Chapter 3: EFFECT OF TEST WIRE LENGTH ON DAMAGE DETECTION

The effect of length of the test wire on damage detection capabilities was to be studied. An issue that is dealt with is the way in which frequency response from the interrogated PZT is affected with varying test wire lengths. Loss of signal with increasing test wire lengths is another issue of concern.

3.1 INTRODUCTION

In most experiments within the laboratory, the test wire that runs from the terminals of the impedance analyzer to the piezoelectric (PZT) being interrogated, is short and hence the effect of its length is not of concern. However, in practical field applications, the structure being interrogated and the impedance analyzer have to be separated by varying distances depending on the application. Most often, it is because of physical and safety constraints that the analyzer has to be distant from the structure. In one particular application, health monitoring of bridge supports was to be carried out. It was a physical problem for the analyzer to be close to the structure being interrogated. In another application, 5 x 5 feet walls were loaded to failure with a large MTS machine. In this case it was a safety concern and hence the analyzer had to be located at a safe distance from the structure in concern.

It can be safely concluded that in real-life field applications the structure being interrogated will be distant from the impedance analyzer. The effect of the length of the test wire, hence, is of concern. Its effect on the frequency response of the PZT was studied. Effects of loss of signal with increasing wire length is also dealt with.
3.2 EXPERIMENTAL SET-UP

A simple structure was used for the analysis. A PZT was bonded onto one end of a long, flat beam. At the other end, two holes were drilled; Two screws were fitted into these two holes. The presence of both the screws constituted the baseline reading. The removal of the first screw, constituted damage #1. The removal of the second screw as well, constituted damage #2.

The HP 4192A impedance analyzer is used to interrogate the structure. A short (0.3 m) connector wire is used to connect the terminals of the analyzer to chosen points on the actual test wire. The connector wire is used only to facilitate connection and represents the normal wire length that is typically used in lab experiments. Hence, when the connector wire is used to connect the analyzer terminals directly to the PZT, it is considered to be the baseline (without taking into consideration the extra length of the test wire).

The actual test wire is a 30 m, co-axial cable, with 10 leads. The specifications are as follows:
28 gauge, T – 2 (0.009”) insulation, 10 lead wiring (purchased from Piezo Systems, Inc)

The 30 m cable was partially sleeved at various specified lengths and any one particular lead was severed and used; this enabled experiments to be conducted with varying test wire lengths. The lengths that were considered are:
**connector wire** (when the connector wire connects the terminals of the analyzer directly to the PZT), 1 m (when the connector wire connects the terminals of the analyzer to the 1m point of the 30 m test cable), 2 m, 3 m, 4 m, 5 m, 7.5 m, 10 m, 15 m, 20 m and 30 m.

The frequency range used to interrogate the PZT is 45 to 65 kHz. This range was found to have sufficient dynamic interaction for the structure in question. The ‘R – X’ function was used to interrogate the actuator.
3.3 RESULTS AND ANALYSIS

The results from the various test cases were analyzed using the frequency response charts. Damage metric charts, based off the frequency charts are used to quantify the analysis.

While the frequency response charts provide a qualitative approach to the analysis, the damage metric charts quantify the information and provide a comprehensive and quick insight about the extent of damage. A scalar damage metric, referred to as the ‘Average Square Difference’ metric is used to interpret the information from the

Figure 3.1 gives a schematic sketch of the experimental set-up.
frequency charts. The greater the change between the baseline and the reading in concern, the greater the numerical value of the damage metric.

Three separate runs of the experiment were conducted. The first run was done in the order: connecting wire, 1 m, 2 m, 3 m,……,20 m and 30 m. The second run was done in the order: 30 m, 20 m, 15 m,……,1 m and connecting wire. The third run was done in the order: 1 m, 2 m, 3 m,……,20 m and 30 m (same as the first run). Three runs of the experiment were conducted to neutralize equipment and PZT heating effects. However, no significant differences were seen among the three runs. Hence, results from the third run only are presented.

3.3.1 OBSERVATION 1: EFFECTS OF TEST WIRE LENGTH ON FREQUENCY RESPONSE (R VS. FREQUENCY)

The variation of R vs. Frequency, with varying test wire length, was studied. It was seen that there was a uniform vertical shift in the curves with increasing test wire length. The essential pattern of the curves however remained unchanged. Figure 3.2 shows the ‘R vs. Frequency’ plots for the varying wire lengths. All readings shown are taken with the test structure undamaged (both screws are in place).
The importance of figure 3.2 is that it establishes that there is no change in the pattern of the impedance signature with change in test wire length. A uniform vertical shift at the base of the curves can be seen. This shift is absent at the peaks of the curves.

3.3.2 OBSERVATION 2: EFFECTS OF TEST WIRE LENGTH ON FREQUENCY RESPONSE (X VS. FREQUENCY)

The variation of X vs. Frequency, with varying test wire length, was studied. It was seen that there was a uniform vertical shift in the curves with increasing test wire length. The variations of 'R' with increase in wire length are as follows:

Variation of 'R' with increase in wire length
Structure is undamaged (with both screws in place)

Figure 3.2: ‘R vs. Frequency’ chart; variation of the curves with increasing wire length. All readings shown are taken when the structure is undamaged (both screws in place).
essential pattern of the curves however remained unchanged. Figure 3.3 shows the ‘X vs. Frequency’ plots for the varying wire lengths. All readings shown are taken with the test structure undamaged (both screws are in place).

![Figure 3.3: 'X vs. Frequency' chart; variation of the curves with increasing wire length. All readings shown are taken when the structure is undamaged (both screws in place).](image)

The uniform vertical shift at the base of the curves can be seen in figure 3.3. This shift is absent at the peaks. In all instances when the ‘R – X’ function is used to interrogate a PZT bonded onto any structure, the ‘X’ portion of the frequency response is unreactive to change (damage) in the structure. However, in this experiment, the ‘X’ portion of the frequency response is as reactive as the ‘R’ portion; this establishes that
change in test wire length affects both the ‘R’ and the ‘X’ portions of the frequency response.

3.3.3 OBSERVATION 3: DAMAGE METRICS FOR INCREASING TEST WIRE LENGTHS

The ‘Average Square Difference’ method is used to arrive at the damage metrics. The information from the damage metric charts presents a quantitative and comprehensive summary of the information in the frequency response charts.

Figure 3.4 shows the damage metrics based on the ‘R vs. Frequency’ plot. Variations for damage 1 (with screw #1 removed) and damage 2 (with screw #1 and #2 removed), for increasing test wire lengths are shown.
It can be seen from figure 3.4 that with increasing test wire lengths, there is a decrease in damage metric values. Since the extent of damage is held constant, this implies that with increasing test wire length, the ability to detect damage decreases. This decrease is caused more by loss of signal in the wire length. However, the decrease in damage metric values is small; hence, for the test wire length considered (30 m) there is no real cause for concern.

Figure 3.4: Damage metric chart based on ‘R vs. Frequency’. Metrics for damage 1 (when screw #1 is removed) and damage 2 (when screw #1 and #2 are removed) are shown.
Figure 3.5 shows the damage metrics based on the ‘X vs. Frequency’ plot. Variations for damage 1 (with screw #1 removed) and damage 2 (with screw #1 and #2 removed), for increasing test wire lengths are shown.

The information from figure 3.5 is the same as that obtained from figure 3.4. It can be seen that with increasing test wire lengths, there is a decrease in damage metric values. Since the extent of damage is held constant, this implies that with increasing test wire length, the ability to detect damage decreases. This decrease is caused more by loss
of signal in the wire length. However, the decrease in damage metric values is small; hence, for the test wire length considered (30 m) there is no real cause for concern.

The information from figures 3.4 and 3.5 is further simplified, summarized and presented as a line graph in figure 3.6. The length of the test wire (in meters) is represented on the x-axis. The damage metric (Average Square Difference) values are represented on the y-axis. Line plots for both the R and X functions are plotted; for each function values for damage 1 (when screw #1 is removed) and damage 2 (when screw #1 and #2 are removed) are shown.

![Figure 3.6: Line plot for damage metric values versus test wire length. Plots for R and X functions with variations for both damage 1 (with screw #1 removed) and damage 2 (with screw #1 and #2 removed) are shown](image-url)

Variation of damage index with increase in wire length. Variations for R and X functions for Damage 1 and Damage 2 are shown.
It can be seen from figure 3.6 that with increasing test wire length, there is an almost linear decrease in damage metric values. This implies that with increase in test wire length, there is a corresponding decrease in the ability to detect damage. However the decrease is small enough so as not to cause concern.

3.4 SUMMARY

The effect of length of the test wire on damage detection capabilities was studied. Its effect on the frequency response was seen. From the frequency response charts it was found that there was a uniform vertical upward shift, for both the R and X functions, with increasing test wire length. This shift was more at the base of the curves than at the peaks. The critical aspect of the frequency response charts is that they establish that there is no change in the essential signature pattern of the curves. Hence, it is deduced that increase in test wire length causes a uniform capacitance line drift and a simultaneous shift of almost all structural modes.

Damage metric charts were used to quantify the change in frequency response with increasing test wire length. Damage metric charts, based on both the ‘R and X vs. Frequency’ plots revealed the same information: with increase in test wire length there is a decrease in the metric values. This implies that with increasing test wire length, the ability to detect damage decreases. However, the decrease in damage metric values is small; hence, for the test wire length considered (30 m) there is no real cause for concern.

A line plot of damage metric values versus test wire length was plotted. The plot revealed an almost linear decrease of metric values with increase in test wire length.

It can be concluded that although there is a decrease in the ability to detect damage with increasing test wire length, for wire lengths under 30 m, there is no real cause for concern. It can however be suggested, based on the observations made
previously, that to increase the sensitivity to detect damage, the test wire length must be kept as small as is practically possible.