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DEFINING RESONANT PLATE SHOCK TEST SPECIFICATIONS IN THE TIME DOMAIN

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ABSTRACT

Resonant plate testing, commonly used for simulating high-energy pyroshock events in the laboratory, is traditionally defined by a shock response spectrum. This test definition methodology is uniquely different from almost all other shock test methodologies. Most shock test methods are defined in terms of physical properties such as drop height, velocity change, impact velocity, charge standoff, pulse duration, or similar. In contrast, the shock response spectrum definition for a resonant plate test allows for a wide range of test inputs due to the non-unique nature of the spectrum transformation. This paper investigates the feasibility of defining resonant plate test specifications in terms of temporal parameters rather than spectral parameters. The paper presents a comparison of two methods to evaluate potential test tolerance ranges. The paper also presents a case for the importance of controlling shock duration as a means of limiting fatigue damage in the unit under test. An example is presented comparing peak acceleration and rain-flow analysis, showing that the non-uniqueness of the shock response spectra can lead to substantially different exposure results in the unit under test.

INTRODUCTION

Resonant plate testing is a common method for simulating high-energy pyroshock type events in the laboratory. This test methodology has been used for many years and is relatively easy to implement. In addition, the availability of a mechanical test in the laboratory has many benefits as compared to an actual pyroshock test in the field. Figure 1 shows a sketch of a typical resonant plate test. A test article is attached to the front side of a tuned resonant plate with free-free boundary conditions while a gas gun fires a projectile at the back center of the plate. Alternatively, a hammer can be used to strike the back of the resonant plate. The impact of the projectile or hammer against the plate causes the plate to resonate, thus exciting the test article. Ideally, the plate response should be a two-sided oscillating response, similar to a decaying sinusoid as shown in Figure 2. The physical size of the resonant plate is tuned such that the primary excited frequency corresponds to the primary frequency in the SRS test requirement. Gross tuning is performed by selecting the physical dimensions and plate material. Fine tuning the response is usually accomplished by adjusting the impact mass and velocity, adding damping material to the plate, and installing pulse shaping material between the impacting projectile and the plate.

Resonant plate test specifications are typically defined by a simple, three-point shock response spectra (SRS) along with standard test tolerance bounds. The three points are the knee frequency, corresponding to the plate's primary bending mode; the high-frequency point, typically about one decade higher than the knee frequency; and the low-frequency point, typically about one-half to one-quarter of the knee frequency and defined to give a slope of about 12 dB/octave to the specification. Figure 3 shows an example of a 2 kHz 3,000 g resonant plate test specification with ±6 dB test tolerance bounds.

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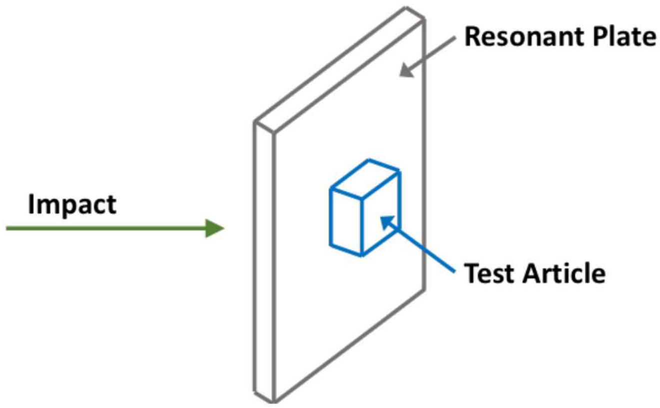

Figure 1: Typical resonant plate test configuration

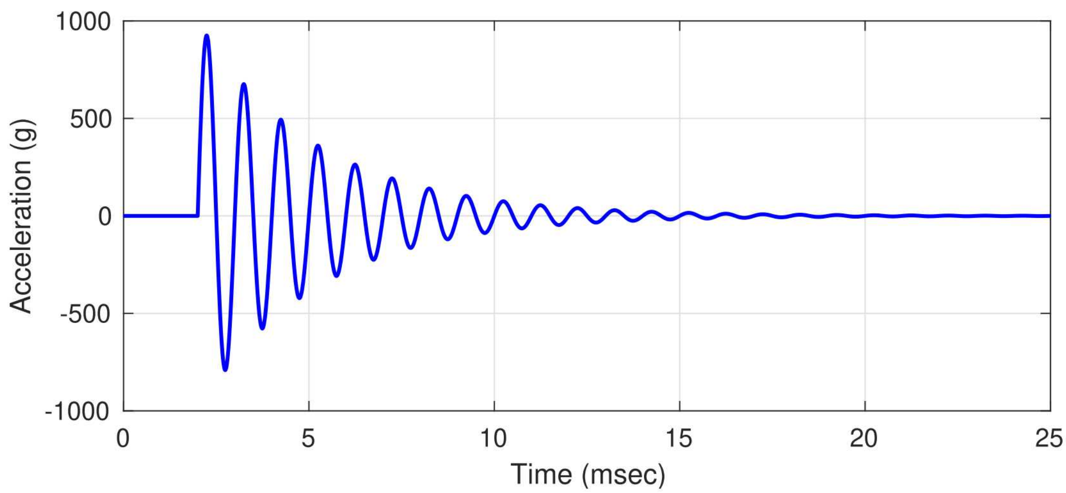

Figure 2: Ideal time history from a 1 kHz resonant plate shock

While resonant plates represent a unique test capability, their test specification definition with the SRS is also equally unique. Nearly all shocks are analyzed using SRS; however, most shocks are not actually specified by the SRS. For example, drop table shocks are defined by a velocity change and a pulse width or a peak acceleration and pulse width. Likewise, U.S. Navy shock is defined by a hammer drop height or a charge standoff [1]. Transportation shocks in MIL-STD-810 are defined by saw-tooth shocks with a peak acceleration and pulse width [2]. Rail impact is defined by a collision speed. Package drop is defined by a drop height on a floor or an impact velocity. It appears that almost all standard shock test methods define success against some sort of physical or temporal parameter. This stands in stark contrast to the SRS definition of a resonant plate shock test. The origin of this significant difference in test specification definition is not known. It is assumed to be a function of the more limited availability of resonant plate shock machines or their more specialized application.

The concept of defining a resonant plate test specification in the time domain is to develop a test specification based on the acceleration time history waveform rather than the resulting SRS. It is well known that the SRS can mask the character of the underlying time history. There are several benefits of moving from an SRS based test specification to a temporal based test specification. The most obvious is the desire to better replicate the measured field environments in the laboratory. While many laboratory tests are intended to demonstrate a minimum level of robustness within a part, an excitation that substantially differs from the measured field environment is not optimum for qualifying that component. For example, MIL-STD-1540C defines a pyroshock as a high-frequency acceleration transient that decays in 5–15 milliseconds [3]. However, many resonant plate tests require more time to decay than suggested in MIL-STD-1540C. Some

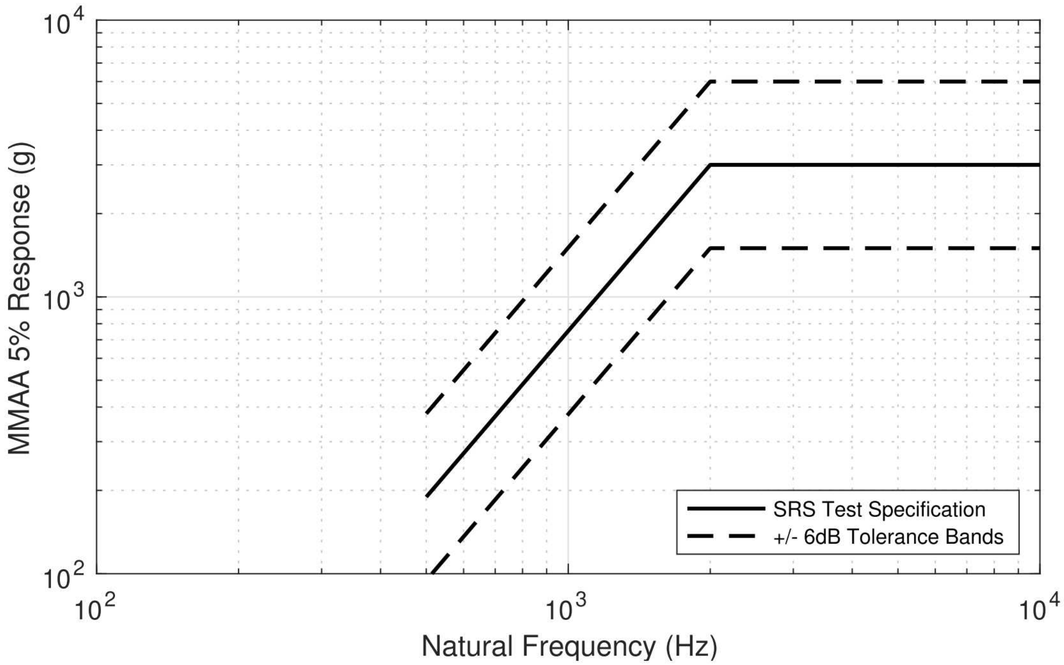

Figure 3: Sample resonant plate test specification for a 2 kHz, 3,000 g shock

low-frequency resonant plate tests can ring for many times the maximum desired duration.

An additional advantage to time history specifications is added control over the shock excitation at a wider range of frequencies. For example, most resonant plate tests are defined with SRS test specifications in the 100 Hz–10 kHz range. This typically means that a test laboratory will only plot SRS results within that frequency range, masking responses outside the defined test range. For example, if the resonant plate system imparts a very high acceleration in the 20–30 kHz range, this might be damaging to the component and unknown to the engineer. On the other hand, a peak acceleration limit specification could immediately identify that shock as problematic. Typically, accelerations beyond 10 kHz are not significantly damaging to metallic components; however, ceramics can often be particularly susceptible at frequencies beyond 10 kHz.

The fundamental goal is not to augment the resonant plate SRS test specification with temporal data, as suggested by many researchers in the past. Rather, the goal is to replace the resonant plate SRS test specification with a temporal-based test specification. This paper discusses one proposed methodology for defining temporal specifications with temporal-based test tolerances and compares that methodology with the current SRS method.

MOTIVATION FOR CHANGING TO TEMPORAL TEST SPECIFICATIONS

Figure 4 shows an example of the measured acceleration time history obtained from the same sample component tested at two different shock test laboratories. Table 1 gives the maximum peak acceleration from each time history, the 10 percent amplitude duration of the shock pulse, and average SRS dB error against the test specification. Figure 5 shows the resulting SRS from these two acceleration time histories. Both of the shock laboratories are well respected and competent at resonant plate shock testing. Both tests satisfied the SRS test specification within the defined tolerance requirements. The shock test data from laboratory one had an average dB error of –0.65 dB while the data from laboratory two had an average dB error of +0.43 dB. Since both tests meet the SRS test specification and were well within the tolerance bounds, both are considered to be passing tests. However, a cursory examination of the time history indicates that there is an obvious and somewhat drastic difference in the overall exposure. Furthermore, this exposure difference is completely masked by the SRS data presented in Figure 5.

SRS theory states that if two shocks produce nominally the same SRS then they are nominally equally damaging. Thus, according to the SRS test specification definition for resonant plate shock tests, the two

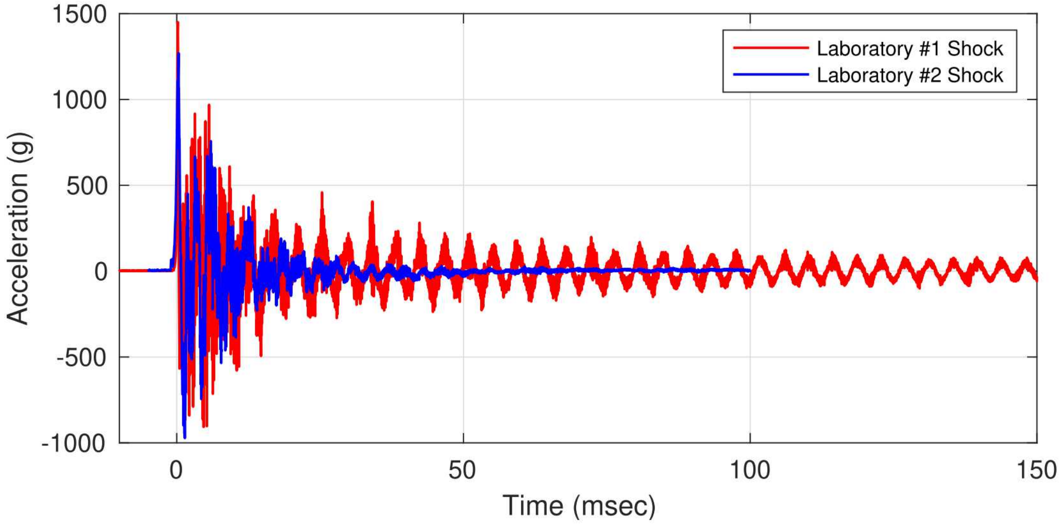

Figure 4: Example time history response from the same sample component tested at two different shock laboratories

Table 1: Summary of temporal parameters from sample component shock test data

	Laboratory 1	**Laboratory 2**
Maximum Acceleration	1450 g	1270 g
Pulse Duration (10 % Amplitude)	89.2 msec	20.4 msec
Average SRS dB Error	−0.65 dB	+0.43 dB

shocks shown in Figure 4 must be assumed to be equally damaging. The reality is that this is very likely not true. Since the peak acceleration between the two shocks is comparable, as shown in Figure 4 and Table 1, the peak strain and the resulting peak stress is also likely to be comparable. This suggests that a first passage failure, caused by over straining the material, would likely present on either test. However, the test from laboratory one clearly exposes the component to more fatigue cycles. Fatigue exposure and fatigue failures are typically not associated with a pyroshock test. After all, pyroshock testing is supposed to be a very short duration, high-amplitude exposure as described in MIL-STD-1540C. Nevertheless, given the high strain amplitudes experienced in many of these tests, fatigue damage can accumulate rapidly.

Figure 6 shows a plot of a rain-flow analysis performed on both of the acceleration time histories shown in Figure 4. Rain-flow analysis estimates the number of stress reversal cycles within a given amplitude range. Figure 6 indicates that above about 800 g, the number of stress reversal cycles is essentially equal between the two shock events. However, as the acceleration amplitude decreases, the resulting rain-flow cycle counts begin to diverge significantly. Table 2 presents a summary of the cycle count differences between the two acceleration time histories. The acceleration time history from laboratory one had a consistently higher rain-flow cycle count compared to the shock from laboratory two. Table 2 indicates a relatively minor cycle count difference at 400 g and above but a significant cycle count difference below 400 g. While a 50 g or 100 g cyclic loading is significantly below the 1400 g peak loading, a 50 g cyclic loading is not insignificant for many components. Furthermore, the difference in number of cycles experienced here has easily crossed the threshold into the high-cycle fatigue regime.

Table 2: Summary of rain-flow cycle count differences—Laboratory 1 versus Laboratory 2

Acceleration Level	> 800 g	400 g	200 g	100 g	50 g
Exposure Difference	About Equal	+30 cycles	+100 cycles	+420 cycles	+1600 cycles

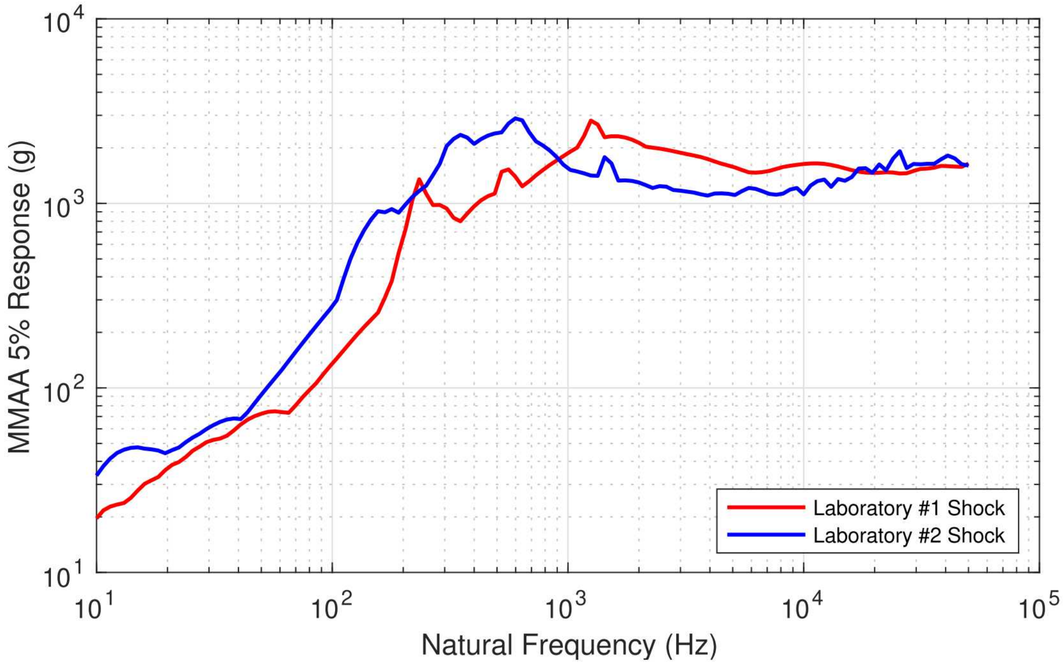

Figure 5: Calculated SRS from the same sample components tested at two different shock laboratories—both tests were within the defined tolerance bands

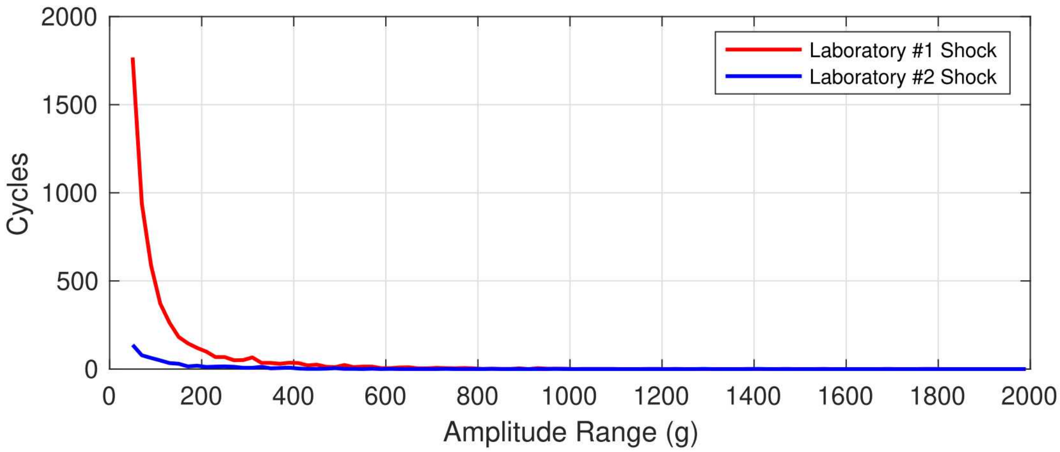

Figure 6: Rain-flow analysis results from the two sample component shock tests

Part of the motivation for defining resonant plate shocks with temporal parameters is to prevent the excessive fatigue exposures shown in this example. A second motivation is to control peak accelerations. While the peak accelerations in this example were well behaved, it is not uncommon to experience wide disparities in peak acceleration with differences in test setup. Furthermore, the SRS can mask these disparities in peak acceleration, especially if they occur beyond the defined frequency range of the test specification.

PROPOSED RESONANT PLATE TEST SPECIFICATION METHOD

What is being proposed is a method for replacing the traditional SRS test specification definition for a resonant plate test with a time-domain test specification method. Many previous researchers have suggested adding temporal requirements to the SRS test specification to supplement the SRS definition. The most common recommendations are to include a measure of the shock pulse duration, either the duration specifically or with the temporal moments RMS duration [4, 5]. In contrast, the proposal here is to replace the SRS specification methodology entirely with a temporal-only test specification based on three parameters: resonant plate frequency, positive and negative peak accelerations, and shock pulse duration. Undoubtedly the SRS will continue to be calculated for comparison purposes, just as it is for other shock machines and shock test methods; however, it will not be used to evaluate the goodness of the shock test.

The first test specification requirement is against the resonant plate frequency. Currently, it is assumed that the knee frequency in the test specification corresponds to the plate's first bending mode, but this is not explicitly required. Under this new temporal-based specification method, the plate's primary bending frequency is a part of the test specification. This ensures that all test laboratories will use nominally the same plate design for a given test.

The general equation for the fundamental natural frequencies of a square plate with four free edge boundary conditions is given by:

$$f_i = \frac{\lambda_i^2}{2\pi l^2}\sqrt{\frac{Et^3}{12\gamma(1-\nu^2)}}. \quad (1)$$

In the above equation, λ_i is a constant and a function of the mode shape indices, γ is the mass per unit area, ν is Poisson's ratio, E is the modulus of elasticity, t is the plate thickness, and l is the length of one side of the square plate. Values for λ_i are 13.49, 19.79, and 24.43 for modes one through three, respectively [6]. In addition, the actual response frequency is influenced by the mass and stiffness of the test fixture, the unit under test, and any ancillary items added to the plate such as constrained layer damping treatments. The exact frequency of the as-used resonant plate could be determined beforehand using a modal test; however, it is unreasonable to ask a production laboratory to repeat a modal test for every test series. As such, the frequency requirement should be defined with some latitude to allow for test-to-test variability. For most tests, with small components and large resonant plates, the requirement should be very straightforward. If needed, a simple hammer test or Fourier transform post-test can be used to ensure the system was within the desired tolerance range.

The second test specification requirement is against peak acceleration. Currently there is no check or tolerance against the peak time history acceleration. Under the new temporal-based specification method, the maximum and maximum return acceleration are part of the test specification. Here the use of positive and negative is deliberately avoided due to the fact that a resonant plate test is defined as a two-sided oscillating excitation. Figure 7 shows a plot of the ideal acceleration time history overlaid with the proposed acceleration time history tolerances. On the absolute peak acceleration, a minimum and maximum tolerance is levied to ensure that the shock is not too severe or benign. Figure 7 shows a nominal ± 20 percent tolerance band on the maximum absolute acceleration although wider tolerance bands could be used if desired. The return acceleration tolerance is specified to be greater than one-half of the peak absolute acceleration tolerance. The requirement on the return acceleration is relatively loose, but ensures that a two-sided shock is used for the test. The requirement definition is intended to be applied regardless of whether or not the maximum amplitude acceleration is measured as positive or negative acceleration. Thus, the specification is not attempting to define positive and negative measurement directions and the shock laboratory or customer can define those accordingly.

To meet the acceleration time history tolerance requirements, the measured acceleration will need to be filtered with a low-pass filter. This is necessary to filter out the accelerometer gauge resonances that appear

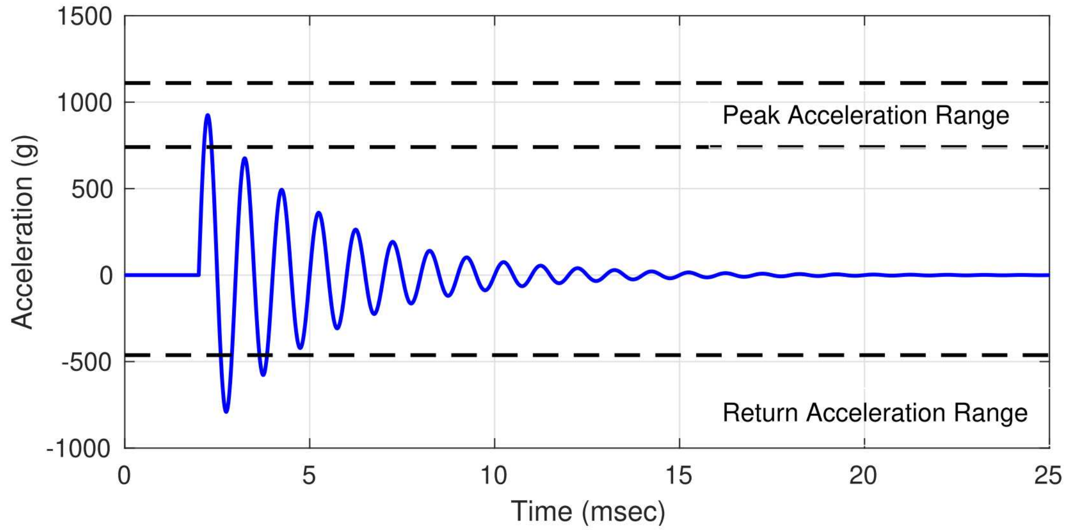

Figure 7: Ideal time history with acceleration tolerance bands

in the raw data signal. This process of fairing the peak amplitude is routinely used for drop shocks and should be well-known. However, in this application, it may be necessary to filter at a much higher frequency. Ideally, the filtering should be performed at about half of the accelerometer gauge resonance and well above any frequencies of concern to the unit under test.

The final test specification requirement is on the shock pulse duration. Some measure of shock pulse duration has been suggested for addition to the SRS by many researchers although it does not appear that any such measure has gained widespread acceptance. Ironically, shock duration is surprisingly difficult to quantify in the laboratory. For an analytical shock, the duration is actually quite simple. The duration of a half-sine shock is defined from the instant the acceleration rises above zero until the instant that the acceleration returns to zero. However, the presence of the instrumentation noise floor in measured test data greatly complicates this definition. The shock duration is better defined by the time between the response rising above the noise floor until the response decays back into the noise floor. The problem is that this is no longer a clean mathematical definition. Unfortunately, the definition of shock duration in MIL-STD-810H is also subjective. MIL-STD-810H defines the overall shock duration, T_e, as the “duration from the time the signal rises above the noise floor until the perceived termination of the shock” [2]. While two test engineers can come to an agreement on the perceived termination of a shock pulse, a computer algorithm has no such ability.

The temporal moment RMS duration, originally defined by Smallwood [4, 5], has been frequently suggested as a measure of shock duration, although RMS duration can be significantly influenced by additional noise floor data. RMS duration does not represent the actual duration of the shock, but rather the time window centered about the shock centroid where the most significant portion of the shock transient occurs. Figure 8 presents an interesting example of how much the RMS duration calculation can be affected by the shock record’s accumulated noise floor. The shock event shown in Figure 8 represents a good data set and a reasonable analyst might estimate the shock duration to be on the order of five to ten milliseconds. However, in this example, a full 100 milliseconds of data were recorded. Calculating the RMS duration on the full record gives an RMS duration of 1.73 msec, highlighting the difference between RMS duration and overall shock duration. However, if the data record was cropped to 20 msec, the RMS duration is reduced to 0.778 msec, less than half of the original value. The reason for this difference is that temporal moments are calculated using the square of the time history. Thus, the noise floor is always additive in the calculation. As a result, using temporal moments to define a shock pulse duration requires us first to define a shock duration over which the temporal moment should be calculated.

A common approach used with drop shock is to fair the test data to remove noise spikes and gauge resonances, find the maximum acceleration, then the first point where the shock signal rises above ten percent of the maximum and the last point that the shock signal is above ten percent of the maximum.

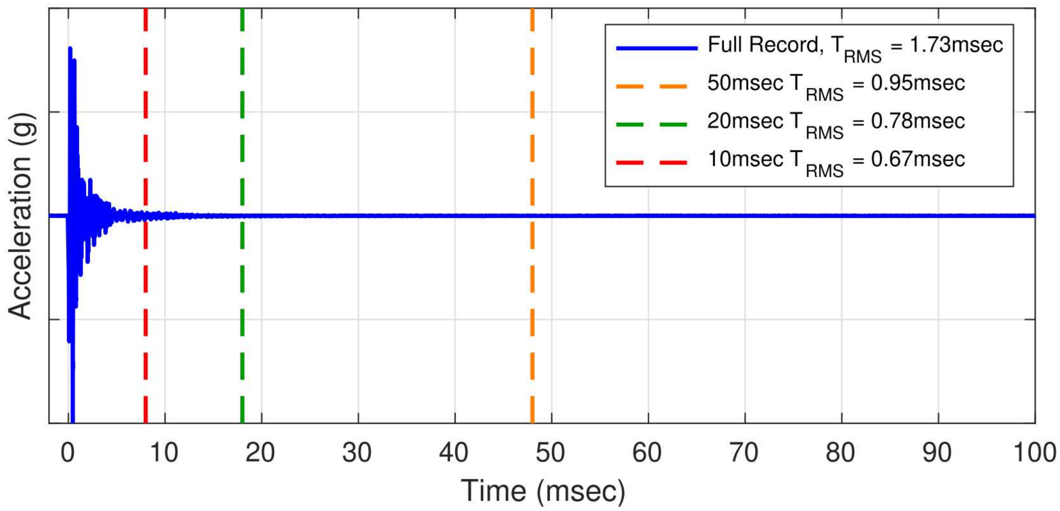

Figure 8: Shock time history showing how signal length impacts the RMS duration temporal moment calculation

The time between the ten percent points is referred to as the ten percent amplitude pulse duration. This methodology is somewhat consistent with MIL-STD-810F [7], which defines a shock duration as the RMS time history duration between the ten percent amplitude points. While this approach is usually used for one-sided classical shocks, taking either the absolute value of the time history or the RMS values, it would be applicable to a two-sided oscillating shock waveform as well. Using the absolute value approach, the shock duration from Figure 8 is estimated at 2.7 msec.

RESONANT PLATE RESPONSE VARIATIONS

Defining test tolerances against the SRS is straightforward. High and low tolerance bands are drawn about the baseline SRS on the plot and the resulting SRS from the test is plotted for comparison. If the test SRS falls within the tolerance bounds, then the test is good. If the intention is to switch to a temporal based test tolerance scheme, then it is important to understand how much variation in the temporal parameters relates to variation in the resulting SRS. Since the SRS will undoubtedly continue to be used as an analysis tool.

To understand the expected variation from a resonant plate test, it is instructive to first consider the response variation from an ideal resonant plate. An ideal resonant plate is approximated with a single exponentially decaying sine tone at the fundamental bending frequency of the resonant plate. An example of an ideal 1 kHz resonant plate response with a peak amplitude of about 1,000 g, and a pulse duration of 7.29 msec was shown in Figure 2. The effective shock pulse duration for these examples is calculated using the ten percent amplitude method calculated against the absolute value of the acceleration time history. Figure 9 shows the SRS from the decayed sinusoid time history along with ±6 dB tolerance bands.

To understand how the SRS shifts with changes in the time history, a series of 1,000 Monte Carlo variations of the original time history were generated and analyzed. For this analysis, the sine tone amplitude was allowed to vary ±20 percent, the sine tone frequency was varied ±10 percent, and the damping ratio was varied by ±20 percent, all three with an assumed uniform random distribution. Varying the damping ratio changed the length of the shock pulse and the number of oscillations. Figure 10 presents the SRS results from these simulations and indicates that all of the simulations fall well within the standard ±6 dB tolerance bounds of the nominal SRS. Figure 11 presents a histogram of the average dB error between the Monte Carlo simulations and the nominal SRS in the left-hand plot. This plot shows a consistent distribution of average errors with almost all of the results falling within ±2 dB of nominal. Depending on the levied SRS tolerances, any of these hypothetical shock events could satisfy the test requirement. The right-hand plot in Figure 11 shows a histogram of the variation in shock duration from the various Monte Carlo simulations shown in Figure 10. The shock duration for the nominal pulse, shown in Figure 2 is 7.29 msec. The data shown in Figure 11 indicates a range of shock durations from 5.7 msec up to 10.3 msec with a median of

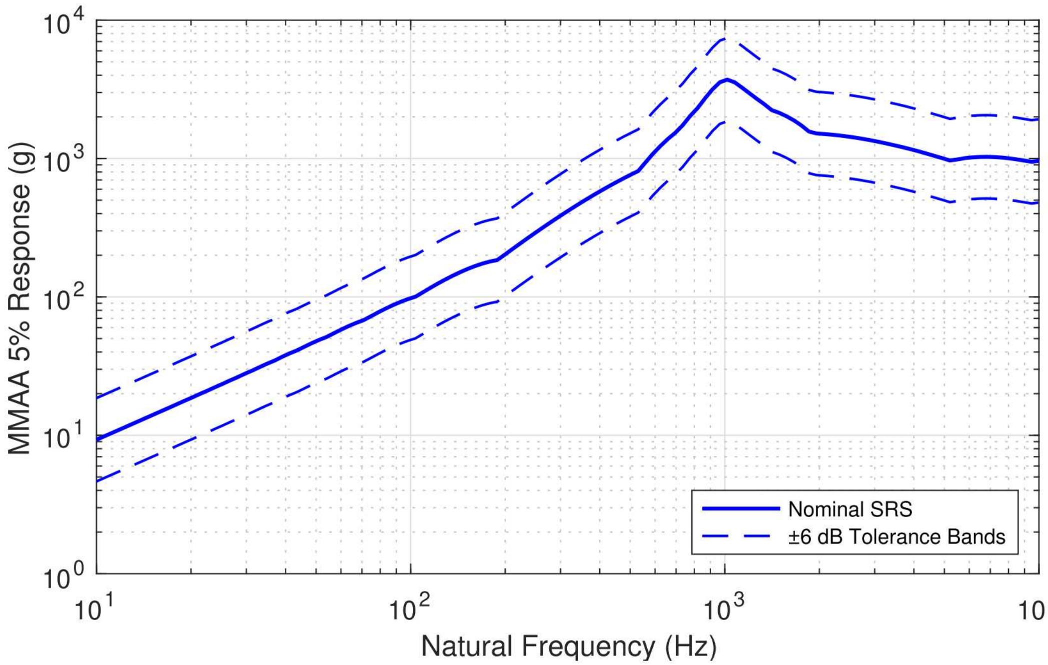

Figure 9: SRS from the ideal 1 kHz resonant plate shock

7.37 msec. The data in these plots are used to gain an understanding of the acceptable level of test-to-test variation or acceptable variation from the desired test.

Given that the results from these Monte Carlo simulations were all well within the assumed tolerance bounds for the nominal shock, the analysis was repeated with a wider allowed variation. Figure 12 shows analogous results from 1,000 Monte Carlo simulations where the sine tone amplitude was allowed to vary ±30 percent, the sine tone frequency was varied ±20 percent, and the damping ratio was varied by ±50 percent, all three with an assumed uniform random distribution. The SRS results presented in Figure 12 shows that almost all of the simulations fall at or within the ±6 dB tolerance bands with only a few exceedances. Figure 13, in the left-hand plot, shows the corresponding histogram of the average dB error between the Monte Carlo generated SRS and the nominal SRS. This data shows that all of the simulations have an average dB error greater than about −4 dB with the vast majority of the simulations greater than −2 dB. Admittedly, a test with a −4 dB average error is not desirable for component qualification; however, it should be possible to avoid these results with proper calibration tests. The majority of the simulations with average error less than −2 dB were a result of having a high knee frequency and an average or below average amplitude. Thus, if calibration testing reveals an above nominal resonant plate frequency, then the test should aim for an above nominal amplitude.

The right-hand plot in Figure 13 shows a histogram of the shock duration variation from the Monte Carlo simulations shown in Figure 12. The shock duration for the nominal pulse remained the same at 7.29 msec. Figure 13 also shows a range of shock durations from a low of 4.1 msec up to a high of 18.4 msec with a median duration of 7.34 msec.

The results from these Monte Carlo simulations can be used to derive an understanding of appropriate tolerances for an acceleration time history based resonant plate shock test. The simulations indicate that tolerances of around ±30 percent on shock amplitude and ±20 percent on frequency should keep the resulting test within the same nominal ±6 dB tolerance bands usually applied to an SRS based test. Variations in the pulse duration had less effect on the resulting SRS, although they were measurable. Figure 11 and Figure 13 both show similar distributions and similar ranges. The median pulse duration was essentially the same for both cases (7.37 msec versus 7.34 msec). However, the maximum pulse duration did vary substantially, increasing from 10.3 msec to 18.4 msec. It was noted that longer pulse durations tended to drive toward larger variations in the average dB error. As a result, it seems reasonable to add some tolerance controls on pulse duration although, tight pulse durations tolerances are probably not warranted. In addition, limiting

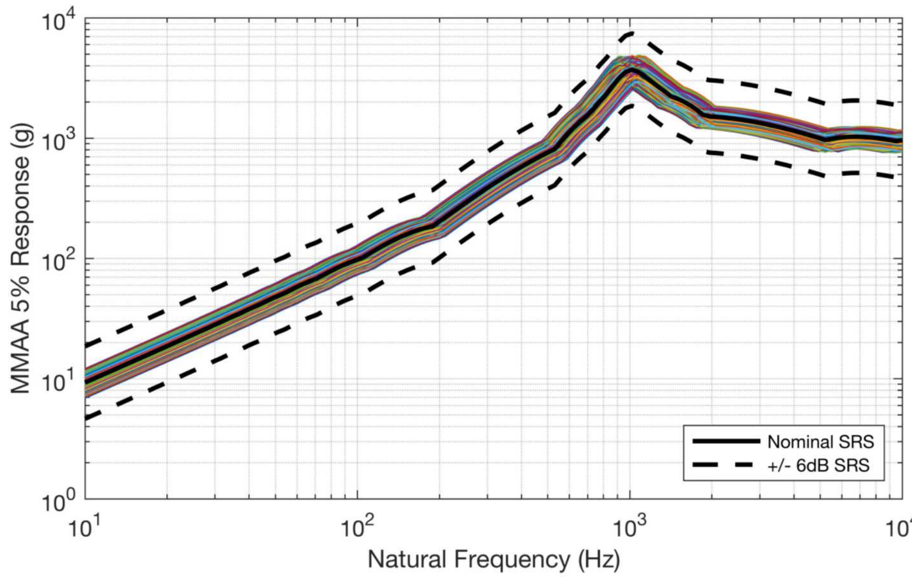

Figure 10: SRS results from 1,000 Monte Carlo simulations with ±20 % amplitude variation and ±10 % frequency variation

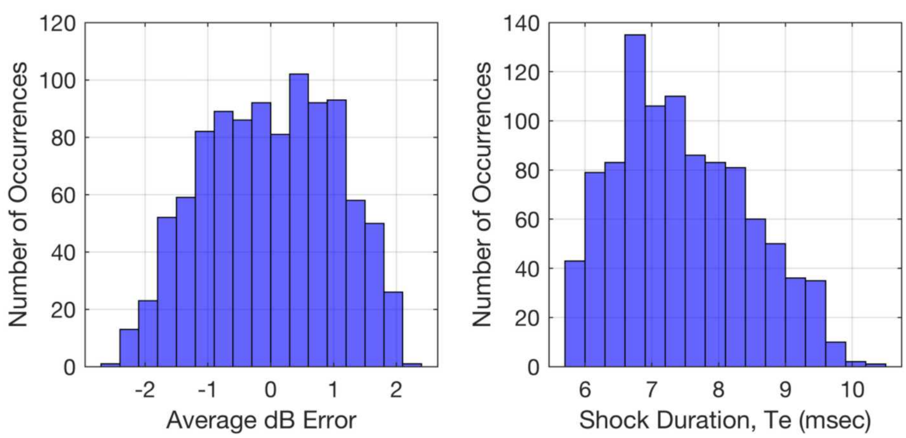

Figure 11: SRS dB error and shock pulse duration results from 1,000 Monte Carlo simulations with ±20 % amplitude variation and ±10 % frequency variation

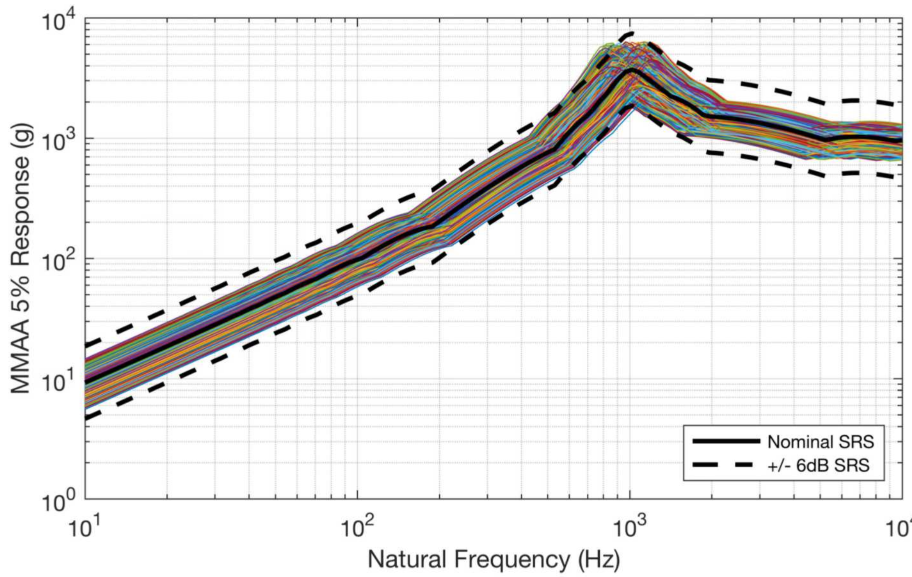

Figure 12: SRS results from 1,000 Monte Carlo simulations with ±30 % amplitude variation and ±20 % frequency variation

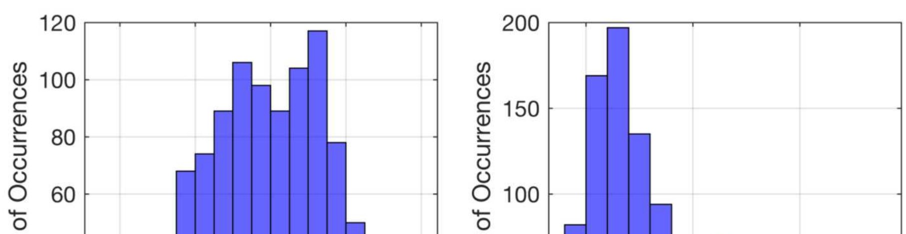

Figure 13: SRS dB error and shock pulse duration results from 1,000 Monte Carlo simulations with ±30 % amplitude variation and ±20 % frequency variation

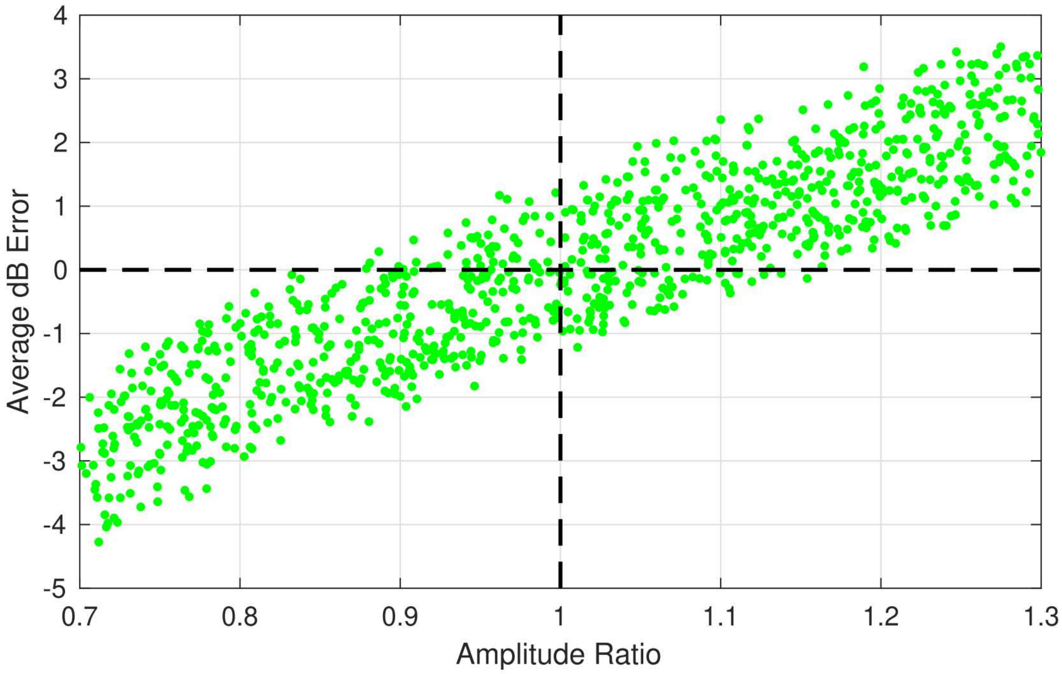

Figure 14: Effects of shock amplitude variation on dB error from 1,000 Monte Carlo simulations

pulse duration helps to ensure that the spirit of the short duration pyroshock event is satisfied and fatigue exposure is minimized.

Another way of presenting the Monte Carlo results is shown in Figures 14, 15, and 16. Figure 14 shows the normalized variation in peak shock acceleration amplitude versus the average dB error against the nominal SRS. While there is an obvious banding to the data, the overall trend is basically linear. Above nominal shock amplitudes generally equate to a positive dB error, an above nominal test, while below nominal shock amplitudes generally yield a negative average dB error, or a below nominal test. Figure 14 shows that test amplitudes on the extremes of a $\pm 30\,\%$ test specification will probably be outside of the corresponding acceptable SRS range. Low peak amplitudes are more likely to be outside of the acceptable shock range with the worst case low amplitude here being about 4.5 dB low compared to the worst case high amplitude being about 3.5 dB high.

Likewise, Figure 15 shows the normalized variation in shock frequency versus the average dB error to the nominal SRS. Here again, there is an obvious trend to the data, although the effects are not as pronounced. The scatter plot shows a wide banding of data with a slight downward slope. Thus, tests with a substantially above nominal response frequency are more likely to have a greater negative dB error. Tests with a lower than nominal frequency will generally yield an above nominal (positive) dB error. While the scatter plot indicates that test frequency has a correlation to dB error, the wide spread in the data and the shallow slope indicates that it is not the most significant factor in the final average dB error number.

Finally, Figure 16 shows the normalized variation in the $10\,\%$ amplitude shock pulse duration versus the average dB error with the nominal SRS. In this case, there is not an obvious trend through the data scatter. It is apparent that the extremes should probably be avoided since the very short pulse durations tend to equate to a negative average dB error and a below nominal shock event. Likewise, very long pulse durations tend towards higher average dB errors and above nominal shock events. While these general statements are true, the scatter in this data is significant. This plot tends to imply that test duration is not particularly critical for maintaining a shock within a certain range of the nominal SRS, but rather that pulse duration is more important for limiting fatigue damage as shown by the earlier rain-flow analysis.

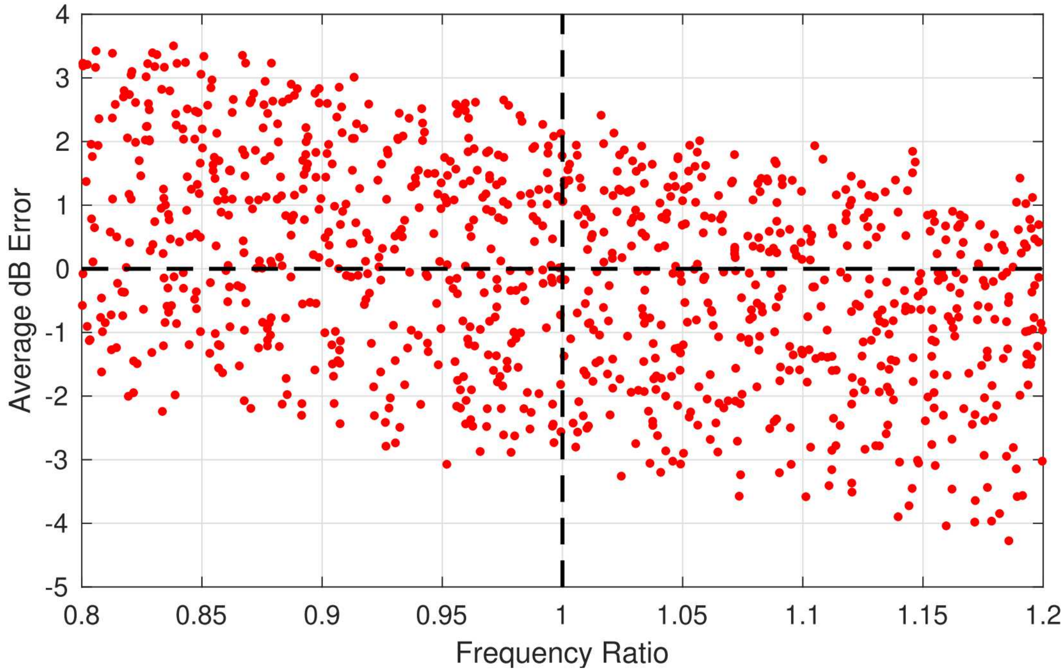

Figure 15: Effects of shock frequency variation on dB error from 1,000 Monte Carlo simulations

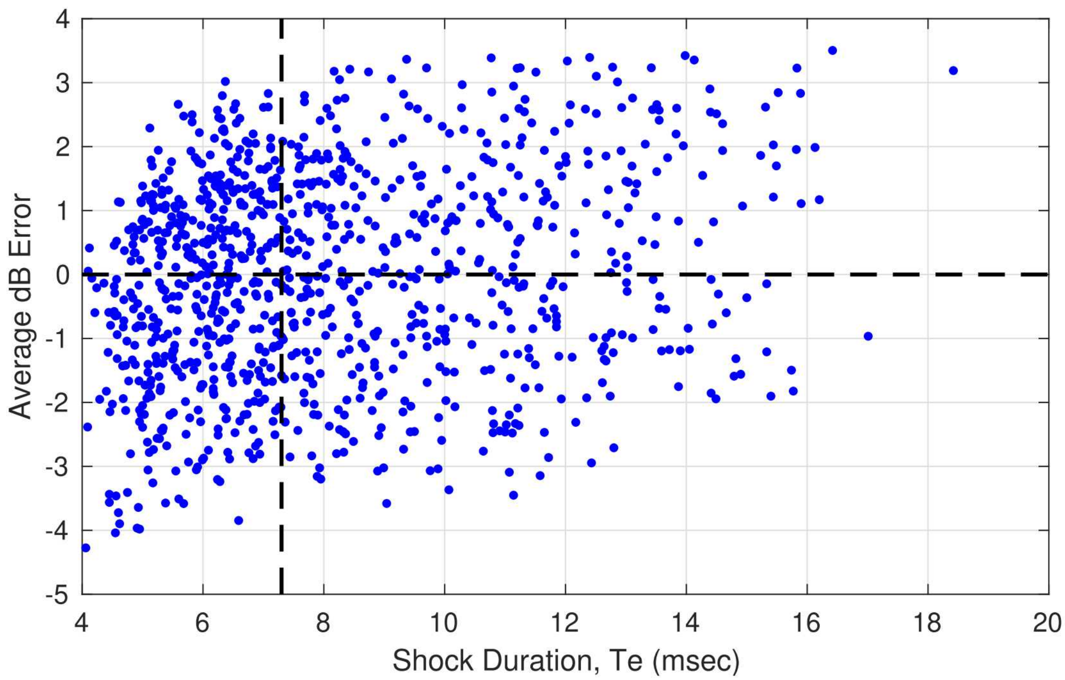

Figure 16: Effects of shock pulse duration variation on dB error from 1,000 Monte Carlo simulations

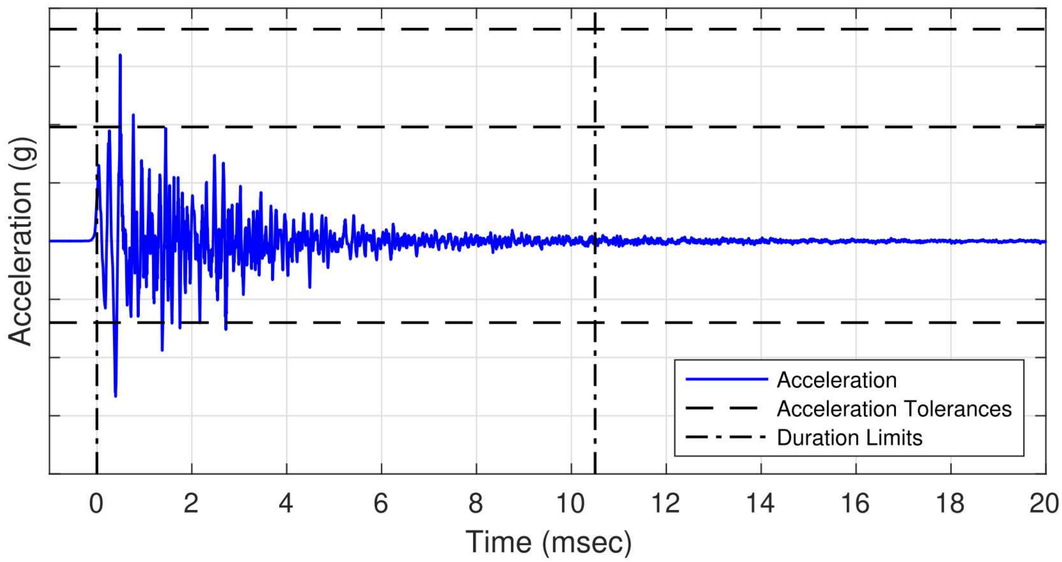

Figure 17: Acceleration time history from a recent test using time-domain shock test specifications

EVALUATION OF RECENT TEST RESULTS

To test the possibility of using time-domain test specifications for resonant fixture testing, a series of tests were performed on a sample component at the Sandia National Laboratories Mechanical Shock Laboratory. For this test series, the same component was tested on two different resonant plates and one resonant pedestal fixture. The tolerances used for this initial test series were ±30 % on the shock amplitude, ±20 % on the resonant fixture frequency, and +50 % on the 10 % amplitude shock pulse duration. The pulse duration tolerance was written such that the 10 % amplitude pulse duration must be less than 1.5 times the defined pulse duration.

Figure 17 shows a sample acceleration time history plot from one of the component tests along with acceleration and duration tolerance bounds. As can be seen in this figure, the absolute peak acceleration fell well within the ±30 % tolerance and the return acceleration easily surpassed the two-sided pulse criteria. The shock pulse can also be seen to decay well within the maximum pulse duration window defined as about 10.5 msec for this test. It should be noted that all of the acceleration time history data for this shock test series was filtered with a 100 kHz low-pass filter.

Perhaps more important to this work is an understanding of how difficult it was to meet the time-domain test specifications. All resonant plate testing is preceded by a series of calibration shocks on mass-mock hardware to ensure that the shock parameters are correctly set for the real component testing. Using the time-domain test specifications, the first test series required 14 calibration shocks to dial-in the shock test parameters. This is a little more than desired but not unreasonable for a new test methodology. The second test series on a different resonant plate with different time-domain test specifications required only nine calibration shocks before testing the real part. Finally, the third test series on a third resonant plate with a third set of time-domain test specifications required just four calibration shots. The ability to rapidly converge on an appropriate shock test configuration with this new test specification methodology is an indication of its potential viability to replace the SRS for future testing.

POTENTIAL CHALLENGES WITH TEMPORAL-BASED TEST SPECIFICATIONS

There are two potential challenges with defining resonant plate test specifications in the time domain. The first is developing a consistent definition of faired peak amplitude. It is necessary to filter the acceleration time history signal to remove the accelerometer gauge resonance from the test data. This cannot be avoided. However, low-pass filtering a signal can alter the apparent maximum peak amplitude of the signal. Thus, it is necessary to define an acceptable low-pass filter frequency, and potentially a filter type, such that

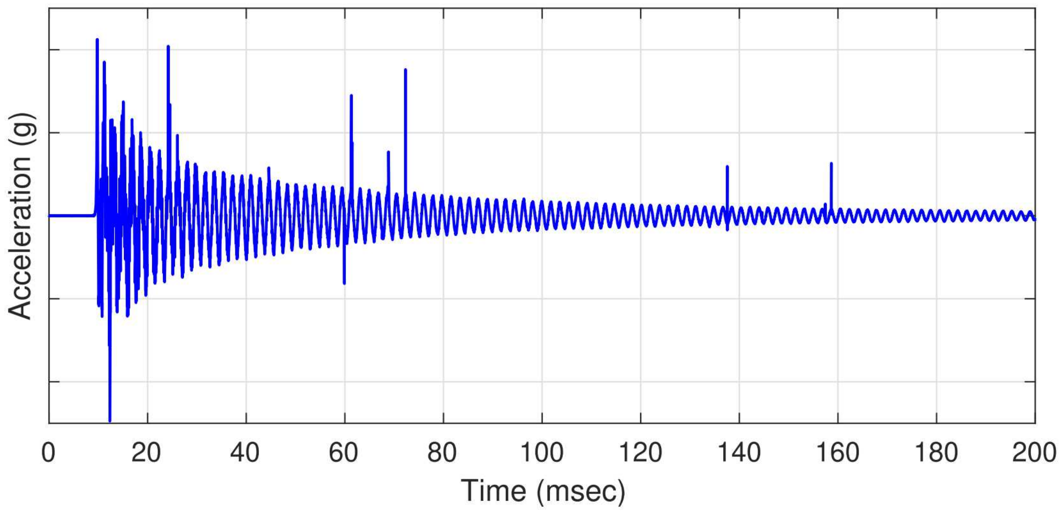

Figure 18: Example of acceleration time history data from a bad resonant plate shock test

accelerometer gauge resonances are removed but acceleration content of concern remains. Typical undamped piezoresistive accelerometers have gauge resonances much greater than 100 kHz. As a result, defining a low-pass filter frequency at 100 kHz is not unreasonable. On the other hand, some damped piezoresistive accelerometers have gauge resonances around or slightly below 100 kHz. In these cases, a 100 kHz filter frequency would be inappropriate. The problem is further complicated by the fact that many if not most accelerometers are not calibrated beyond about 10 kHz. While the gauges are not typically calibrated above 10 kHz, it is well known that they respond and record accurately well beyond 10 kHz.

What is currently being proposed as a requirement for fairing the acceleration time history is to low-pass filter the data at one-half the manufacturer's stated gauge resonance or 100 kHz, whichever frequency is smaller. Inherent in this requirement is that the same accelerometer type will be used for testing all components in a test series. While this proposed fairing methodology may not be the optimal solution, filtering down to 10 kHz will likely remove or obscure significant content of concern to many electronic components and is thus unacceptable. Likewise, a specific frequency must be defined to ensure the filter frequency is not simply iterated until the test data comes into tolerance.

A second potential challenge with time history test specification is the definition of pulse duration. Secondary impacts or part damage will often present as a shock pulse duration failure. This can be more problematic than at first appears. For example, if a part cracks during a resonant plate shock test, an additional spike will typically appear in the time history data representing the release of the stress wave from the failed metal. The problem then is that the test may have been a good test but the test specification tolerances fail due to the subsequent shock from the part failure. From an auditing perspective, how does the laboratory assert that the test was properly performed if the test tolerances are not satisfied. This problem is not entirely unique to temporal-based test specifications, since the shock from a failed component will also appear in the SRS and may even push the SRS out of tolerance. Clearly most test laboratories have a method for dealing with such an incident; however, this type of occurrence may become slightly more common with temporal-based resonant plate test specifications.

Figure 18 shows an example from a recent resonant plate shock test with a poor acceleration time history. The applied shock was very poor in large part because of its incredibly long duration. It is clear from this figure that the shock lasted longer than the data collection window. This is in stark contrast the the MIL-STD-1540C definition of pyroshock as a short-duration event. However, even with a 100 kHz low-pass filter applied, the acceleration response in Figure 18 shows several substantial shocks later in time. Several shocks occurred in the 60–80 msec time window and again near 140 and 160 msec. While this shock should not be considered acceptable under any circumstances, it might have passed the SRS tolerance requirement but it obviously would fail a reasonable pulse duration temporal requirement.

CONCLUSIONS

This paper presents a novel method for defining resonant plate test specifications in the time-domain as a complete replacement for the existing SRS-based resonant plate test specification methodology. Monte Carlo analysis of an ideal resonant plate response was used to understand the acceptable range of time-domain tolerance bounds and how changes in the time domain tolerances were likely to impact the resulting SRS which would no doubt be used for shock analysis.

Test data from a recent component test series showed that a resonant plate shock test can be specified using time-domain based test specifications. The resulting tests were easily executed and only required a few calibration shocks to converge on the appropriate test parameters. Furthermore, the test was performed on three different resonant fixture configurations with no problems experienced in any of the configurations. Pulse duration was relatively easy to control so long as a modest amount of damping was added to the resonant plate and the shock duration was defined at a reasonable length. Overall, the calibration requirements were comparable to those necessary for a test with an SRS-based specification.

It is understood that the time-domain test specification tolerances proposed here may not be completely optimized for all shock laboratories. Furthermore, shock testing laboratories will need time to become comfortable testing to a new specification methodology. While more work will obviously be required before this alternative resonant plate test specification approach replaces the current SRS-based specification methodology, the work presented here has shown that it is possible.

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