure 1a changed phase during our collection period of 50 ms due to the ambient motion. For the 25 averaged data sets shown in Figure 1b, the collection period could be reduced from 50 to 8 ms due to signal cancellation caused by the ambient motion. The motion taking place on the orbiter has reduced the amount of information that the current collection technique can obtain.

Due to the large ambient motion, a fieldable system will require modification of either the sensor or the way the resonance information is extracted with the existing sensor. Details of these options are given below; an evaluation of these approaches is being conducted as part of ongoing work.

There are at least two approaches to overcoming the difficulty caused by the ambient motion of the orbiter. The first is to modify the data analysis so that the sensor nonlinearities do not obscure the desired information. This is possible because the large amplitude ambient vibrations do not change the physics of the bond's effect on the tile's dynamic response; a different measurement technique may be required, but the effect is still there. Some possible modifications are to confine the analysis to the first 5 ms after excitation or to measure peak amplitudes of resonance vibrations induced by a CW tone. The latter technique was actually used during the field test at selected resonances. Figure 2 presents data collected on one of the control surfaces. Here a CW tone was used to excite a tile vibration resonance. The data show that during a "turnaround" point the CW tone can be captured and used for data analysis. The second approach would be to continue sensor development to obtain a sensor that is linear over the required range of vibrations. The approach taken to date has been to use...
the existing sensor capability, unless and until it is necessary to expend additional resources to acquire a sensor capable of handling large ambient motion. These two approaches are currently being evaluated.

The most significant finding of the field tests is that the response of the tiles on the orbiter is similar to that observed in the laboratory. While it was not possible, or intended, to vary bond conditions on the tiles examined, it was possible to excite resonances and measure their existence with the acousto-optic sensor in a different fashion than the standard data collection method. Quantification of the ambient vibrations of the OPF environment was also significant as their impact can now be incorporated into any future design of analysis techniques and/or sensors.

EXTERNAL CAVITY

Now that the OPF vibrational environment has been characterized, it is necessary to choose a sensor to operate in this environment. An external cavity has been added to the existing sensor. The cavity consists of a mirror mounted on a piezo pusher and placed in the beam
path to the tile. As excessive motion of the tile is sensed, the mirror is moved in an opposite direction to compensate for the motion. The two types of vibrations are separable by filtering since the large amplitude vibrations are generally of lower frequency than the signal of interest. The cavity can compensate for large low-frequency ambient vibrations of less than 100 Hz (Figure 3). The control signal for this cavity variation is derived from the displacement signal output from the laser sensor. The external cavity has been used to prevent phase inversion of the signal, proving in principle that the approach is capable of improving the fidelity of the signal.

CONCLUSIONS

The past year's work had two basic objectives. The first was to continue development of the sensing technology to the point where preliminary field measurements on the orbiter could be made. This goal was achieved, thanks in large part to the development of the long focal length optics. Valuable information obtained from the field experiments clearly identifies areas where future efforts should be applied.

The second goal was to advance the state of understanding of the physics of tile vibration and vibration measurement to the point where an informed decision could be made on whether or not this approach is viable for field detection of real flaws on the orbiter TPS. This goal was also achieved; concentrating on the pedigree tiles, a number of quantifiable unbond signatures were identified. In addition to this, the measurement techniques developed were shown to work in a field environment without an optical table. Modifications to the sensor or to analysis techniques are necessary to accommodate the large ambient motion present in some areas of the orbiter.
Fig. 3. External cavity block diagram.

The field tests revealed that the ambient vibration of the orbiter is too large for the current sensing method and/or analysis techniques. The current sensor is very good at sensing vibrations with peak-to-peak amplitudes less than 0.5 μm. Motions greater than 13 μm were measured in some areas of the orbiter during the field tests.

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REFERENCES
