The Crossover Effect and Why It Prevails

By Gregg K. Hobbs, Ph.D., P.E.

The Crossover Effect has been included in my seminar since 1989, but a clarification as to why the effect is so pronounced has only recently been advanced. It has been known for many years that many faults due to thermal cycling in the field environment will show up readily due to vibration during HALT. A seminar attendee recently asked why. This short article explains the now obvious.

One failure mechanism that is quite common in HALT and in the field environment is that of cumulative fatigue damage due to mechanical extension and compression. It can be described mathematically as follows:

$$D \cong n\sigma^{\beta}$$

Where D is the cumulative fatigue damage done,
n is the number of cycles of applied stress,
σ is the stress in force per unit area units,
and b is the negative inverse slope of the S-N diagram for the material.

It is noted that fatigue damage is cumulative and cannot be eliminated without re-fabrication, that is, to melt it down and make another one. In general, once damage is done, it is permanent. An equivalent phenomenon is electro-migration. It, too, is permanent and non-reversible.

Let us now consider a system, which has two mechanisms of failure in it, one due to vibration and one due to differential thermal expansion. Let us also suppose that the failure will occur at a local stress concentration, that is, at the same place due to either vibration or due to thermal cycling. An example that I like to give is that of a resistor with a lead that has a sharp 90-degree bend on one of the leads emanating from the resistor body. Either vibration or thermal cycling will cause a fatigue failure at the sharp bend.

Let's calculate the ratio of fatigue damage done in vibration per unit of time to that done due to thermal cycling per unit of time. Let's just assume that the stresses generated are equal so as to make the calculation easy. If the resistor has a resonant frequency of 500 Hz (or the circuit board on which it is mounted flexes at 500 Hz generating the cyclical stresses), then it will experience 500 fully reversed stress cycles per second. If we thermal cycle at one cycle per 10 minutes, a quite rapid thermal cycle, then we get one complete stress reversal every 600 seconds or 1/600 cycles per second.

Now the ratio of damage accumulated every second is:

Vibration damage per second/Thermal damage per second = 500/(1/600) = 500 x 600 = 300,000:1.

This says that the vibration accumulates fatigue damage at a rate of 300,000 times as fast as the thermal cycling (if the stress levels are equal). This illustrates why vibration makes a flawed design fail so fast compared to thermal cycling. In vibration, the cyclic rate ranges from hundreds of cycles per second to thousands of cycles per second where in thermal cycling we may only see a few cycles per hour. Additionally, I have observed that many HALTs do not apply enough thermal cycles to reach failure because it takes too long to do so. This is a failing in the application of HALT, not in the methodology.

One can readily see that the fatigue damage accumulation rate will favor vibration over thermal cycling for a precipitator when both stresses will eventually lead to the same failure. This is precisely why we find so many weaknesses in vibration and fail to find them in thermal cycling. The answer is so simple that I am embarrassed that I did not think of explaining it this way before.