ADAPTIVE SHOCK PULSES ON AN ELECTRODYNAMIC SHAKER

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A physics (kinematics) solver built into a vibration controller is used to optimize reference pulses for classic shock specifications. These Adaptive references are more realistic, more controllable and less prone to nuisance aborts than industry-standard pre-constructed references.

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INTRODUCTION

Many industries require hardware to survive sharp mechanical shocks as a test of field durability. Originally performed on crash sleds and drop tables, these tests are increasingly being run on electrodynamic shakers because of their ease of use and high degree of controllability. However, unlike a crash sled, an electrodynamic shaker does not have a great distance to get up to speed before delivering its shock. Instead, motion is limited to a few inches of stroke. For this reason, electrodynamic shakers use a 'pre-pulse' to get the product moving in the opposite direction of the intended shock pulse and a 'post-pulse' to bring it to rest afterward. By way of illustration, a method to run a 100 g, 11 msec half-sine pulse (a common "car crash") on a shaker with only 2" of peak-to-peak displacement is shown in Figure 1.

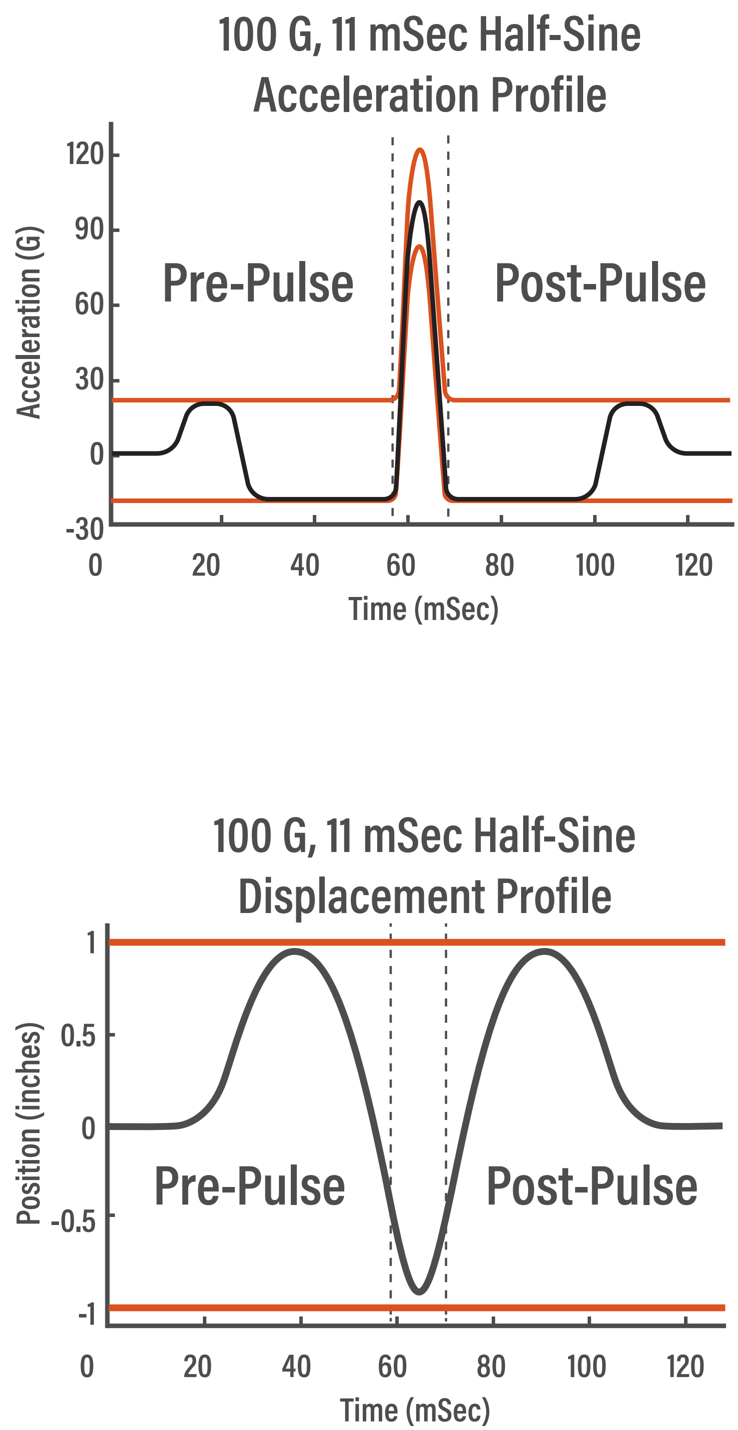

Figure 1

Various shock test standards limit the amplitudes of pre- and post-pulse compensation and set other requirements to ensure that the pulse as run on the shaker is similar to an ideal shock pulse. For example, IEC specification 60068-2-27, along with the vast majority of automotive specs, limits the amplitude of anything outside the pulse window to 20% of the peak pulse height. In order to achieve the minimum possible displacement on large pulses, vibration controllers often run their pre-pulse and post-pulse levels right up to these specification limits. Unfortunately, these minimum-displacement references are then saved in memory and scaled to match any pulse specified with the same pre- and post-pulse limits. So, for example, the extreme compensation needed to run a 100 g, 11 msec "car crash" is applied to a 40 g, 6 msec "door slam" unnecessarily. In the past, extreme pre- and post-pulse compensation was often necessary to stay within the very limited working displacement of the shaker, but such stroke limitations have eased in recent years. For example, Thermotron's entire DSX line of electrodynamic shakers now supports 3" peak-to-peak displacement as standard.

PROBLEMS WITH MINIMUM DISPLACEMENT

Harsh compensation increases the damage content of the pulse in its most damaging frequency range while artificially limiting its low-frequency content, so it should be avoided whenever possible. Figure 2 shows Shock Response Spectra (SRS) for a series of "door slam" shocks, all of which technically meet the automotive specification. An SRS trace shows the maximum acceleration experienced by a resonating product as a function of its resonant frequency. The Ideal SRS (shown in black) is taken from IEC 60068-2-27. For resonant frequencies around 40 Hz, a minimum-displacement shock (shown in orange, 20% pre- and post-levels) represents a 50% over-test; for products resonating at 20 Hz it delivers only half the ideal shock level. By contrast, a pulse using only 5% pre- and post-pulse compensation (shown in blue) stays within a few percent of the ideal SRS damage for all product resonances down to 20 Hz. While the '5% pre/post' pulse takes three times as long to run (170 msec instead of 55 msec) and uses up three times as much displacement (0.31" instead of 0.105"), these numbers are too small to matter on a modern shaker.

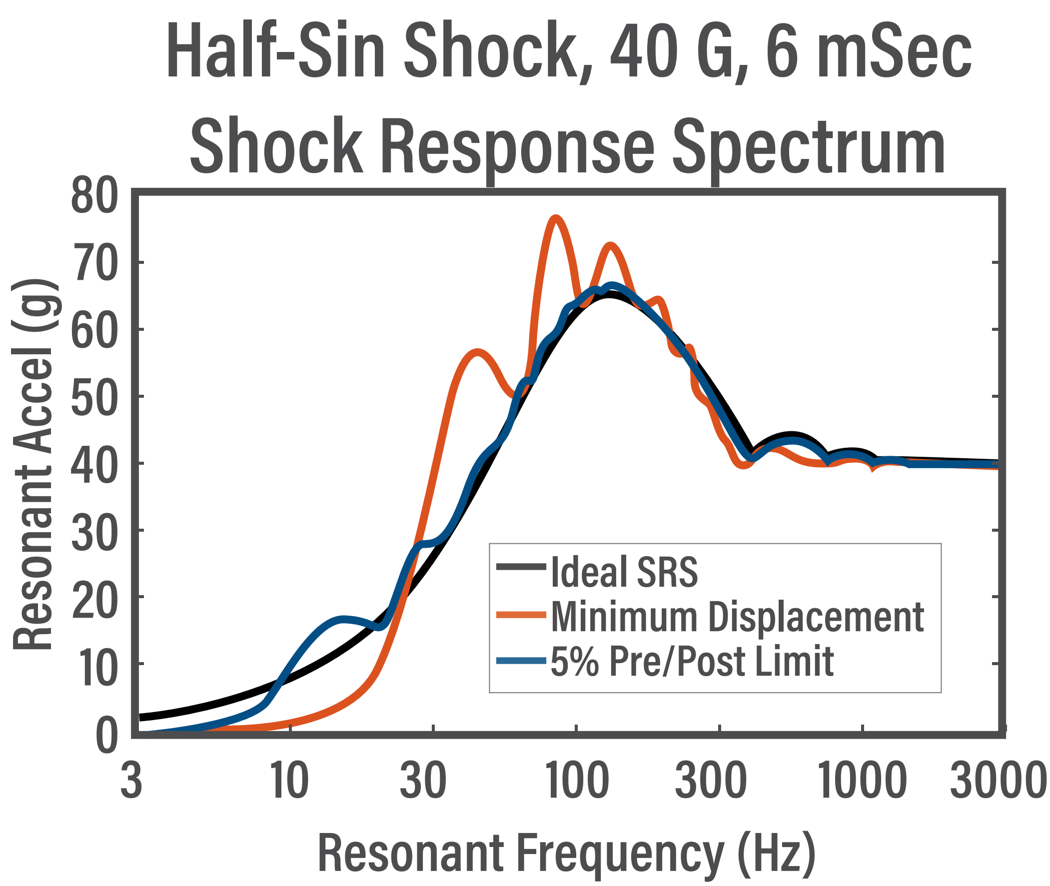

Figure 2

In addition to providing more accurate damage, lower compensation levels are inherently easier to run within tolerance. The ‘minimum displacement’ and ‘5% pre/post’ references are shown in Figure 3 along with the IEC 60068-2-27 limits. It would not take very much noise or controller instability to push part of the ‘minimum displacement’ pulse out of spec, while the lower, longer ‘5% pre/post’ pulse is much more fault-tolerant.

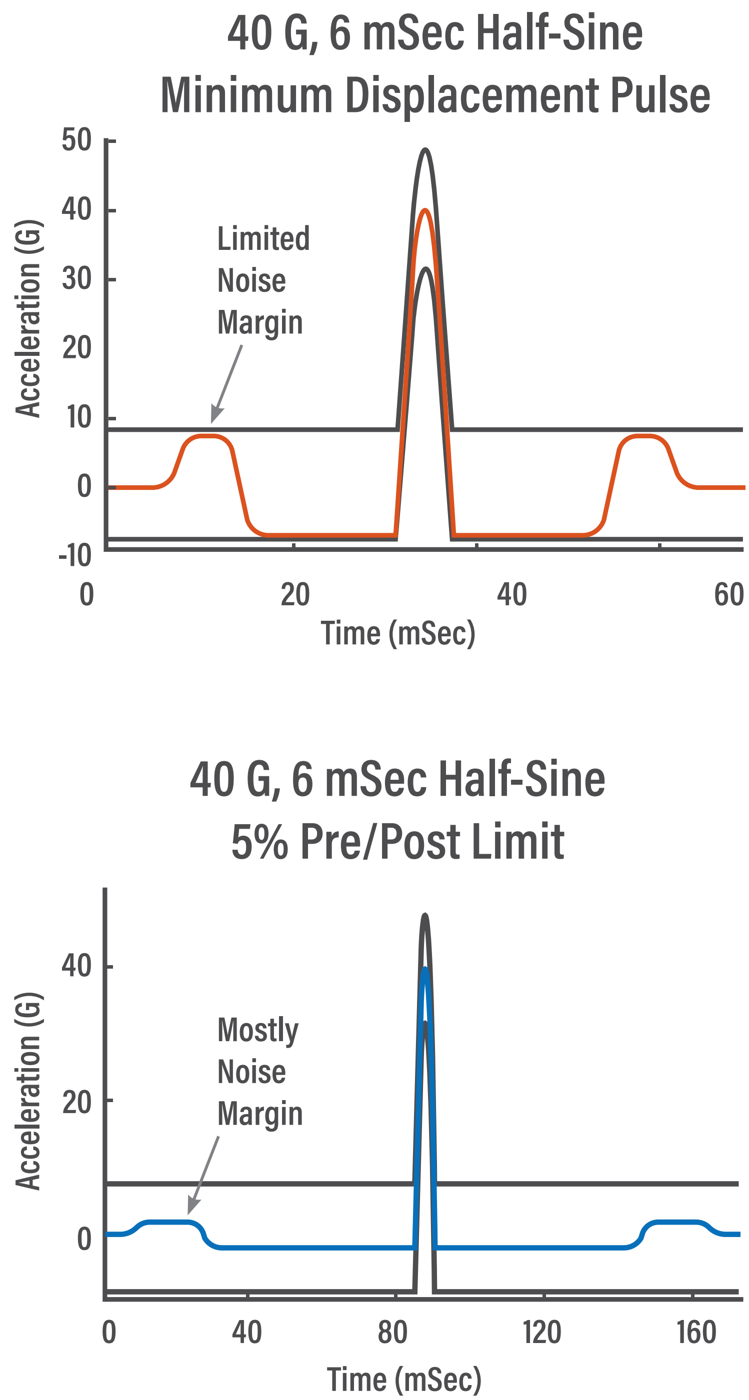

Figure 3

CHOOSING THE RIGHT REFERENCE

Many vibration controllers offer several compensation options for each specification. In addition to the balance of damage content against shaker capability mentioned above, the expert user can manually balance requirements of frequency content and noise margin. One popular controller even offers a reference that does not leave the shaker centered ... because their alternative reference that *does* re-center contains high-frequency jerks between acceleration levels! For the novice user, these options can be bewildering and counterproductive.

Shock pulse compensation can be broken into five steps, depicted here for a positive shock. (Refer to Figure 4.) The first region offsets the shaker armature to maximize the available stroke. The second region maximizes velocity in the direction opposite the pulse. The third region, which delivers the pulse itself, reverses the direction of motion and ends with the maximum velocity. The fourth region brings the velocity back to zero. Finally, the fifth region returns the armature to its centered position and brings it to a stop.

Choosing the optimal accelerations and times in the above regions would be straightforward except that the transitions between acceleration levels must be continuous and smooth. The smoothness requirement significantly complicates the calculations required, but the result is worth it. When the vibration controller solves the compensation problem for each test, the operator no longer needs to select from a range of options with strengths and weaknesses that may not be readily apparent.

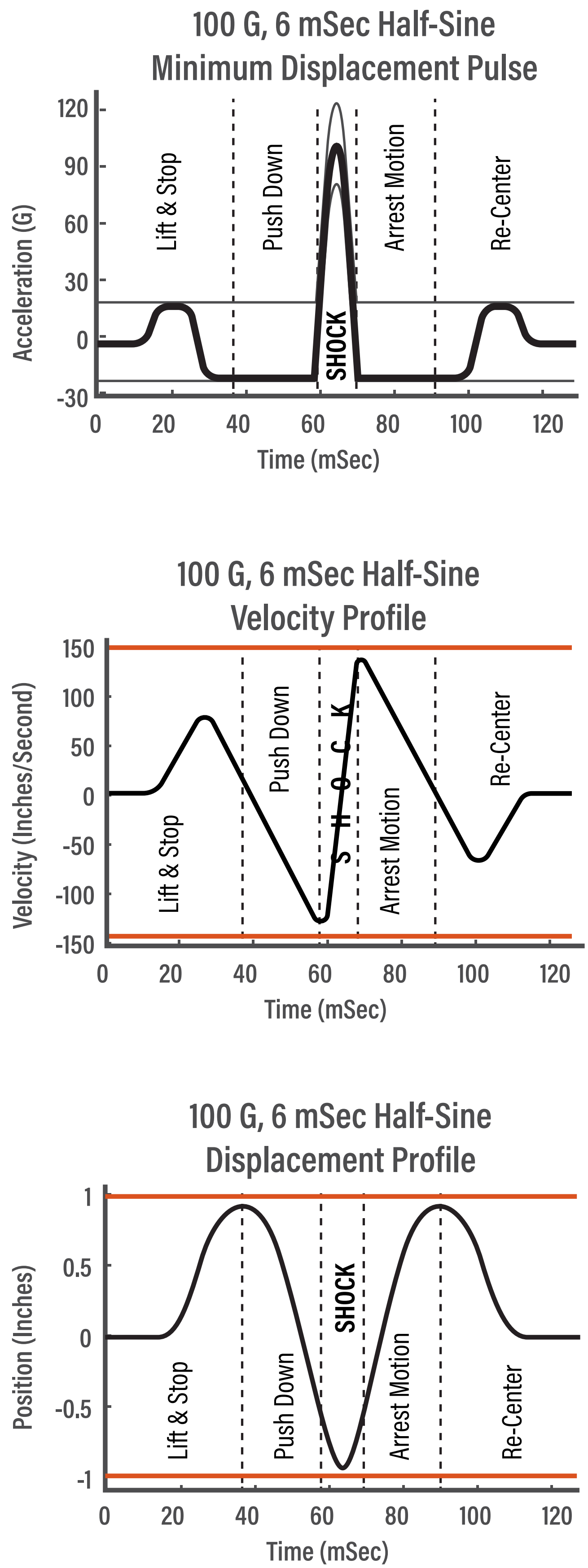

Figure 4

RESULTS

In 2016 an inline kinematics solver was added to Thermotron's WinVCS 2 vibration controller to create pulse compensation for any specification at the time of test definition. These Adaptive Shock Pulses are optimized to maximize the safety margin away from specification limits while respecting the limits of the shaker. In the process, they automatically deliver as close to 'true' (i.e. stroke-unlimited) damage as possible. Because the solution contains smooth transitions, spurious high-frequency content is kept to a minimum.

Adaptive Shock Pulses always have zero net velocity change and zero net displacement, even when running custom compensation requirements. If this were not the case, a series of pulses at high displacement could "walk" the armature away from center until a pulse aborted half-way through with a loud bang followed by a frantic call to the service center (at least, in our experience). By insisting on a stationary, centered end state, operators do not have to balance the desire to finish their test quickly with a need to wait on the mechanical centering system.

When running very low-level shock pulses, where the ambient level of electrical noise is comparatively large, it is recommended practice to switch to an accelerometer with higher sensitivity (often 100 mV/g) so that the measured compensation stays inside the specification. At higher g levels a lower sensitivity (often 10 mV/g) must be selected to avoid over-ranging the vibration controller's accelerometer input. Since the introduction of the Adaptive Shock algorithm, which automatically maximizes noise margin for low-level pulses, operators at Thermotron and elsewhere save time by leaving their 10 mV/g accelerometer in place for a wider range of shock tests.

Finally, although this is less apparent at the time, an operator selecting an Adaptive reference is assured of performing a test which is as close to the intended damage as possible. This means that a product tested against 10,000 "door slam" shocks is more likely to survive 10,000 actual door slams, and a product that would survive 10,000 actual door slams won't be artificially damaged in testing because it happens to resonate at a frequency that is over-tested by some poorly selected reference.

CONCLUSION

Choosing the correct compensation reference is an important part of classic shock testing on an electrodynamic shaker. Both the desirable properties of the reference and the mechanical constraints of the shaker are known beforehand and do not change with test specifications. Therefore a parameterized shock solution can create an optimized reference for any shock profile without the operator entering any information that is not needed to use a canned (non-parameterized) solution. It is found that this Adaptive solution is more robust against noise and distortion problems that often trouble classic shock testers. It allows inexperienced operators to run quality tests more reliably, both protecting the shaker and minimizing over-testing caused by shaker limitations.

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About the Author

Dr. Benjamin Shank, Thermotron engineer, earned his Ph.D. in physics from Stanford University for characterization and modeling of quantum calorimeters for the Cryogenic Dark Matter Search. His work at Thermotron focuses on vibration test system control and associated applications.