A COMPARISON OF SINE AND RANDOM VIBRATION VIA TUSTIN'S DEMONSTRATION DEVICE Revision A

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Introduction

Wayne Tustin has correctly written in Reference 1 that there is no "equivalency" between random and sine vibration. To prove his point, he built and tested a device similar to the one shown in Figure 1. Furthermore, he wrote that this device could represent circuit boards in an avionics component, mounted in an aircraft or rocket vehicle.

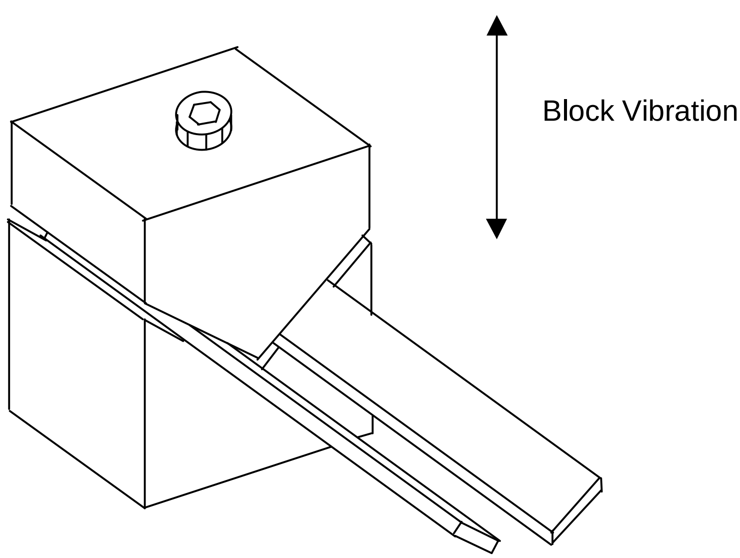

Figure 1. Tustin's Demonstration Device

The demonstration device consists of two reeds which protrude from the clamp block as cantilever beams. Each reed has unique properties. Assume that the reed on the left has a natural frequency of 17 Hz and that the reed on the right has a natural frequency of 34 Hz.

The device is then mounted to a large shaker table, which is not shown in the figure. The shaker applies base excitation to the device. The excitation is in the vertical axis only. Each reed, however, responds primarily with out-of-plane bending motion, at a 45 degree angle from the vertical axis.

The device is first subjected to sine sweep vibration. Then it is subjected to a separate random vibration test.

A "failure" results if the reeds contact one another. This collision is most likely to occur between the free ends of the reeds.

The point of the experiment is that the reeds pass the sine sweep test but fail the random test.

Sine Sweep Test Results

During the sine sweep test, a single frequency is excited at any given time. Each reed tends to resonate only when it is excited at, or near, its natural frequency. A reed experiences a large relative displacement during resonance.

The respective natural frequencies of the reeds are separated by one octave, however, since the higher frequency is twice the value of the lower. Again, the respective natural frequencies are 17 Hz and 34 Hz.

Thus, as one reed experiences a resonant response, the other remains nearly still. The reeds never touch during sine sweep vibration.

Random Test Results

During random vibration, a broad band of frequencies are excited at any given time. Thus, the reeds can simultaneously experience some degree of resonant excitation. The reeds are thus prone to eventually collide, assuming the base input is sufficiently high.

Analytical Experiment

Again, Wayne Tustin actually built and tested the device in Figure 1. He documented the results in an instructional video. The purpose of this report is to repeat this experiment in an analytical sense.

Consider that the reed tips will collide if each simultaneously experiences a displacement of 5 mm or greater. A supporting diagram is shown in Figure 3. Note that the displacement is measured relative to the block.

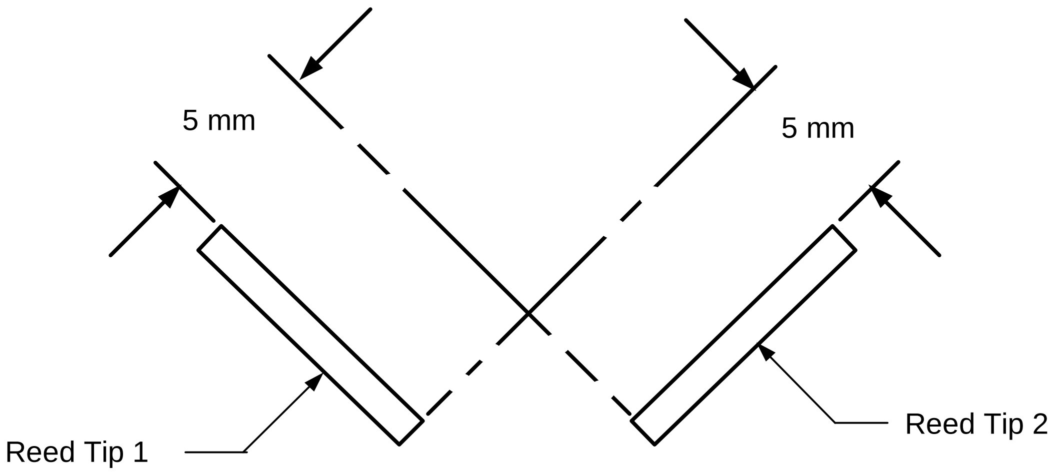

Figure 3. Reed Tip Diagram

The reeds are considered to be single-degree-of-freedoms systems, with a common amplification factor of Q=10. Again, the first reed has a natural frequency of 17 Hz. The second reed has a natural frequency of 34 Hz.

The device is subjected to a sine sweep test and a random vibration test, as specified in Tables 1 and 2, respectively. The tests are performed separately. For analytical purposes, the level normal to each reed is taken as 0.707 times the input level.

Table 1. Sine Sweep Test	
Frequency	10 Hz to 50 Hz
Amplitude	5 G
Duration	2 minutes
Sweep Type	Log

Table 2. Random Vibration Test	
Duration = 2 minutes, Overall Level = 3.0 GRMS	
Frequency (Hz)	PSD (G^2/Hz)
10	0.225
50	0.225

The analysis is carried out in the time domain.

Time histories are synthesized for each specification, using the methods in References 2 and 3. The response of each reed is then calculated using the relative displacement equation from Reference 4.

The sine sweep results are shown in Figure 4.

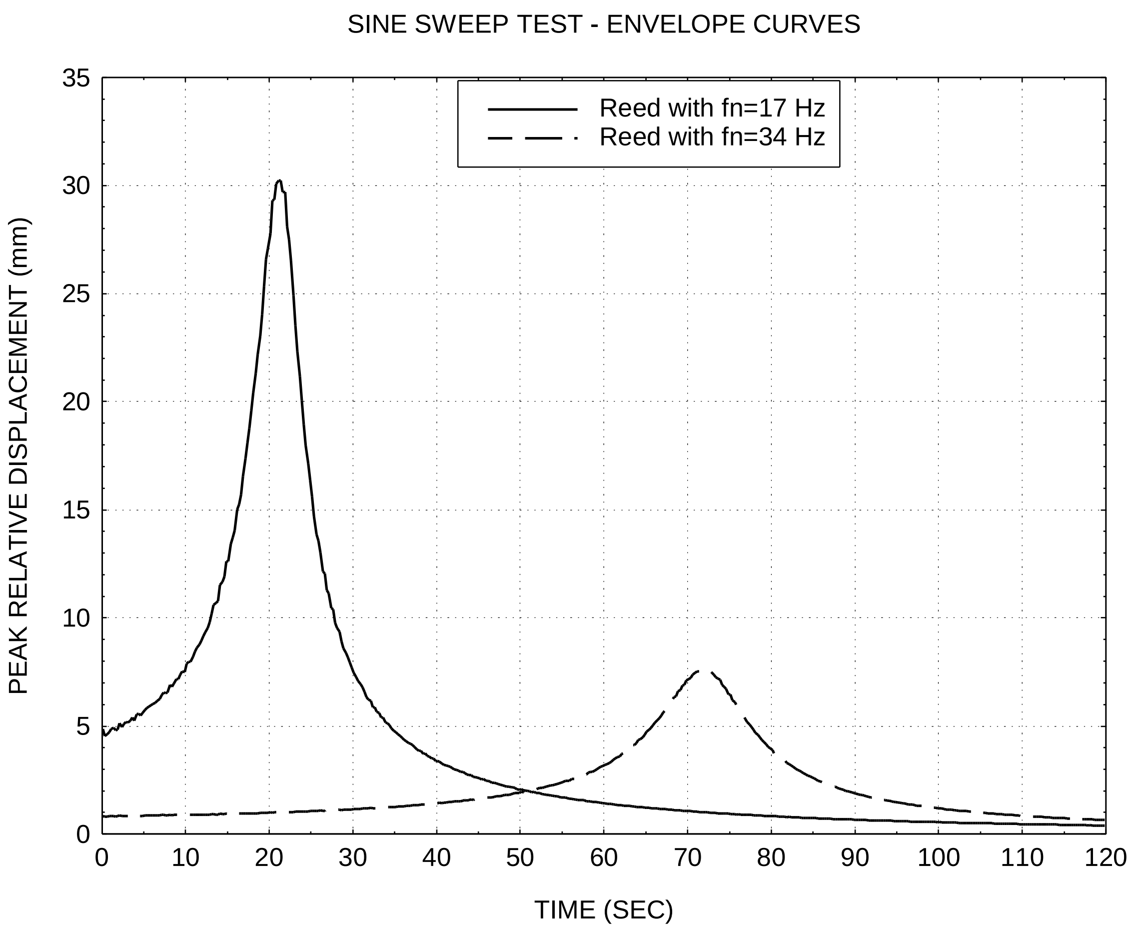

Figure 4. Sine Sweep Test Results

Both the 17 Hz reed and the 34 Hz reed have excursions beyond the 5 mm threshold. The excursions, however, occur independently. Thus, collision does not occur. The reeds "pass" the sine sweep test.

The random vibration test results are shown in Figure 5. The time history in this figure is a brief segment of the entire test.

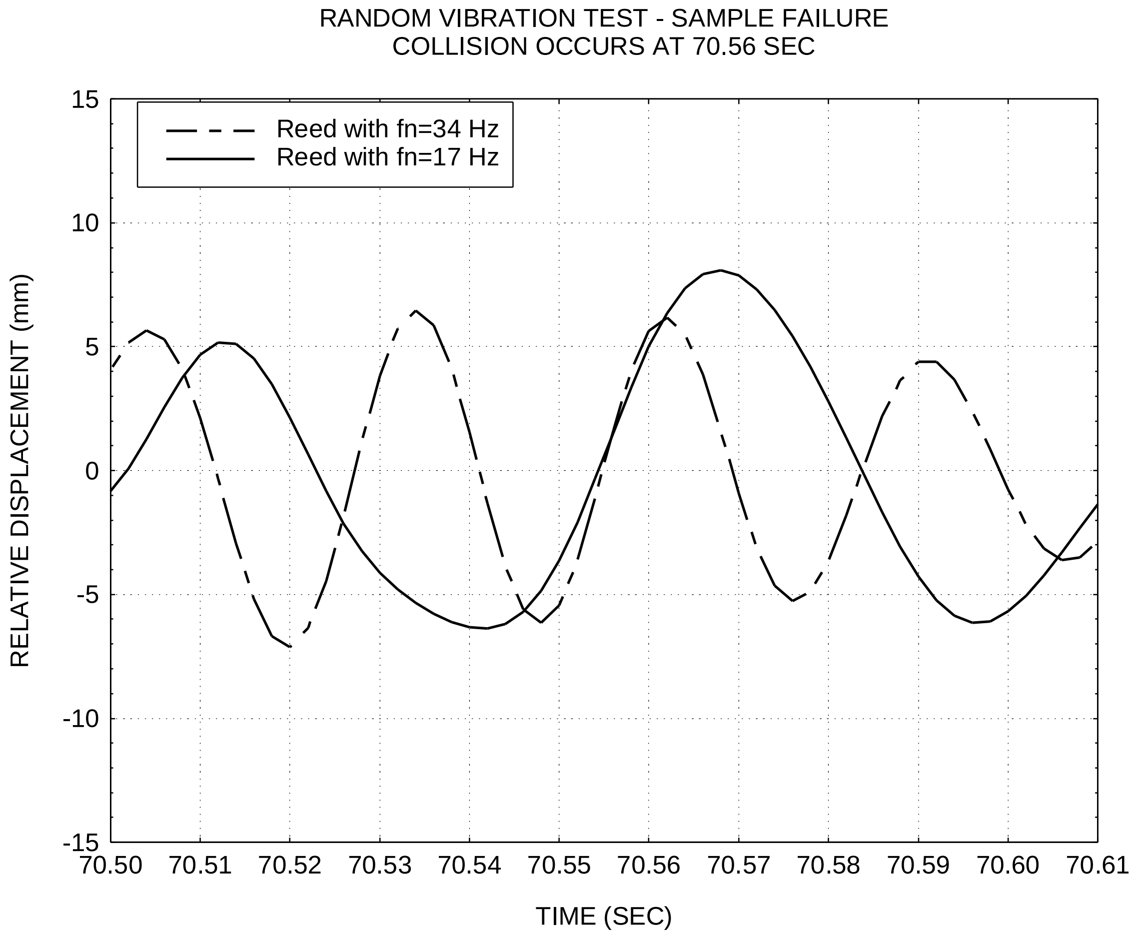

Figure 5. Random Vibration Test Results

The sample in Figure 5 shows that the reeds would collide at about 70.56 seconds, since each would have a displacement of 5 mm or greater. Thus, "failure" occurs.

<u>Conclusion</u>

The failure in the example could represent an electrical short between two parts on adjacent circuit boards. The circuit boards could be mounted in an avionics component.

The failure mode in this example was collision due to relative displacement.

There are other potential failure modes, including buckling, ultimate stress failure, and fatigue.

References

1. W. Tustin and R. Mercado, Random Vibration in Perspective, Tustin Institute of Technology, Santa Barbara, 1984.

2. T. Irvine, Sine Sweep Test Parameters, Vibrationdata.com Publications, 1998.

3. T. Irvine, A Method for Power Spectral Density Synthesis, Vibrationdata.com Publications, 2000.

4. T. Irvine, An Introduction to the Shock Response Spectrum, Vibrationdata.com Publications, 2000.