A Different Type of HALT Stimulus
Case history

By
George Henderson
GHI Systems, Inc.,
and
Kim Kral
SCI Corporation

I. Introduction.

The title of this paper could have been "Defects Can Be Precipitated By the Production and Handling Environments." The paper describes tests done during a circuit board routing operation. The router is used to divide large circuit board panels into smaller individual circuit cards following surface mount part placement and soldering. During the routing process, vibration induced into the large panel by the router bit was suspected of causing lead fractures of a large surface mounted capacitor. Preliminary analysis had predicted that the primary vibration would be mainly in the X- y plane of the board, with little in the vertical Z axis direction, and excitation at or near the capacitor's estimated resonance frequency of 400Hz must be present.

Acceleration versus time recordings of excitation in the three orthogonal axes indicated a different condition in that the Z axis was higher than that of the x- y plane. Acceleration records were processed with spectrum analysis tools to obtain both the PSD and the DP(t) (Damage Potential Spectrum) of the excitation input. The PSD's indicated a very high Z axis acceleration spike at/or about 370Hz. It is believed that this excitation frequency is within the lightly damped response bandwidth (400Hz +/- 40Hz) of the capacitor. The DP(t) analysis indicated that at or very near the component's resonance frequency, the magnitude of damage potential was 1E12 times greater than the mean of the DP(t) spectrum.

Failure analysis of several parts showed that the leads had microscopic stress fractures at a forming bend having both small radius and cross section. This is where fractures resulted. It was concluded that capacitor self resonance was the cause of the failure.

II. Measurements

A test was made by bonding a triaxial accelerometer array to the large panel directly behind the failing component. Some limitations arose due to the physical restraints of the router head geometry. The mass of the accelerometers was less than a percent of the mass of the large board, so only very minor frequency shifting can happen. In addition, the board was restrained by vertical mounting pins and damped by a cellular foam pads. Programming for the router movement had to be adjusted to provide a stop prior to the tool damaging sensor cables taped to the large panel. Figure 1 shows the test arrangement.

The data system, an analog to a digital converter transient recorder with amplitude triggering, was set to capture 6.5 seconds of acceleration time history [1].

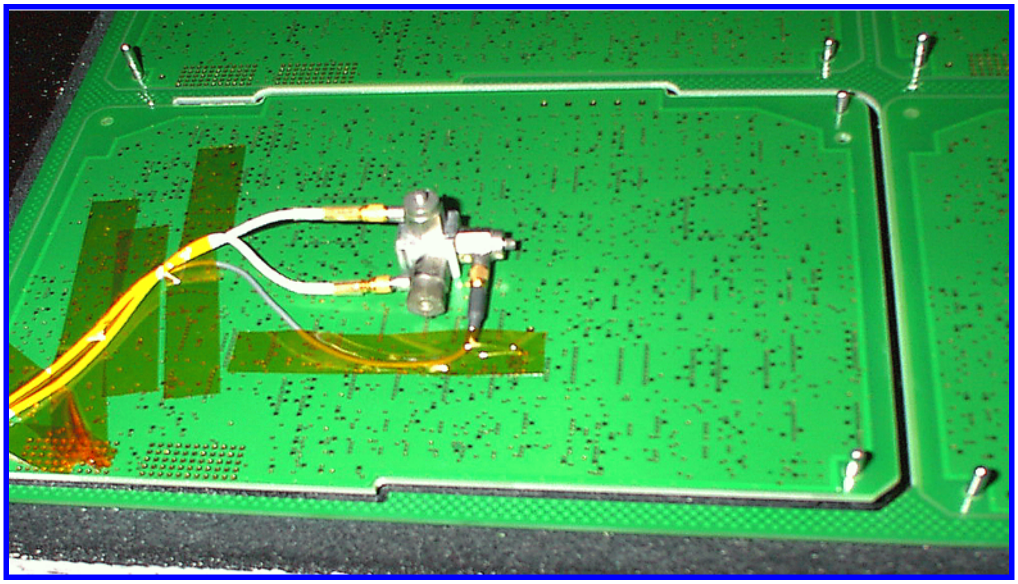

Figure 1. Location of triaxial accelerometer array on opposite surface of small board section of larger board panel. Router path can be seen.

This duration was equal to the time the router took to cut a third of the small board outline.

The digitizing rate for this recording was 5KHz/ch. The anti alias filter was set at 80% of the Nyquist frequence of the digital conversion process, or 2KHz.

Figure 2 shows the acceleration versus time history plots for one of the tests. They do not appear as periodic as expected and the highest peak amplitude is in the Z axis as compared to the other two axes.

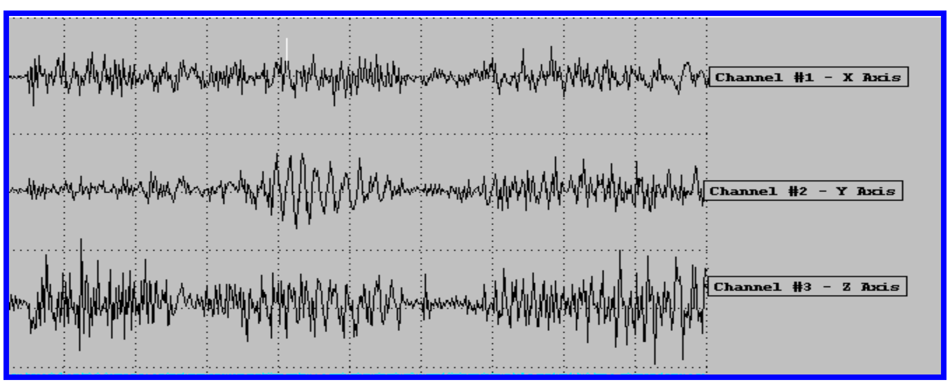

Figure 2. Expanded time history of one 6.5 sec recording. The highest acceleration levels are on the Z axis (vertical). The amplitude reached 20g's, peak to peak.

Peak to peak amplitudes reached more than 20g's on the Z axes. RMS values for the accelerations were X Ch = 1.525 g's, Y Ch = 1.796 g's and Z Ch = 2.74 g's. Observation of the structure of the time histories shows that there are large changes in amplitude and spectral content.

III. Spectral Analysis

Time data were analyzed with a standard PSD analysis routine[2]. Figure 3 shows a typical PSD obtained from the test. This PSD is from the record made during the router pass as shown in Figure 1. It is interesting to note that both the acceleration time history plots, as well as the PSD plots, looked very much like those from quasi -random hammer excited stress screening machines with thick solid tables. One major difference is the dramatic reduction of the PSD amplitude above 2KHz as a result of the anti alias filter cut off.

The spectrum in Figure 3, as well as other spectra, show a very high spike at about 370Hz. The amplitude of the peak in this plot, $0.09261g^2/Hz$, is about three orders of magnitude higher than the mean of the spectrum.

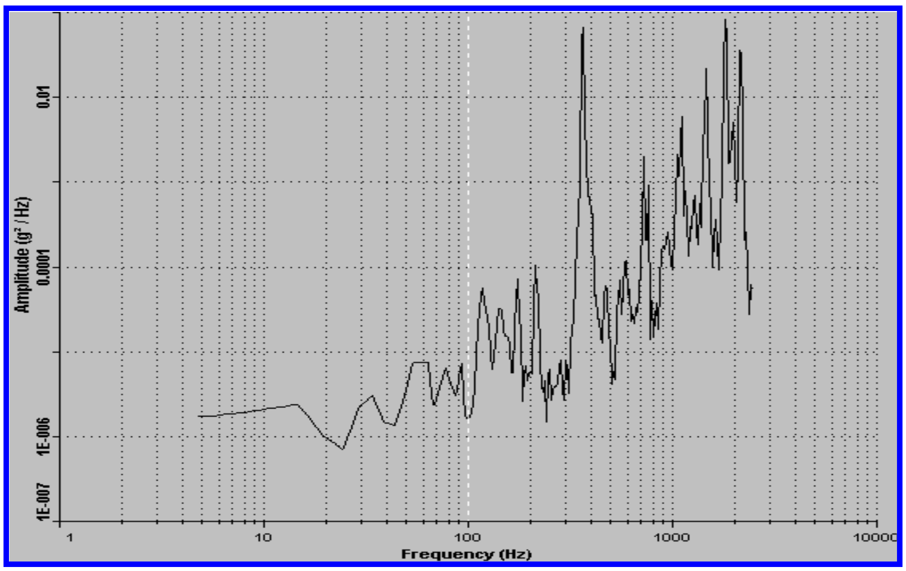

Figure 3 PSD of Z axis acceleration created by router during PC board routing operation. The peak at 370Hz was obvious in all records.

IV. Comparative Fatigue Damage Potential Accumulation Rate

The acceleration versus time recordings were further analyzed with the Damage Potential Spectrum, DP(f)[3]. This plot appears in Figure 4.

The Damage Potential spectrum shown above was estimated using the following calculation variables: 1) Total duration of excitation for last small board = 1.3 ms, 2) Damping ratio = 5%, 3) S/N fatigue beta = 8. The data file used was from the second 6.5 second portion of the recording from the first board panel being routed. Since there are approximately 19.5 seconds of excitation produced for each small board and four boards are routed per panel, the last board will receive 1.3 minutes total excitation when the process is completed.

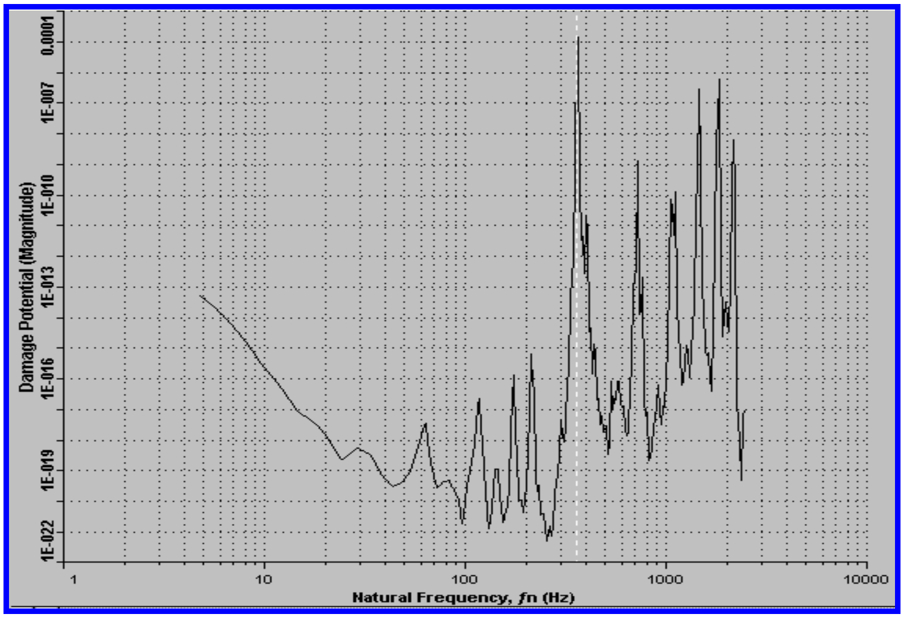

Figure 4 The DP(f) for the complete routing operation for all four boards. The peak at 370Hz is 1.1E-4 DP units. Compare this to the mean of E-16.

For the DP(f) shown above, the peak at 370Hz has a magnitude of 1.1 E4. The peak at 370 Hz is a million million (E12) times higher than the mean of 1E-16! From this enormous disparity, one must assume that the vibration induced damage is related to the forcing function frequency of 370Hz.

V. Discussion of Spectra

In Figure 4, several low intensity harmonics of the first mode frequency; 740Hz, 1110Hz, etc., are seen at frequencies above the basic mode of 370Hz. The question "Do these harmonics add to the fatigue damage at the resonant frequency of the capacitor?" is answered in the negative. These frequencies are outside the damped bandwidth of the resonating capacitor and also are several orders of magnitude lower .

VI. Failure Analysis Confirmation

It was determined that 4% of the mounted capacitors of this type were failing during the routing operation. As previously mentioned, photomicrographs indicated stress cracking on the upper bends of the bifurcated solder mounts. A failed capacitor is shown in Figure 5.

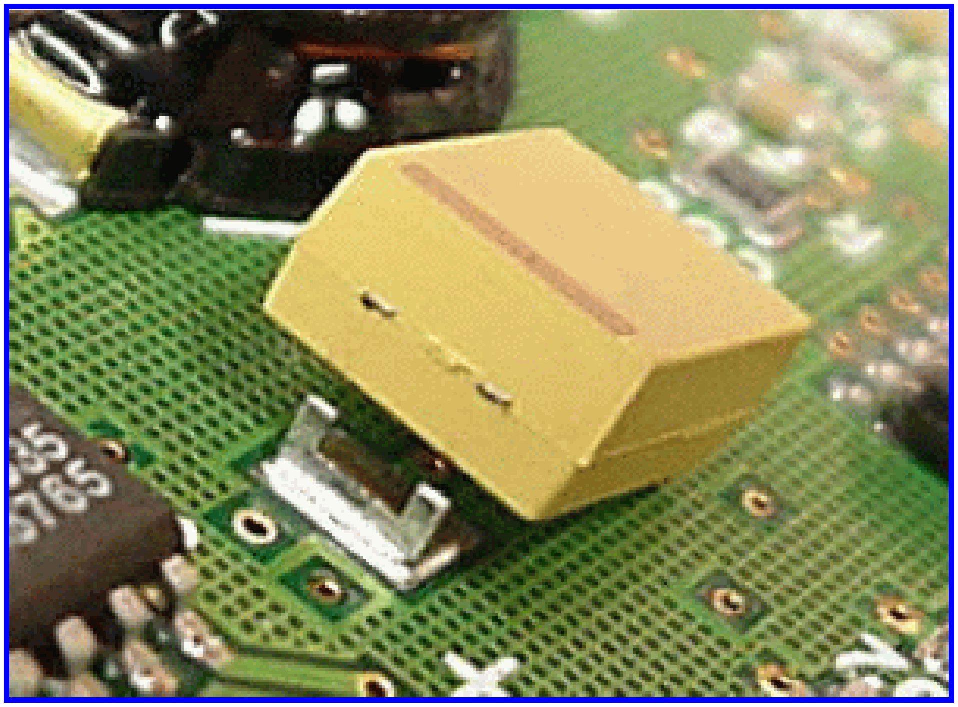

Figure 5 View of failed surface mount capacitor. Failure was due to fatigue fracture accelerated by stimulus of router tool. Solder pad portion of lead is still connected to circuit board.

VII. Conclusion

The intense Z axis vibration induced by the router had a narrowband spectral peak which overlapped the resonance bandwidth of the failed component. The part failure was probably accelerated by the fact that there were pre-excitant stress cracks at a critical bend. Because of this condition, the slope of the fatigue curve for the component's lead material was greatly increased. As a result, a relative few number of resonant cycles of vibration caused the part to fail. This same defect could have been precipitated by either a typical shaker or an RS machine, however the difference would have been time. When subjected to the router stimulus, the defect precipitated in less than 2 minutes. Because the excitation at the critical frequency of the component as produced by the router operation was several orders of magnitude greater than that produced by most RS machines, an RS machine would have taken substantially longer to achieve the same results. The extremely high amplitude of the in-band forcing function at 370 Hz from the router was several orders of magnitude higher than that of any shaker this author has measured. This is indeed an unfortunate case of a coincidence between the high spectral peak of the forcing function and the resonant frequency of the component.

This is a clear case of failure due to vibration stimulus. It is not anticipated that this defect could have been produced by thermal stresses alone.

Perhaps the most important point of this study as bourn out by Figures 3, and 4, is the difference between the DP(f) and the PSD. The DP(f) defines relative damage magnitudes spectrally, its peaks are direct indicators of accumulated fatigue potential. A way of understanding this is that if a peak at one frequency is twice that of another at a second frequency, the first represents twice the fatigue accumulation. It follows that if two analyses are made and two different times, if a first test produces a peak which is twice the amplitude as a peak at the same frequency on a second test, the first has twice the fatigue accumulation as the second.

On the other hand, the acceleration PSD, which may have high PSD peaks, does not directly represent higher damage potentials by the magnitude of its peaks. This can only be indicated by a velocity based spectrum.

Footnotes and References

1. *GHI Systems, Inc., CAT (Computer Aided Test System), with spectrum analysis software.*

2. *Bendat, Julius S. and Piersol, Allan* G., *"Random Data: Analysis and Measurement Procedures 3rd Edition,* "
Wiley lnterscience, New York, 2000.

3. *Henderson, G.R.., and Piersol, Allan G., "Fatigue Damage Related Descriptor for Random Vibration Test Environments.* " Sound and Vibration, pp 20-24, October 1995.