Fixture Evaluation for Shock Testing

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This article examines approaches for fixture evaluation, attempts to evaluate different fixture designs, and investigates the effect of shock machine choice on fixture performance.

Environmental test specifications sometimes include pulse-type shock events intended to be reproduced on a mechanical drop shock machine or other pulse-generating machines. Common aerospace pulse shocks are specified by pulse acceleration amplitude in g, pulse duration in milliseconds (msec), and a pulse shape. The pulse shape is proscribed by terms like haversine, half-sine, approximate half-sine, etc., which have the basic characteristics of starting with an acceleration value near zero g, rising to some specified peak acceleration value, and returning to near zero acceleration.

The ability of an environmental testing lab to provide these types of shock events depends on the performance of the shock machines available, the measurement systems available, and the fixture used to secure the unit under test (UUT). Depending on the duration of the shock pulse, the structural performance of the fixture can lead to unintended effects and shock events applied to the UUT that are quite different from the specified shock.

Response to Pulse Shock Loads

The nature of the response of a structure due to an approximate haversine pulse shock load applied on a given axis depends primarily on the duration of the pulse and the natural period of the structure that is excited by the shock load. If the duration of the pulse is long, compared to the natural period of the structure, the structure appears stiff, and the acceleration measured anywhere on the structure will be the same as the applied shock pulse. If the duration of the pulse is near or less than the natural period of the structure, the structure will usually respond as a damped single-degree-of-freedom system.

Acceleration measurements on the structure now vary depending on measurement location. The initial acceleration of the responding structure (the primary response) can be up to twice the acceleration amplitude applied at the base of the structure, and the structure will subsequently exhibit a damped-sine-like response (the residual response.) Unfortunately, the applied acceleration pulse and the primary response pulse will also have different durations.

Locations on the structure farthest from the table/fixture interface are most prone to the damped-sine response just described. Unfortunately, those locations are often the most convenient or only possible accelerometer mounting locations if testing processes specify that the acceleration measurement location should be on the fixture rather than on the shock machine structure (drop table). In this situation, the lab technician may have to attempt to adjust the pulse applied by the shock machine so the measured shock pulse looks like a haversine – a difficult if not impossible task, since the natural response of the structure is a damped sine.

The shock response spectrum for a single-degree-of-freedom (SDOF) system subject to a haversine base input can be found in the literature.* The spectrum predicts the ratio of the primary and residual acceleration response to the peak acceleration input at the base, given the ratio of the base shock duration to the natural period of the SDOF responding system.

Although actual fixture structures attached to mechanical shock machines have many dynamic modes, often there is one dynamic mode that dominates the shock response when a pulse shock is applied. The natural period of the dominant mode, therefore, could be used in conjunction with specified pulse duration and the SDOF shock response spectrum to predict the values of the primary and residual acceleration. The primary and residual response accelerations are important indicators of the suitability of a given fixture structure (and specific measurement point) to perform a specified haversine pulse shock.

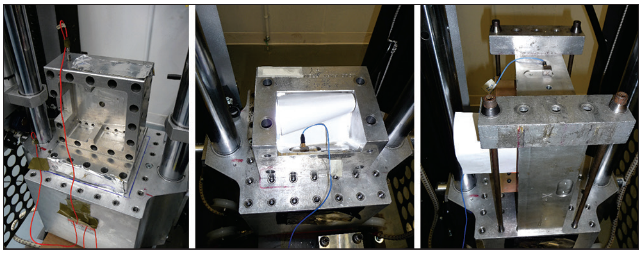

Figure 1. Fixture B with adapter plate, fixture D(Y), fixture E with straps.

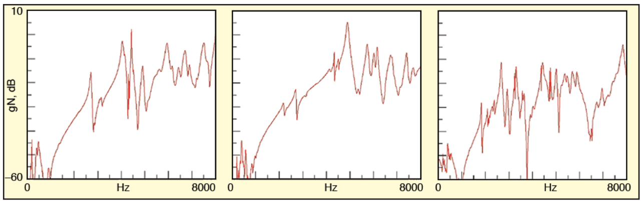

Figure 2. Driving-point FRFs for fixture D(Y), D(Y)alt, and fixture E.

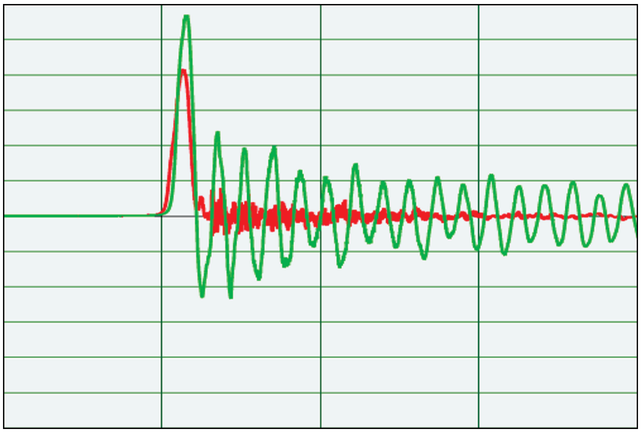

Figure 3. Table (red) and Fixture B (green) measured acceleration; duration at table – 0.37 msec.

Test Method

A simple experimental method to evaluate the suitability of a shock fixture structure to perform shocks of a given pulse duration was desired. When applied, the method should clearly show whether an approximate haversine response is possible or whether the fixture would have a strong residual response. Since legacy considerations can determine fixture structures and specified measurement locations, it was desired that the method would predict if a residual response could be low enough to be considered acceptable. For example, a residual response at a level less than 20% of the primary response pulse could be considered acceptable in some situations.

A fixture survey was planned where a variety of fixtures would be installed on an appropriate drop shock machine, FRF measurements made, and the ability of the fixture structure to perform a haversine test at the measurement point was assessed. In addition, the expected relative level of the residual acceleration was assessed.

The specific method to predict the response characteristics of the structure is as follows:

1. Perform a driving-point acceleration FRF measurement *in situ*

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*Lalanne, C., *Mechanical Vibration & Shock Volume II Mechanical Shock*, p. 43,Taylor and Francis, New York, 2002.

Based on a paper presented at the 87th Shock & Vibration Symposium, October 17-20, New Orleans, LA, 2016.

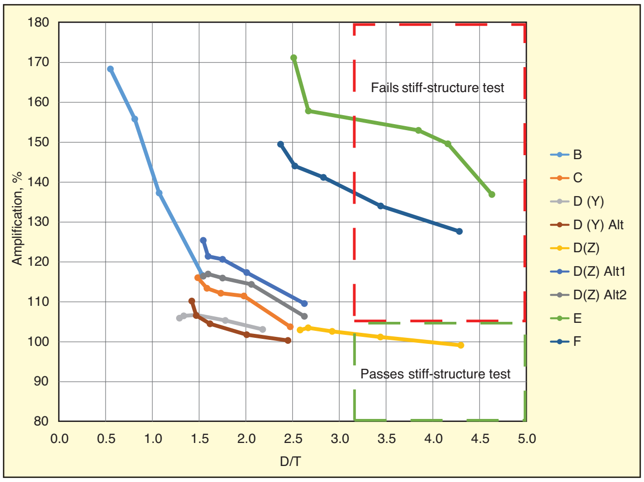

Figure 4. Pulse amplification and stiff structure test.

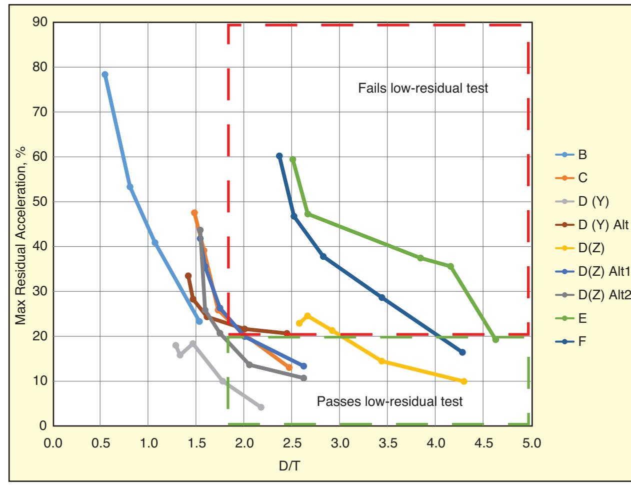

Figure 5. Maximum residual acceleration and low residual test.

at the proposed measurement location.

2. Use the highest peak in the FRF measurement as the indicator of the natural period (T) of the structure. The highest peak is assumed to be the most significant and relevant dynamic response of the structure.
3. Form the ratio of intended haversine pulse duration (*D*) to the natural period (T).
4. Use a single-DOF response model and the duration to natural period ratio (D/T) to predict the character of the shock response at the measurement location. Expected characteristics were:

a) A ratio greater than 1.8 was expected to produce a residual acceleration response of less than 20%. This expected characteristic was used to form the low-residual test. The 1.8 value was taken directly from published values for shock response of a single-DOF system to a haversine base input.

b) A ratio greater than 3.2 was expected to produce an approximate haversine shock response (acceleration response at the fixture measurement location less than 105% of the table acceleration.) This expected characteristic was used to form the stiff structure test. The 3.2 value is an arbitrary relaxation of alternative ratio values of 4 and 5.36 that can be derived from the shock testing literature.

A series of pulse shocks of varying durations would then be performed to test the predictions. A haversine shock pulse would be developed and measured at the shock machine interface (drop table), and the acceleration at the intended measurement location on the fixture would also be measured. The fixture amplification and residual response are calculated and then compared to the predicted values.

Fixtures and Driving-Point FRFs

Table 1 provides a list of test structures evaluated, while Figure 1 illustrates example test configurations. FRF and shock testing was performed on a drop shock machine with a 10-inch drop table capable of performing pulsed shock durations down to 0.2 msec. Test structures were secured to the drop table with 3/8-inch, diameter steel cap screws.

Driving point FRF measurements were acquired with an LMS Scadas system, a PCB triaxial accelerometer, and a PCB impact hammer. For the FRF measurements, the table was supported by low-stiffness silicone foam rubber with the table brakes released to replicate the free-falling table environment as closely as possible. In all cases, the driving-point measurement was made at or as near as possible to the intended measurement point on the fixture or at an alternate location likely to be used by a lab technician for the shock measurement. Figure 2 shows an example of driving-point FRF measurements.

The natural period of the fixture was estimated by using a cursor on the FRF displayed by the measurement system to determine the frequency of the highest peak and simply inverting the frequency value. The highest or dominant peak in the FRF was usually not the first peak in the measurement. Estimates using this approach for the natural period are summarized in Table 2.

Shock Test Series

For each fixture and measurement configuration, a series of shock pulses was performed. Acceleration was measured at the interface to the shock machine (top of drop table) and at the previously described fixture measurement location. The acceleration

Table 1. Test structures evaluated.

Fixture	Description	Attachment to Machine	Measurement Location
B	7 × 7 × 4 -inch pocket fixture (10 lb) with no UUT installed	6.5 lb adapter plate, 1-inch grip length on all bolts.	Furthest surface from table interface
C	5 × 5 × 4-inch pocket fixture (8.9 lb) with UUT installed	Four bolts, 4.7-inch grip length	Furthest surface from table interface
D	7 × 5 × 5 inch pocket fixture (10.8 lb) installed in Y axis direction; UUT installed	Four bolts, 3.25-inch grip length	D(Y) – designed-in location near machine interface
			D(Y)alt - on the furthest surface from the table interface
	7 × 5 × 5-inch pocket fixture (10.8 lb) installed in Z axis direction; UUT installed	Four bolts, 3.25- and 1.25-inch grip lengths	D(Z) – designed-in location near machine interface
			D(Z)alt1 – on furthest surface from table interface
			D(Z)alt2 – at another location on furthest surface from table interface
E	10 × 11 × 4 inch pocket fixture (34.5 lb); UUT installed.	Four bolts with two straps, 13-inch grip length	Furthest surface from table interface
F	10 × 10 × 1.5-inch plate fixture (15 lb); UUT installed	Four bolts with two straps, 11.5-inch grip length	Furthest surface from table interface

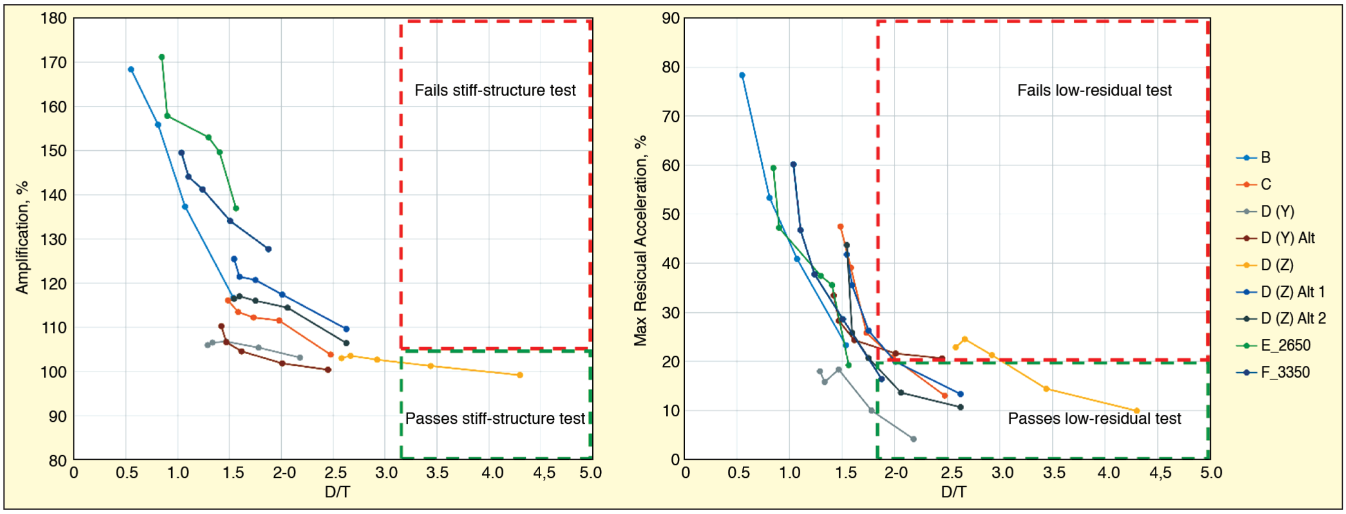

Figure 6. Amplification and residual acceleration with D/T adjusted on fixtures D and E.

measurements were made with a Lansmont TestPartner4 measurement system and Kistler 8742 accelerometers. Generally the shock series began with approximately a 2000 g, 0.2 to 0.3 msec pulse. On a drop shock machine, reducing the drop height will lead to lower peak acceleration levels and correspondingly longer pulse durations. This phenomenon was leveraged to form a series of about three or four progressively longer duration (and lower amplitude) shock pulses out to durations of approximately 0.5 msec.

For each shock measurement, the measured table pulse was assumed to be the specified pulse, and the duration value D was set to the measured 10% pulse duration. (10% pulse duration begins when the primary pulse acceleration reaches 10% of its eventual maximum value on the rising edge of the pulse and ends when the primary pulse drops below 10% of the maximum on the falling edge of the pulse.)

The amplification of the pulse is the ratio of the maximum pulse response at the fixture measurement location and the maximum value of the table pulse, reported in percent. The residual acceleration value is the ratio of the highest magnitude excursion of the residual response at the fixture measurement location and the maximum primary pulse value at that location, reported in percent. An example of the data collected is shown in Figure 3. Relevant duration and acceleration values, amplification and residual values, and D/T ratio are shown for Fixture B as an example in Table 3.

Values for pulse amplification and maximum residual acceleration at the fixture response location were collected and plotted in Figures 4 and 5, respectively. For pulse amplification, the stiff structure test can be shown graphically as a horizontal line on the plot at 105% and bounded on the left by a D/T ratio of 3.2, or alternatively. a green box showing data points passing the test, and a red box showing data points failing the test. Similarly, for residual acceleration, the low residual test can be represented by a horizontal line at 20%, bounded on the left by a D/T ratio of 1.8. Box outlines showing passing or failing points are again used.

For both tests, the data show a dramatic failure of the technique for fixtures E and F. Amplification and residual acceleration are greater than predicted by the technique. A reasonable conclusion is that the value predicted for the natural period of the responding system, obtained from the highest peak in the driving point FRF, was incorrect. Additional work will be required to understand this phenomenon. It was observed that the technique failed for the fixtures with measurement surfaces farthest from the table, at 11 and 10 inches. In addition, both fixtures were secured to the table with straps and long bolts.

Upon examination, the data also show unexpectedly low amplification results for fixture configurations D(Y) and D(Y)alt, as well as unexpectedly low residual acceleration for the D(Y) configuration.

Table 2. Natural period estimated from driving-point FRF.

Fixture and Measurement Point	Dominant Peak	Estimated Natural Period "T," msec
B	2900	0.34
C	4950	0.20
D(Y)	4450	0.22
D(Y) Alt	4900	0.20
D(Z)	> 8000	< 0.13
D(Z) Alt1	5150	0.19
D(Z) Alt2	5150	0.19
E	7850	0.13
F	7650	0.13

Table 3. Shock series measurements and calculations for Fixture B.

	Fixture and Measurement Location B			
Table pulse D, msec	0.19	0.28	0.37	0.53
Table amplitude, g	2077	1990	2062	1546
Location pulse, msec	0.21	0.24	0.31	0.43
Location amplitude, g	3497	3101	2831	1803
Location max residual, g	2740	1654	1157	420
Location amplification, %	168%	156%	137%	117%
Location max residual, %	78%	53%	41%	23%
Natural period T, msec	0.34 (estimated from FRF)			
D/T	0.6	0.8	1.1	1.5

Table 4. First-significant-peak estimate for natural period of bolt and strap configuration.

Fixture and Msrmnt. Point	Dom. Peak, Hz	Est. Natural Period T, msec	1st Sig. Peak, Hz	Est. Natural Period T, Msec
B	2900	0.34	-	-
C	4950	0.20	-	-
D(Y)	4450	0.22	-	-
D(Y) alt	4900	0.20	-	-
D(Z)	> 8000	< 0.13	-	-
D(Z) alt1	5150	0.19	-	-
D(Z) alt2	5150	0.19	-	-
E	7850	0.13	2650	0.38
F	7650	0.13	3350	0.30

Potential Correction for Bolts and Straps

Alternative values for the natural period of the responding system for the bolt and strap configuration were proposed, since the highest peak in the FRF measurement failed to provide a good prediction of the response. A first-significant-peak approach was attempted, where the first significant peak in the FRF was used for the value of T. This approach was only tried for fixtures D and E, and the data and estimated natural period are shown in Table 4. The entire data set with D/T ratios recalculated for fixtures E and F (only) are shown in Figure 6. SV

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