Response-Limited Shock Testing

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When conducting dynamic testing on shakers, it is often prudent to limit the response of the test article to protect the unit from over-testing and to more closely represent the environment. This is an accepted practice with random vibration testing. A methodology is presented here for response-limiting shaker shock testing. The method allows multiple response limit channels with independent shock response spectra limit profiles. The notches to the input shock response spectra are determined with iterative solutions of the inputs with the system transfer functions to the responses with limits.

Transient vibration testing on shakers has been common practice for many years.[1] Several commercial packages are now available to perform transient testing on shakers. Typically the response is measured in terms of the shock response spectra (SRS). In some respects, these packages are limited by liability issues. As a result, Sandia Labs has maintained and improved its internal software for transient testing.

The internal software is used primarily for system-level testing, where the limits imposed by the commercial software are most apparent. Small packages and components are tested using commercial software. The single point response of a large structure to a shock is often not a very good representation of the response of the overall structure. In random vibration testing, this limitation is addressed by averaging responses or adding limit channels. This article discusses how averaging and limits are addressed for shock testing where the measure of success is the SRS.

The software package used at Sandia is called *TShaker*, and it's used to control transient testing on both electrodynamic and electrohydraulic shakers. The system works with transients synthesized to match the SRS using sums of decayed sinusoids, wavesyn, and other user-defined time histories.

Control Process

The algorithm is derived from the SRS correction algorithm in *TShaker*. The FRF needed to derive the drive waveform necessary to reproduce the control waveform is estimated in the usual manner for transient testing. The system is excited with a low-level broadband waveform, and the FRF is estimated. The drive waveform needed to reproduce the required response is estimated. A low-level test is then preformed and the SRS at the control location(s), and the limit locations are computed.

Modification of the Drive to correct the SRS error is a nonlinear process both at the current level and as the level is increased to the desired final level. The SRS is not a linear transformation, and the test item might not be linear. For a particular test, the FRF is a characteristic of the system under test and normally does not change. The Drive waveform is modified by updating the magnitude of the estimated FRF and not changing the phase.

The test operator selects the parameters used for the error correction. The operator can pick the: frequency range, the correction factor, and the option to amplify only, attenuate only, or both amplify and attenuate. Obviously an experienced operator is required to rationally pick these parameters.

Test and Control Setup

The Control location(s), if averaging is used, and Response limit locations are defined. The required SRS is defined for each location. The required SRSs can be the same or different for each location. The required SRSs are interpolated to the same frequency spacing as the frequency response function (FRF) from the control system. The limit options include: amplify only, attenuate only, and attenuate and amplify.
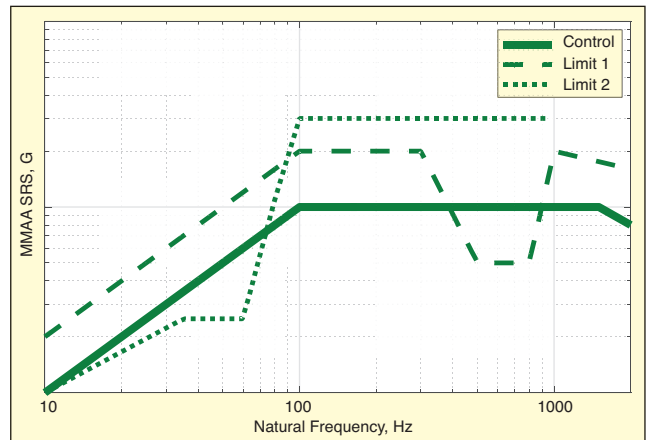
Figure 1. Example with two limit channels; reference control and two limit spectra.
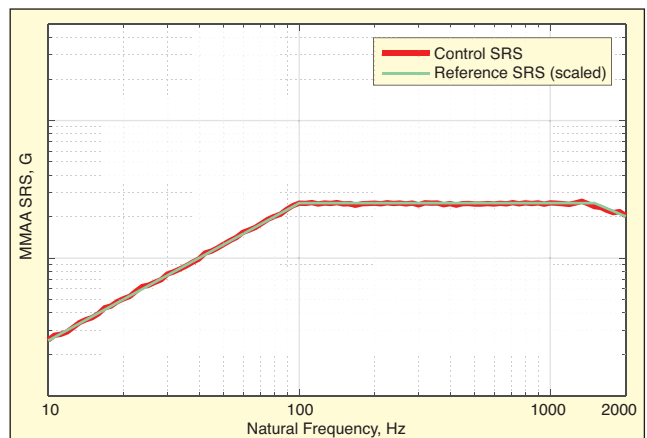

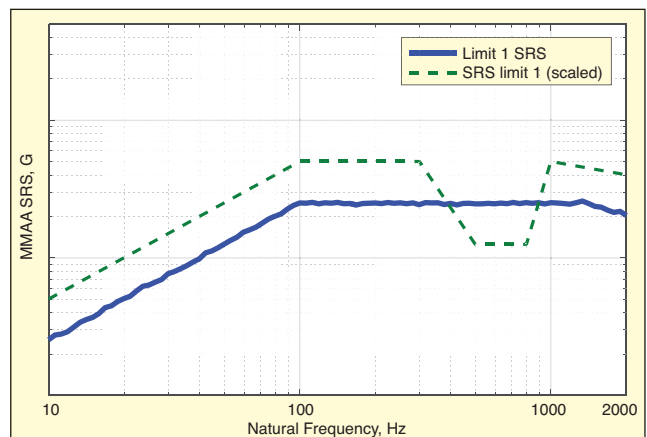Figure 2. Control SRS without the limits.

Figure 3 Two limit example, −12dB, Limit 1.

Control Scheme

A low-level broadband input is run. The error calculation is performed at the control and limit locations.

$$Error = Achieved\ SRS\ /\ Reference\ SRS$$

The error for limit locations is only considered if greater than one. Based on the largest error source for each frequency line, the magnitude of the FRF is modified with a weighting. The weighting for the correction is always less than 100% because of non-linarites. The weighting is an operator-picked parameter based on the cur-
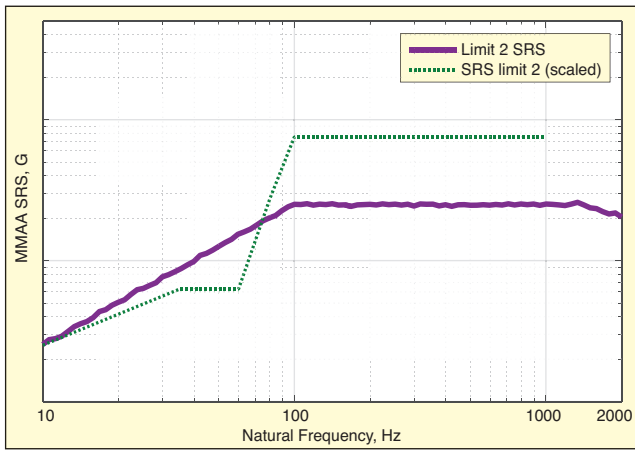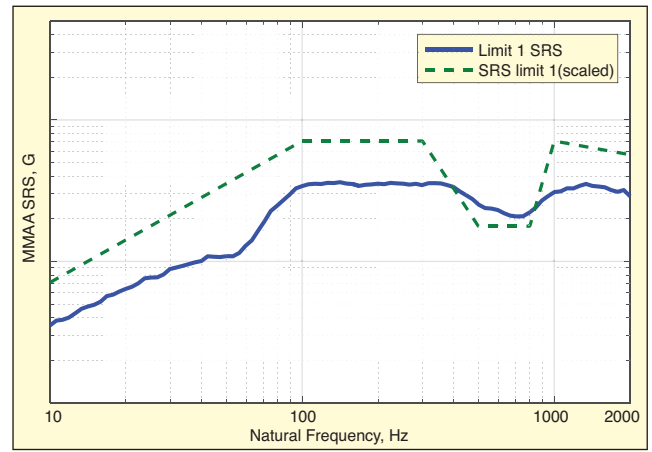
Figure 4. Two-limit example, –12dB, limit 2.

Figure 5. Two-limit error, –12dB.

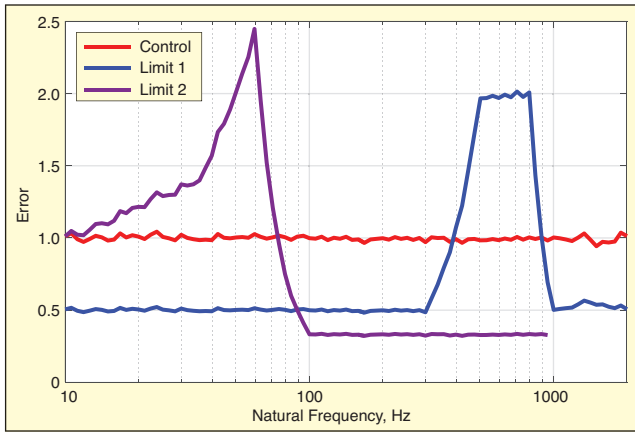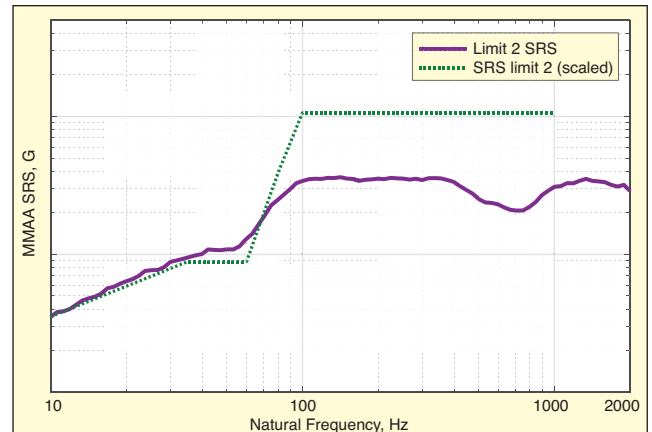Figure 6. Two-limit example, –9 dB, control.
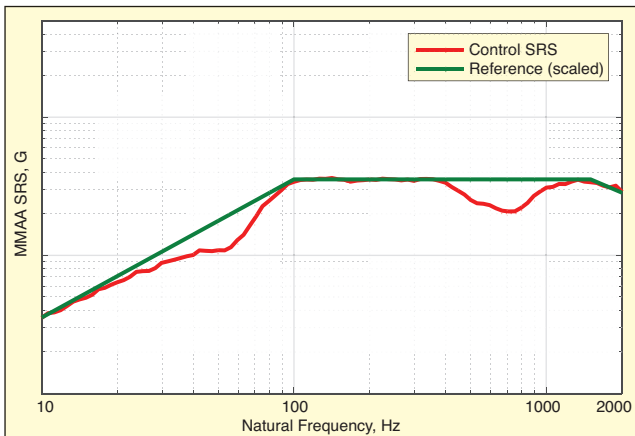

Figure 7. Two-limit example, –9 dB, error.
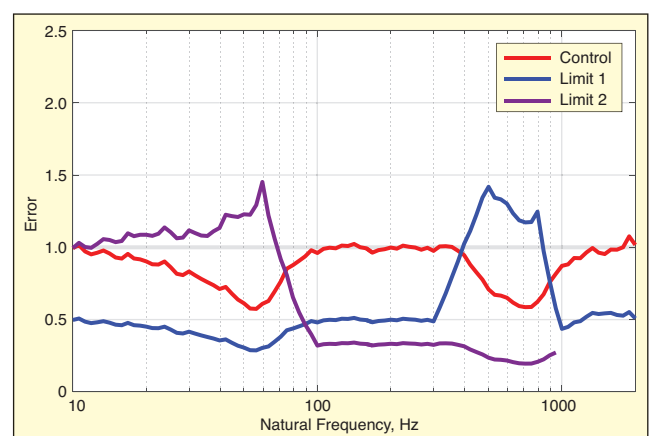

Figure 8. Two-limit example, –9 dB, limit 2.

Figure 9. Two-limit example, –9 dB, error.

rent results.

The level is increased (typically in 3-dB increments) with the new computed input using the modified FRF, and the process is repeated until full level is reached.

Error Update Weighting

Structural Nonlinearities. Damping often increases with level. The weighting helps to make sure the control does not overshoot.

Nonlinearities in the SRS. Low-frequency response will change the SRS at higher frequencies. The weighting helps to help assure the control does not overshoot at frequencies above the limiting band.

The update weighting factor is manually selected. The same weighting factor is used for all frequencies. It may be necessary to iterate the weighting without increasing the level. The weighing historically never reaches 100%.

Typical Weighting. Test Level (dB)/Weight (%): –12/50; –9/70-75; –6/80-85; –3/80-90; 0/80-90.

Examples

Closed-Loop Example. The first examples were generated with the system in closed loop (the FRFs are unity). A control spectrum and two limits were defined (Figure 1). Sums of exponentially decaying sinusoids were used for this example. Other waveforms should work but have not been tested.

The control spectrum at –12 dB without the limits is shown in Figure 2. Since the system was closed loop, the SRS of the limits is the same as the control spectrum. The initial SRSs of the limits together with the desired limit spectrum are shown as Figures 3 and 4.

As can be seen, the limit is exceeded for Limit 1 in a band near 800 Hz. The limit is exceeded for Limit 2 below about 80 Hz. The error for each channel is shown in Figure 5.The corrected control
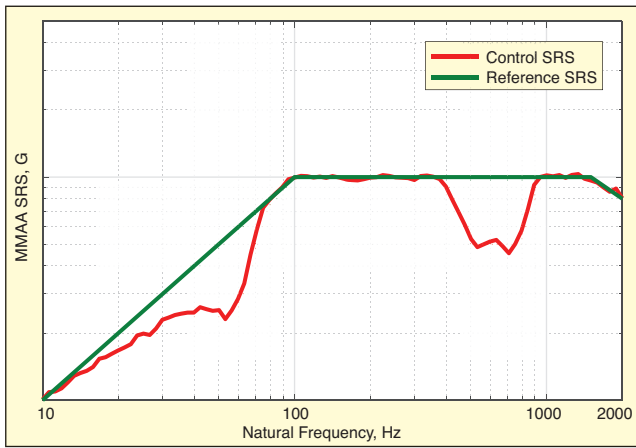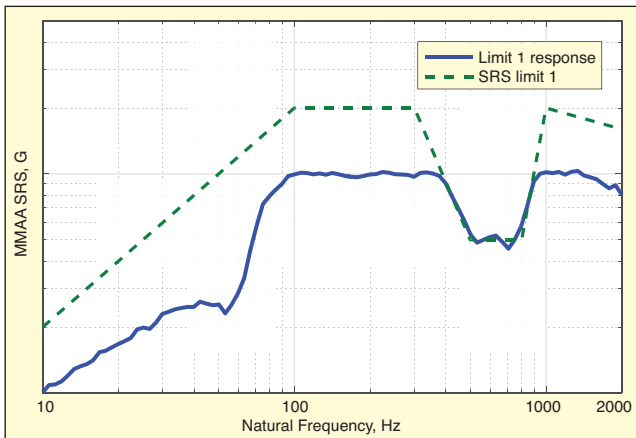
Figure 10. Two-limit example, 0 dB, control.
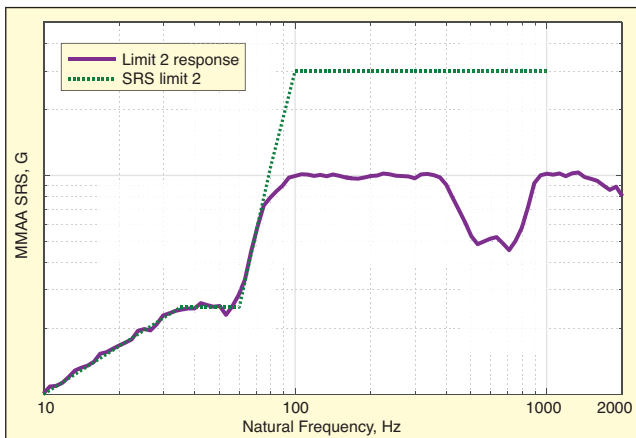

Figure 11. Two-limit example, 0 dB, limit 1.

Figure 12. Two-limit example, 0 dB, limit 2.

Figure 13. Two-limit example, 0 dB, error.

Figure 14 Two-limit example, FRF magnitude, no limit/with limit comparison.

Figure 15. Simulated external store.

SRS at –9 dB is shown in Figure 6.

The SRSs of the two-limit channels after the correction at –9 dB are shown in Figures 7 and 8. As shown by the SRS, the limit SRSs are improved but not completely corrected. This is because the correction factor was not set to 1. Also note that because the SRS is a nonlinear function, when a correction is made at a frequency, the change affects other frequencies. The error correction method accounts for these effects, which is evident in Figures 6 and 7. The error at –9 dB is shown as Figure 9, and Figure 10 shows the Control SRS error.

The error has been considerably reduced; finally the level is increased to 0 dB. The reference SRS (Figure 10), the SRS of the Limit 1 (Figure 11), and the SRS of the Limit 2 (Figure 12) are shown. Figure 13 shows the error at 0 dB. The error does not significantly exceed 1 at any frequency. Since the system is a closed loop, the FRF is a constant. Figure 14 shows the modification to the magnitude of the estimated FRF.
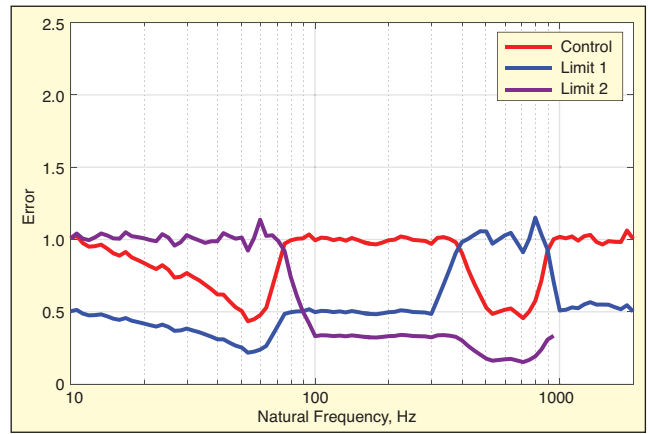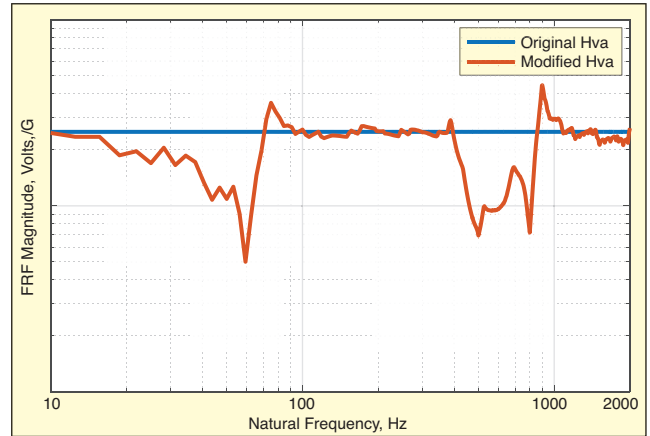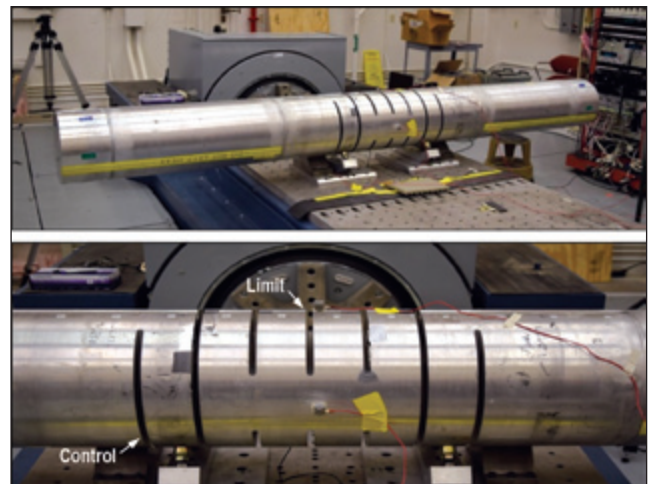
Example with Test Article

The test item was a simulated external store (Figure 15), and the Control was at the aft lug. A single Limit channel was on the top of the store. The full-level Control SRS without the limit is shown in Figure 16. The Limit SRS was 6 dB above the Control SRS. The Limit SRS with no limiting is shown as Figure 17, and the Limit is exceeded in several frequency bands. Figures 18 and 19 show the final result for the Control and the Limit SRS. Note that the Limit SRS does not exceed the Limit at any frequency. Figure 20 shows the modification of the estimated FRF.

Exponentially decaying sinusoids were used for this example.

Acknowledgements
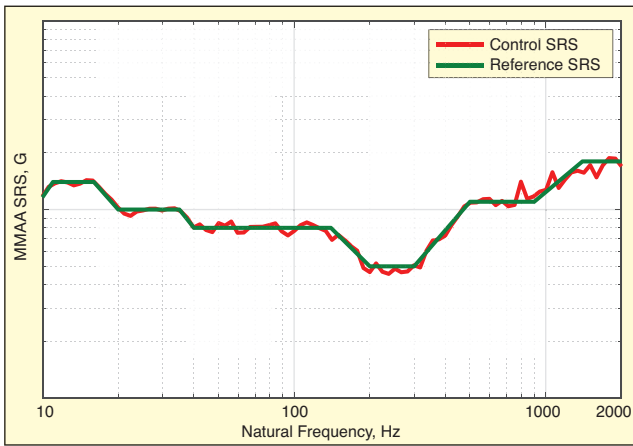
Figure 16. Control SRS and reference SRS with no limiting.

Figure 17. Limit SRS response with no limiting.
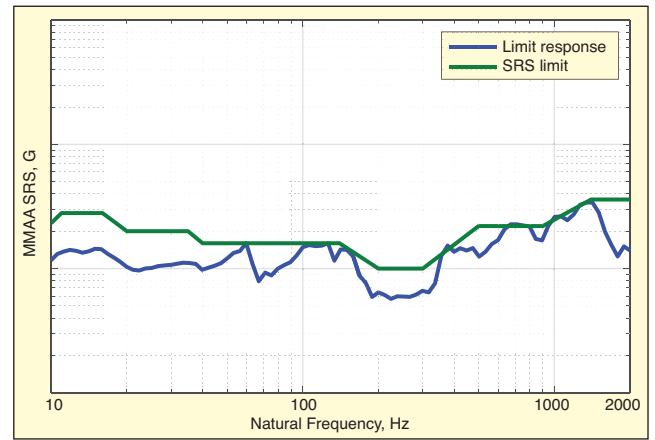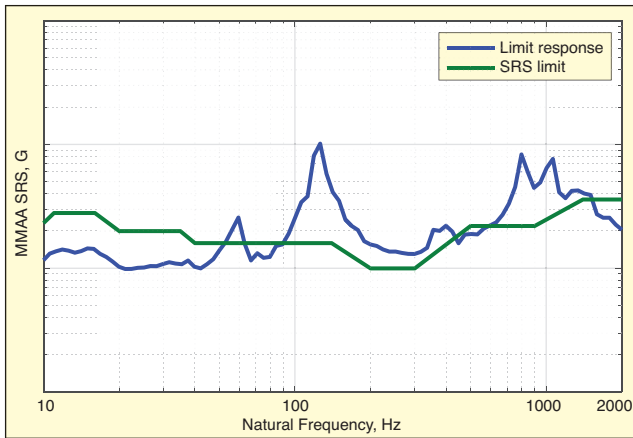

Figure 18. Simulator SRS with limiting.

Figure 19. Simulator limit SRS with limiting.
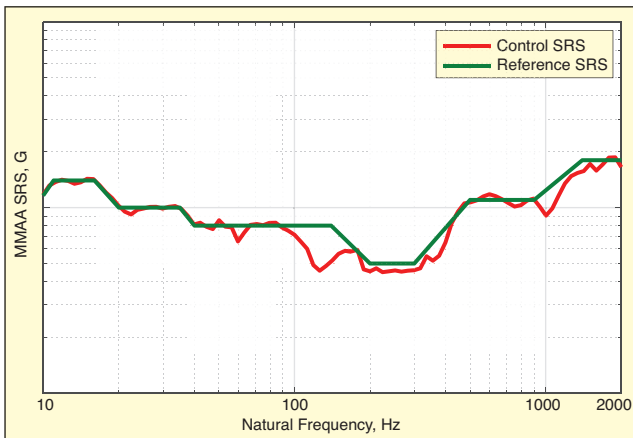

Figure 20. Modifications of magnitude of estimated FRF.

and LeBrun[2] in the early 1970s. This work[1,2] evolved into *TShaker* written by Ron Coleman. The primary software is LabView™, with MATLAB™ running in the background. LabView provides the user interface and controls the hardware used for signal generation and data acquisition. The acquired data are routed to MATLAB for additional analysis. The availability of this software for external distribution has not been determined.

References

1. D. O. Smallwood, "Time History Synthesis for Shock Testing on Shakers," *Seminar on Understanding Digital Control and Analysis in Vibration Test Systems*, Part II, pp 23-42, Publication of the S&V Information Center, NRL, Washington DC, May 1975.
2. J. D. Favour, J. D. LeBrun, "Transient Waveform Control of Electromagnetic Test Equipment," *Shock and Vibration Bulletin*, No. 40, 1969.
3. D. O. Smallwood, "Shock Testing on Shakers Using Digital Control," *IEST Technology Monograph*, 1986.

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