

Chapter 2: EFFECTS OF VOLTAGE ON DAMAGE DETECTION

Voltage levels used in the interrogation of piezoelectrics (PZT's) and how these voltage levels affect damage detection capabilities was to be studied. The issues that are dealt with are the sensing range of PZT's, damping effects and the appearance of the frequency response curves at various voltage levels.

2.1 INTRODUCTION

Damage detection using the impedance approach is carried out usually at the default voltage of the Hewlett Packard impedance analyzers. This voltage is set internally at 1.0V. An issue that was to be dealt with was the effect of voltage on the sensing range of a PZT. Another practical issue that was to be studied was the effect of voltage on the damage detection capabilities with change in structural damping. Finally, it was to be determined what the lower limit on the voltage level was, before noise effects set in.

2.2 EXPERIMENTAL SET-UP

Since three separate effects were to be induced (sensing range, damping and voltage level limits), the following experimental configuration was set up. Two flat aluminum beams were considered. The beams were bolted together (with a small area of overlap) using two bolts. This was done to be able to alter the structural damping by tightening/loosening the bolts. At the extreme end of one of the beams, a PZT patch was bonded onto the surface. At the extreme end of the other beam, a hole was drilled and a small screw was slipped in. The presence or absence of the screw represented damage. The experimental set-up is shown in *figure 2.1*.

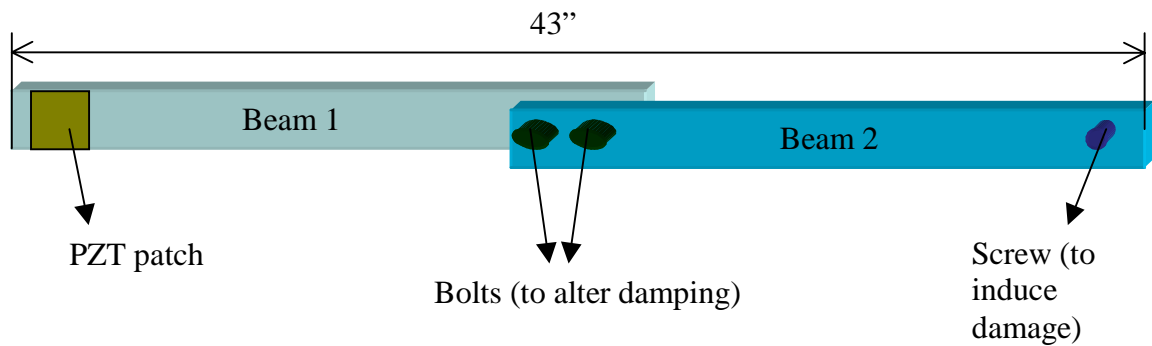


Figure 2.1: Experimental set-up to determine effect of voltage change on damage detection

The PZT is interrogated using the HP 4192A impedance analyzer. The frequency range employed is 45-55 kHz. This range was found to have sufficient dynamic interaction for the structure in question. The R – X function was chosen to interrogate the actuator.

Four different voltage levels were considered: 1.0 V, 0.5 V, 0.1 V and 0.01V. All test cases considered were done at these four voltage levels. The upper voltage limit for the HP 4192A analyzer is 1.0 V and hence that is the maximum voltage level considered.

The following two cases were considered:

- The two connecting bolts were completely tightened. A set of readings, at the four voltage levels, was taken with the screw in place. The screw is then removed (to induce damage) and another set of readings was taken.
- The two connecting bolts were then loosened (to induce damping effects). A set of readings, at the four voltage levels, was taken with the screw back in place. The screw is then removed (to induce damage) and another set of readings was taken.

2.3 RESULTS AND ANALYSIS

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

It was seen that the 'R' portion of the 'R – X' function is more reactive to change than the 'X' portion. Hence, only the 'R vs. Frequency' charts were used to perform 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 'Correlation' metric is used to interpret the information from the frequency charts. The mathematical formulation is one minus the correlation coefficient between the reading in concern and the baseline. Hence, if the baseline reading and the reading in concern are exactly the same, the correlation equals one, and $1 - \text{correlation}$ equals zero. The range of values for this damage metric is 0 to 2. This implies that the greater the change between the baseline and the reading in concern, the greater the numerical value of the damage metric.

2.3.1 OBSERVATION 1: LOW VOLTAGE EFFECTS

On observing the frequency charts, it was immediately apparent that a voltage level of 0.01 V was too low and well into the noise range. There is obvious indication of this when the frequency response curve (for ANY case) taken at 0.01 V, is compared to the frequency response curve (for any case) taken at the other voltage levels. There are random variations along the general frequency response curve as shown in *figure 2.2*.

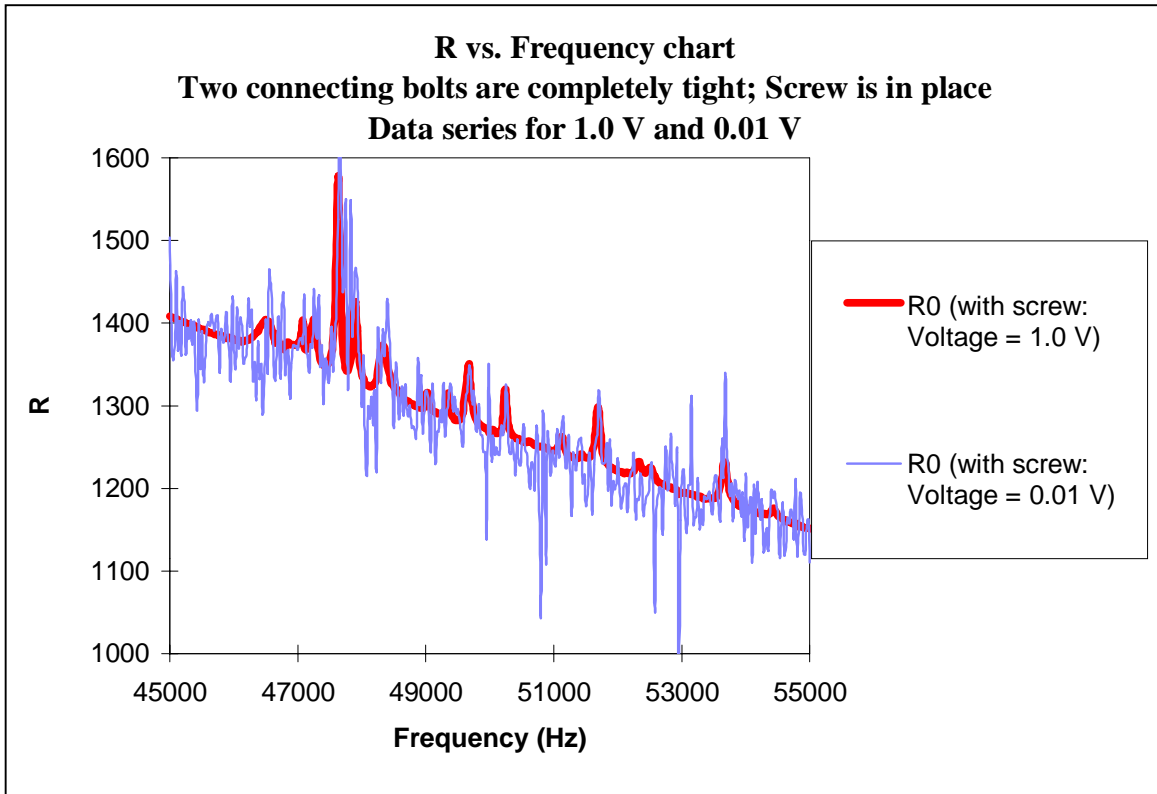


Figure 2.2: ‘R vs. Frequency’ chart. The two connecting bolts are tight and the screw is in place. The figure shows the random variations of the frequency response when the PZT is interrogated at 0.01 V. To serve as a comparison, the frequency response curve (for the same case) at 1.0 V is also shown.

It should be noted that the frequency response curves for the 0.5 V and the 0.1 V follow the same pattern as that of the 1.0 V. These curves are omitted from the figure to prevent cluttering. The random variations shown in *figure 2.2* appear when the PZT is interrogated at 0.01 volts, independent of the condition of the structure in question.

2.3.2 OBSERVATION 2: ABILITY TO DETERMINE DAMAGE WITH VARYING VOLTAGES (WITH CONNECTING BOLTS TIGHT)

The connecting bolts are maintained tight. The screw is in place. Readings are taken at the four voltage levels. The screw is then removed (to induce damage). Another set of readings is taken at the four voltage levels. The two sets of reading are then compared. *Figure 2.3* shows the damage metric chart, based on the '1-Correlation' mathematical formulation.

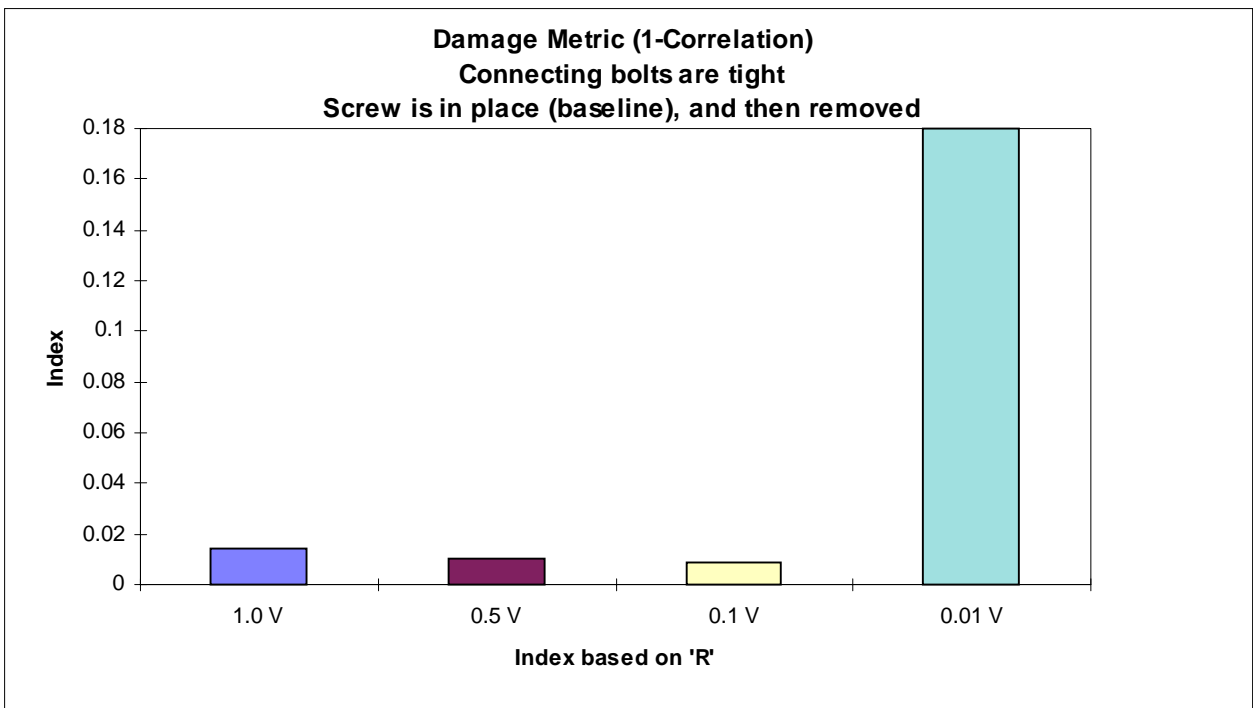


Figure 2.3: Damage Metric chart (1-Correlation). The connecting bolts are maintained tight. The baseline readings are taken with the screw in place. The screw is then removed, and another set of readings is taken. The damage metric chart is obtained by comparing the two sets of readings.

From *figure 2.3* it can be seen that as the voltage level decreases from 1.0 V to 0.1 V, the metric also decreases. Since the extent of damage is constant, this implies that as

the voltage level decreases, the *ability* to determine this damage *decreases*. This reflects on the sensing area of the PZT: with decrease in voltage levels, the sensing area of the PZT also decreases.

The damage metric for 0.01 V has a very high numerical value because of the random variations shown in *figure 2.2*; hence it can be ignored from the observation.

2.3.3 OBSERVATION 3: ABILITY TO DETERMINE DAMAGE WITH VARYING VOLTAGES (WITH CONNECTING BOLTS LOOSE)

The connecting bolts are loosened. The screw is in place. Readings are taken at the four voltage levels. The screw is then removed (to induce damage). Another set of readings is taken at the four voltage levels. The two sets of reading are then compared. *Figure 2.3* shows the damage metric chart, based on the ‘1-Correlation’ mathematical formulation.

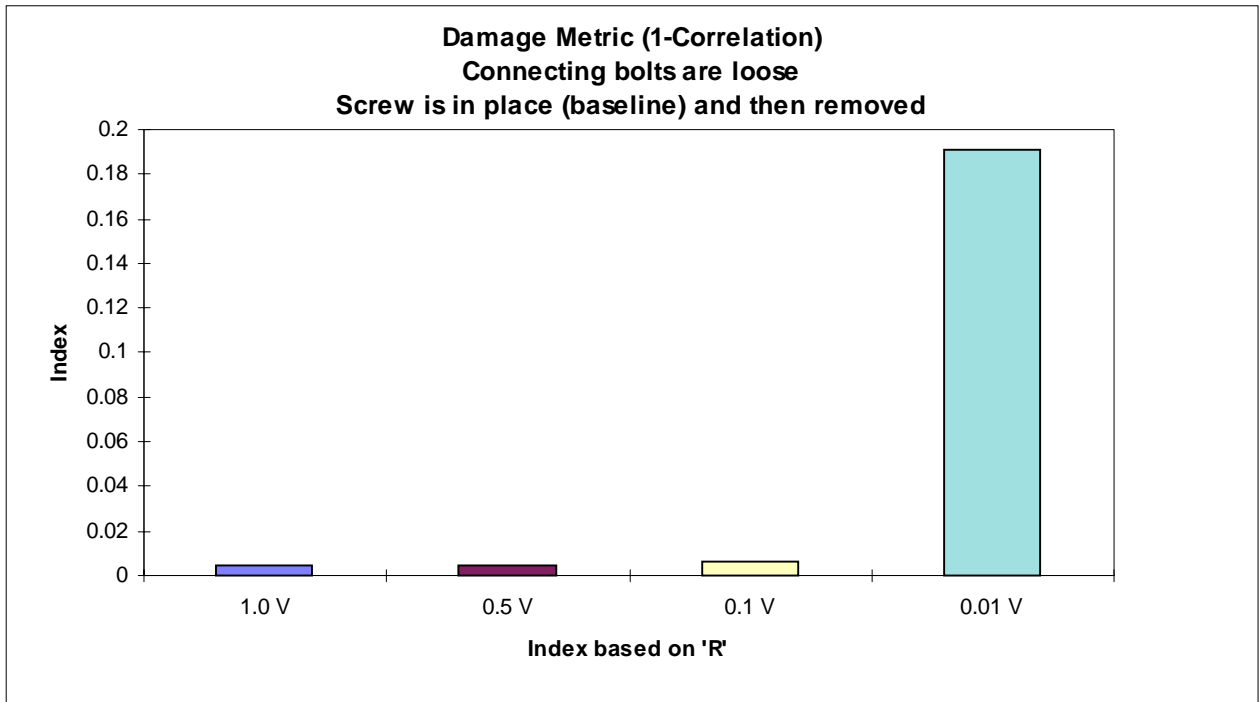


Figure 2.4: Damage Metric chart (1-Correlation). The connecting bolts are loosened. The baseline readings are taken with the screw in place. The screw is then removed, and another set of readings is taken. The damage metric chart is obtained by comparing the two sets of readings.

From figure 2.4 it can be seen that as the voltage level decreases from 1.0 V to 0.1 V, the metric also decreases. Since the extent of damage is constant, this implies that as the voltage level decreases, the *ability* to determine this damage *decreases*. This reflects on the sensing area of the PZT: with decrease in voltage levels, the sensing area of the PZT also decreases.

The damage metric for 0.01 V has a very high numerical value because of the random variations shown in figure 2.2; hence it can be ignored from the observation.

2.3.4 OBSERVATION 4: DAMPING EFFECTS

Structural damping was induced by tightening or loosening the two connecting bolts. On observing the signature pattern from the two cases it was observed that there was a definite and observable shift in the frequency response curves. *Figure 2.3* shows the shift in pattern for two specific cases: voltage is maintained at 0.1V; the screw is in place. A reading is taken with the connecting bolts tight and then another reading is taken with them loose.

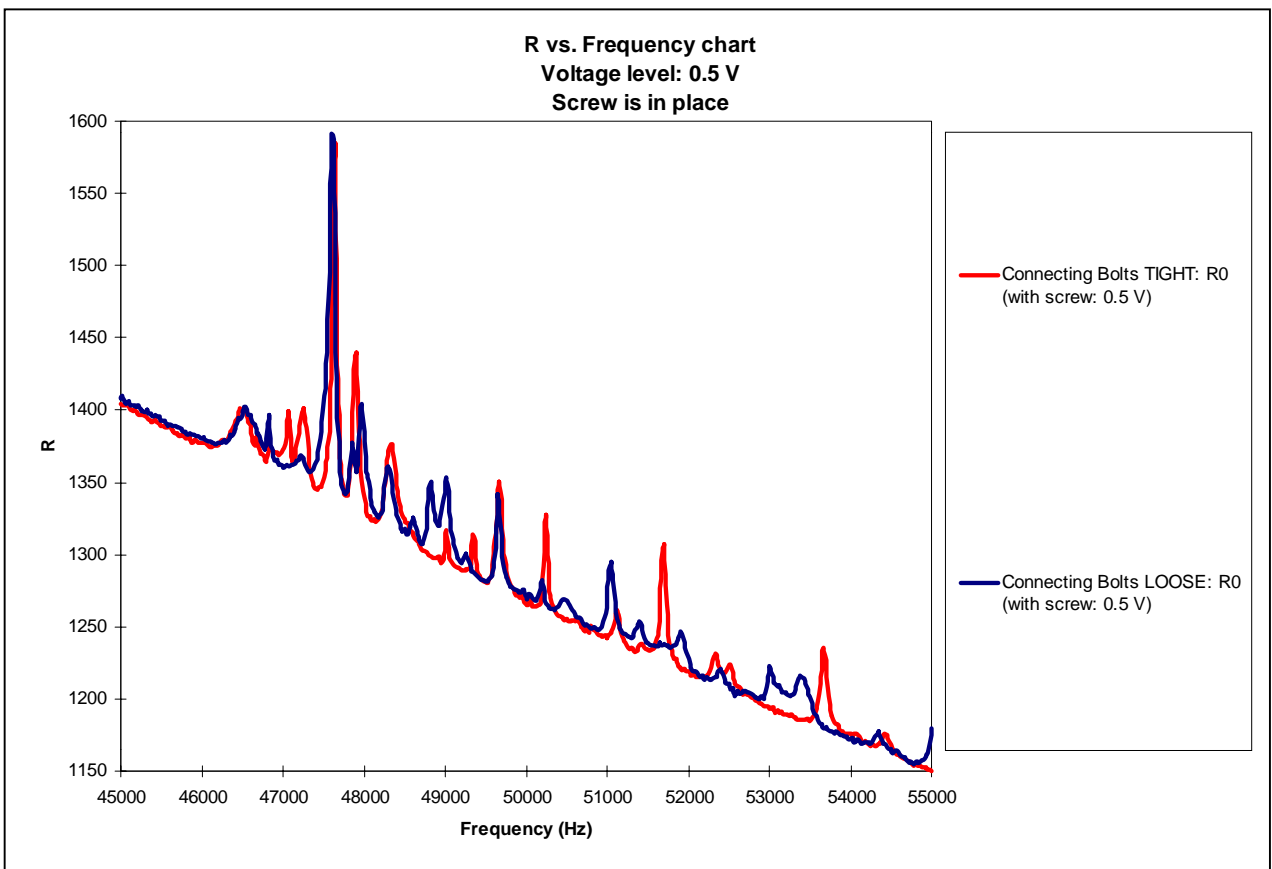


Figure 2.5: ‘R vs. Frequency’ chart. The voltage is maintained constant. The screw is left in place. The two readings are then taken, one with the connecting bolts tight, and the next with them loose.

The change in the signature pattern is apparent from *figure 2.5*.

2.3.5 OBSERVATION 5: ABILITY TO DETERMINE DAMAGE WITH VARYING VOLTAGES AND CHANGE IN DAMPING

To determine the effects of damping and voltage, on damage detection capabilities, two sets of readings were taken. The screw is removed. The connecting bolts are tightened, and a set of readings at the four voltage levels is taken. The connecting bolts are then loosened by a one-quarter twist, and another set of readings are taken at the four voltage levels. The two readings are compared and damage metrics are arrived at. *Figure 2.6* shows the damage metric chart for this case.

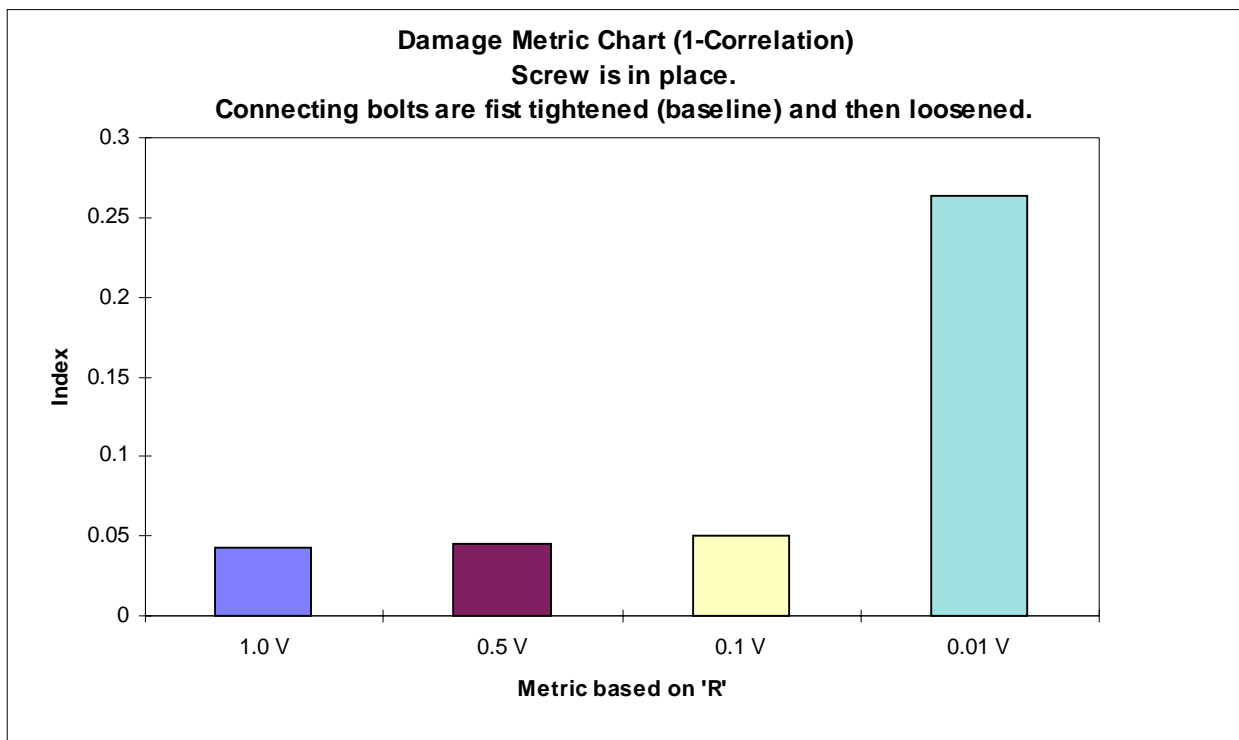


Figure 2.6: Damage Metric chart based on the '1 – Correlation' formulation. The screw is removed. The connecting bolts are tightened, and a set of readings is taken. The connecting bolts are then loosened, and another set of readings is taken. The damage metric is arrived at by comparing the two data sets.

From *figure 2.6* it can be seen that there is very little variation in the damage metric when the voltage level is changed from 1.0 V to 0.1 V. This implies that with change in damping (by the loosening of the connecting screws), varying the voltage level did not have an observable impact on the ability to detect damage. The ability to detect damage, with change in damping, was found to be independent of voltage levels. However, in the case when the voltage is 0.01 V, the damage metric has a comparatively large numerical value. This is due to the random variations shown in *figure 2.2*. Hence, it can be ignored from the observations.

2.4 SUMMARY

Voltage levels used in the interrogation of PZT's and how these levels affect damage detection capabilities was to be studied. The issues dealt with were the sensing range of PZT's, damping effects and the appearance of the frequency response curves at various voltage levels.

The observations made are summarized:

- When the PZT is interrogated using voltages as low as 0.01 V, the resulting frequency response is well into the noise region. There are random variations in the frequency response for this voltage level.
- When the connecting bolts are tight, and there is a good contact between the two beams (which implies that there is a greater connection from the area where the PZT is attached and the area where the damage is being induced), change in voltage levels had a small, but observable effect on the ability to determine damage. With decrease in voltage (from 1.0 V, 0.5 and then to 0.1 V) the ability to detect damage also decreased. This reflects on the sensing area of the PZT: with decrease in voltage, there is a corresponding decrease in the sensing area of the PZT.

- When the connecting bolts are loose, change in voltage levels had a small, but observable effect on the ability to determine damage. With decrease in voltage (from 1.0 V, 0.5 and then to 0.1 V) the ability to detect damage also decreased. This reflects on the sensing area of the PZT: with decrease in voltage, there is a corresponding decrease in the sensing area of the PZT.
- Loosening of the connecting bolts caused a definite and observable change in the signature pattern. It was also determined that with change in damping (by the loosening of the connecting bolts), varying the voltage level did not have an observable impact on the ability to detect damage. It appears that with change in structural damping, change in voltage levels does not alter the ability to detect damage. However, it must be noted that the amount of change in damping that was induced, is minimal for the structure in question. Hence, this result is not entirely conclusive.

From the above observations it can be concluded that the use of very low voltages (< 0.01 V) should be avoided. Increase in voltage level (within limits) increases the ability to detect damage.

In an experiment by F. P. Sun et al [23], a test was conducted on a standard signal analyzer (Zonic WCA) to experimentally check the impact of excitation level on the localization sensing effect of the PZT. A voltage of 15 volts, which is assumed to be the upper limit of the PZT's linearity, is applied. There was no observable difference in the signature pattern when compared to results from a 0.5 V case. This is in agreement with the theory of linear systems. It can be concluded that the sensing radius of the PZT is uniquely determined by the structure configuration and the PZT location. Varying the voltage levels improves the signal to noise ratio but generally does not change the impedance signature pattern. This improvement in the signal to noise ratio with increase in voltage levels, within limits, improves the capability of identifying weak modes and hence the ability to detect damage.