

Chapter 5

Conclusions

5.1 Conclusions

In this thesis, a structural health monitoring technique using multiple piezoelectric sensors and actuators has been investigated. The work is to enhance the capability of the conventional impedance-based structural health monitoring.

In Chapter 2, it was found theoretically and experimentally that ambient temperature changes influenced both on piezoelectric sensor-actuators and structures being monitored. Basically, the temperature change causes vertical and horizontal shifts of the signature pattern in the impedance or admittance versus frequency plot, while damage causes somewhat irregular changes. This feature allows us to remove the temperature effect from the impedance-based technique. Then, an empirical compensation technique based on vertical and horizontal translation of the signature pattern in the impedance or admittance plot was developed. Finally, experiments conducted on a bolted pipe joint proved that the compensation technique could minimize the temperature effect.

In Chapter 3, it was demonstrated experimentally that the global modes of structure at low frequencies were not affected by incipient-type damage. On the contrary, the impedance-based technique, which monitors the local modes at high frequencies, could detect incipient-type damage successfully, while the sensing area was small relative to the dimension of the structure. Next, it was found by coherence measurement that the wave or vibration generated by a small PZT patch could propagate at least all over the 1.8 m high steel bridge joint model. This implies

that we can obtain useful information about structural integrity if multiple PZT sensor-actuators bonded on the structure are utilized effectively. Then, a new impedance-based structural health monitoring technique using electrical transfer admittance was developed to extend the sensing area. This technique utilizes multiple PZT sensor-actuators and evaluates mutual information among them. Finally, proof-of-concept experiments on the bridge joint model and the bolted pipe demonstrated that the new technique could extend the sensing area of the impedance-based method. The correlation-based damage metric was introduced to assess damage.

In Chapter 4, a damage location technique based on the time domain pulse-echo method was proposed. This technique also utilizes multiple PZT sensors and actuators, which can be used for the impedance-based structural health monitoring. The location of damage is identified by tracking the traveling pulse in time domain. Since the waveform of the traveling pulse needs to be longitudinal, a PZT excitation technique to generate a longitudinal wave was presented. A technique to extract traveling pulses from a noisy signal was also presented. This extraction technique is accomplished using discrete wavelet decompositions. A numerical simulation indicated that the technique could extract even ‘invisible’ pulses from a noisy signal. A proof-of-concept experiment on a free-free aluminum beam demonstrated that this time domain damage location technique could assess the location of damage correctly.

These demonstrated techniques, which remove the temperature effects, extend the sensing area and identify the damage location, may solve some crucial problems of the impedance-based structural health monitoring technique. If we combine these techniques with the conventional impedance-based structural health monitoring, its application will become closer to full scale development and commercialization.

5.2 Recommendations

In this section, some recommendations for future work are indicated.

As for the temperature issue, a temperature compensation technique for structures which have temperature distribution or consist of more than one kind of material needs to be investigated. In addition, the implementation of the impedance-based technique to high temperature applications is being in question. A feasibility study on commercialized high temperature piezoelectric material, which has a Curie temperature higher than 1800 °F, is undertaken at CIMSS.

The sensing area is also an important issue. The new impedance-based structural health monitoring technique using electrical transfer admittance could successfully extend the sensing area and the coherence between distributed PZT sensor-actuators may be an index of the sensing area. However, the exact area is still unknown. Therefore, a methodology to assess the sensing area requires investigation.

Concerning the damage location technique, experiments using equipment with higher sampling frequencies should be carried out to obtain finer spatial resolution. Moreover, in order to improve the signal to noise ratio of measurement data, a signal processing technique such as pulse compression [41], which is often used in radar technology, should be investigated. Furthermore, if we observe the attenuation of traveling pulse, it may be related to the energy dissipation and then to the extent of damage.

From the practical point of view, the long term reliability and durability of piezoelectric sensor-actuators, specifically the effects of aging, fatigue and depoling need to be examined.

What is the final goal of structural health monitoring? Industries require not only detecting damage but also assessing the life expectation of structures. In order to assess the life expectation, damage should be quantified, and an appropriate model is necessary for quantitative damage evaluation. However, an approach based on modal analysis may not be available since the frequency range of the impedance-based technique is much higher than the frequency range

for which we understand modal analysis. At high frequencies, non-modal approach such as statistical energy analysis [42] (SEA) may be a useful tool. SEA deals with the vibrational energy flow in structures.