An Accurate, Repeatable Subsidiary Component Shock Test System for the Laboratory

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Abstract

The US Navy needs a modern, computer controlled shock test system for testing a large and growing number of commercial products for use in its newest vessels. Team has been delivering earthquake test systems to test labs around the country for many years. By increasing the velocity capability and linearizing the valve response, these systems are shown to be well suited to doing the Navy's shock tests. Shock pulse waveforms and pseudo velocity spectrums of four separate tests show the accuracy and versatility of the system. The systems are defined, test results presented and future work suggested.

Introduction

In this paper we present a proven, yet previously unrecognized solution for performing subsidiary component and subassembly shock testing in the laboratory. The solution allows the shock pulses to be tailored to meet a wide range of Shock Response Spectra (SRS) or Pseudo Velocity Spectra (PVS) typical of equipment mounted in an isolated principal unit. The test system can be located in a laboratory, easing the task of monitoring the component or subassembly performance during the shock event. It produces repeatable shock pulses that can be fired off within seconds of each other. The subsidiary component can be tested in both horizontal and vertical directions with either the same or different shock pulses in each direction.

Background

The Navy recognizes the need to use Commercial Off The Shelf (COTS) components in their modern fleets in order to take advantage of the rapid advances in technology and to reduce the cost of keeping equipment current. All equipment must pass shock qualification testing, per MIL-S-901 D, and COTS equipment is no exception. Subsidiary components are defined as a sub-assembly mounted to or inside a principal unit. Normally, when a subsidiary component is replaced, the entire principal unit must be re-qualified. That may mean putting the subsidiary component in the principal unit and doing Heavyweight shock tests all over again.

For some programs the Navy has allowed a new approach. *For some programs it allows shock testing the subsidiary component with a shock pulse that matches the PVS derived from the original shock qualification of the principal unit.* This approach is intended to reduce the need to retest the entire principal unit when replacing a COTS subsidiary component or subassembly.

It was in response to a navy contractor's RFP that we first recognized that we had an excellent solution for this application. The contractor presented us with a pseudo velocity spectrum and asked if we could do such a shock pulse with a hydraulic actuator. After studying the problem we determined that our previous experience with similar test requirements provided us with an excellent solution to the Navy's needs.

The Solution to Matching Pseudo Velocity Spectrums in the Lab

Prior to the system presented here, there was no simple means to produce a shock pulse that matched a Pseudo Velocity Spectrum (PVS) as measured on a principal unit undergoing Heavyweight shock testing. The accelerations, velocities and displacements needed have been out of the realm of most laboratory shock equipment. Hammer or drop type shock machines require significant tuning and a number of pre-tests to develop the correct setup parameters.

The solution presented in this paper uses a high performance, computer controlled hydraulic actuator system to generate an acceleration waveform that closely matches the desired pseudo velocity. The high force hydraulic actuator has the displacement needed for these waveforms. It has high response servo valves to simultaneously produce the velocities and the frequency response needed to replicate these shocks to 250 Hz.

The system presented is versatile. It can produce many different waveforms with many different Shock Response Spectra. It has been shown to replicate waveforms that have many characteristics of the *measured* response from a principal unit as well as waveforms generated by commercial SRS software. In all cases, the computer controller produces acceleration waveforms that match the programmed waveform almost exactly.

The system is easy to use, and should substantially reduce test time and total test costs. The process to perform a test would be as follows. First, develop an appropriate shock waveform with the desired PVS off line, for example, in the office. A single waveform can be used in all axes or different waveforms for each axis. Waveforms can be generated with different PVSs for assorted principal units, or envelop all the PVSs with one waveform. Then, you load the waveforms into the computer shock controller and proceed to "iterate the drive file". Iteration requires roughly ten minutes for the computer to calculate the drive signal that produces the desired shock waveform. Once this drive file is generated, it can be used over and over to produce that shock pulse on the Subsidiary Component. Multiple drive files can be produced and saved. To play one on the shock machine, you simply pick it from the list and press the GO button.

What is the *Team* Subsidiary Shock Test System

The Team Corporation Subsidiary Shock Test System (SSTS) is a long stroke hydraulic actuator that can be configured to operate in either a vertical or horizontal position. Each orientation has a robust table on which to mount the subsidiary component. The hydraulic actuator system has sufficient force, velocity and stroke to do transient shock waveforms that meet current typical Pseudo Velocity Specifications.

The hydraulic Actuator is controlled with Team's Harmonic Distortion Reduction System (HDRS). HDRS is a computer controller that iteratively corrects for the actuator's inherent distortion to produce acceleration waveforms that closely match the desired waveform.

Hydraulic power for the shock pulses is provided by accumulators, which reduces the size and cost of the hydraulic power supply.

Team Corporation has manufactured many such systems to test telecommunication equipment for earthquake survivability. The actuators produced for these systems have 10 to 12 inches of stroke and are designed to carry loads of 2000 lb. The vertical tables are typically 36 inches square, and the horizontal table is a 12 inch stroke T-Film table[1] for unmatched load and overturning moment capacity. The actuator is mounted in trunnions to make switching from horizontal to vertical a simple operation.

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[1] The T-Film Table is a slip table design patented by Team Corporation that uses an array of hydrostatic bearings to support the slip plate on a full oil film as well as using an inverted T element riding in an inverted T way to constrain all but a single degree of freedom.

The dimensions of the telecommunication products, the overall weight of the payload and the stroke requirement are all similar to the Navy's needs. These earthquake systems have been proven with 1000s of hours of operation.

Figure 1. An earthquake test system is very similar to a Subsidiary Component Shock Test System

Development of Performance Specifications

As mentioned, a Navy Contractor's RFP triggered the investigation. The equipment under test (EUT) was specified to be 500 lb. with fixturing. Subsequent discussion led to using 600 lb. as the design load.

The Pseudo Velocity Spectrum from the Navy Contractor's RFP was analyzed and several time waveforms were generated that met the PVS. Those waveforms were analyzed to determine the force, velocity and displacement needed. We found that a variety of waveforms could meet the SRS, and that some of them required much more force or velocity or displacement than others. Keeping costs down is important so the specifications for the system are chosen near the low end of the range.

The specifications were determined to be: 17 G on a 600 lb load, with peak velocities of 10 feet per second and a stroke of more than 10 inches. The final system would need 20,000 lbf dynamic force output, 10 ft/sec peak velocity, and 10 inches or more of useable stroke.

Prototype Design and Simulation

These specifications are similar to the aforementioned earthquake test systems in several ways.

The first is the need for over 10 inches of dynamic stroke, which the all the earthquake systems have.

The second specification is for a load capacity sufficient to test equipment mounted in racks with high centers of gravity. The earthquake Equipment Under Test (EUT) generates loads comparable to the subsidiary shocks.

Third, the SSTS needs 20,000 lb dynamic force to generate the appropriate acceleration transients. Earthquake systems produced for several customers have 20,000 lbf.

The final specification is a controllable frequency band of more than 250 Hz. We achieve that using Team Corporation's high frequency response pilot and slave valve set. The pilot is the renowned Team V-20 Voice Coil driven pilot valve, and the slave valve is a Team model V-750, 180 GPM valve.

The V-20 pilot valves can provide rated peak flow to over 500 Hz. Driving the V-750 slave with the V-20 pilot gives the V-750 response to well over 300 Hz. The V-750 valve has advantages over other slave valves in that it produces a more linear response from the input signal to the output acceleration than a standard slave stage.

The SSTS needs 10 ft/sec velocity capability. The flow required to hit 10 ft/sec peaks is about 320 Gallon/Min (GPM). That requires using a pair of V-20 / V-750 valve sets in parallel on the hydraulic actuator.

A simulation was run using Team Corporation's HydraSim hydraulic actuator dynamic simulation software. It predicted that the system could replicate the aforementioned time waveform, and gave us good confidence to manufacture a prototype.

In order to minimize cost, we designed the prototype for only half the load capacity. That dropped the valve requirement to a single valve and reduced the hydraulic power requirement. The prototype has the proper stroke and velocity, but only ½ the force, of the final SSTS. The most important parameter of this prototype is that it has the same dynamic response as the full size system will have.

Once assembled the prototype system underwent a number of performance tests, which are now presented.

Prototype Tests

Pseudo Velocity spec

This is the pseudo velocity specification. Additional requirements were that the acceleration time history is to be less than 2.5 seconds long, and must meet the specification from 3.5 Hz and higher.

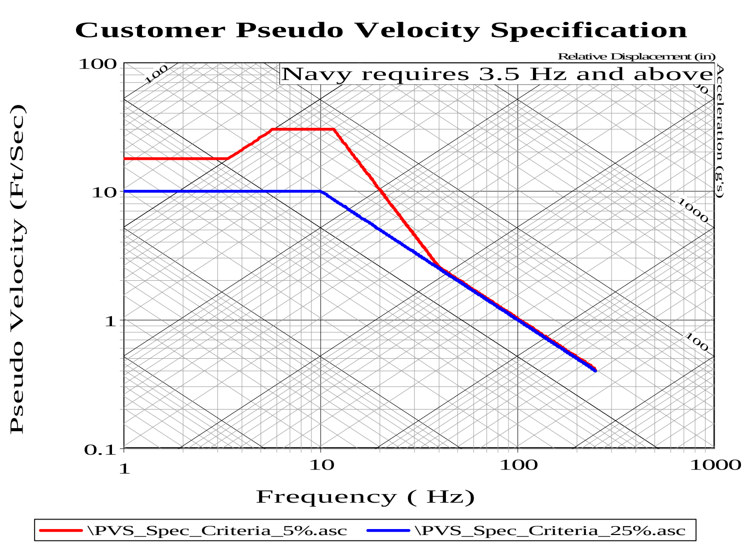

Figure 2. Specified Pseudo Velocity for a 2 second shock event

A commercial shaker control software package from Dactron was used to generate a waveform that was 2 .5 seconds long, met the PVS and required less than 17 g, 10 ft/sec velocity and 7 inches of stroke

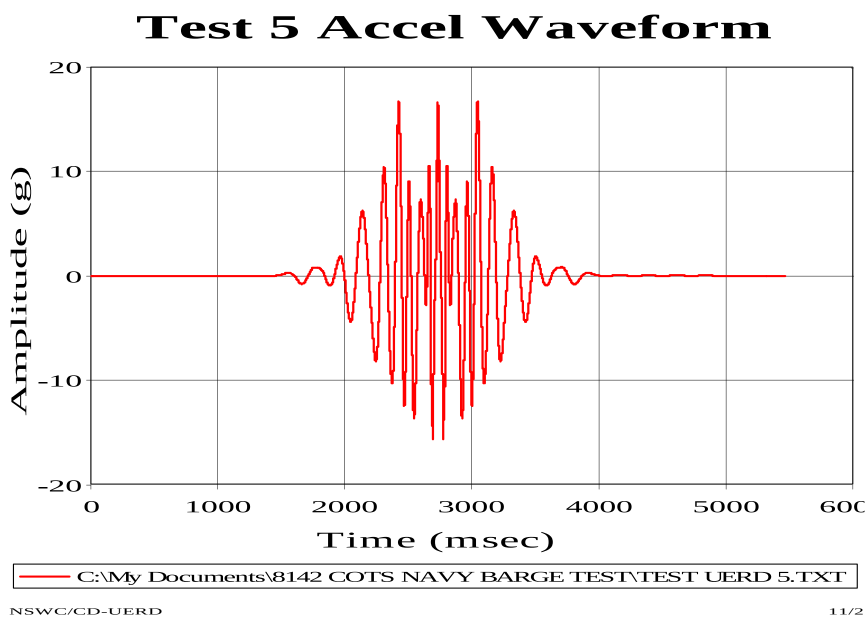

Figure 3. Acceleration Waveform that meets Pseudo Velocity Spectrum

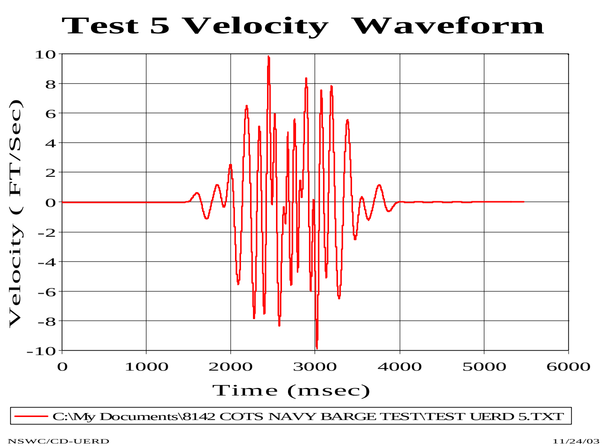

Figure 4. Velocity Waveform

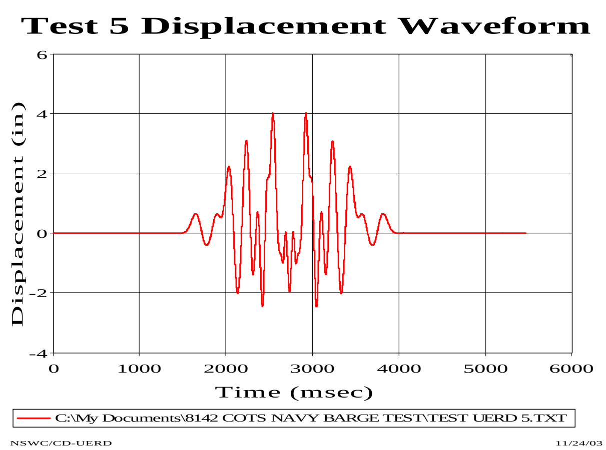

Figure 5. Displacement Waveform

The Half Force Demonstration SSTS Test Results

The SSTS acceleration response is overlaid on the desired response. This was achieved after 8 iterations, which took less than 10 minutes for the controller to generate and run.

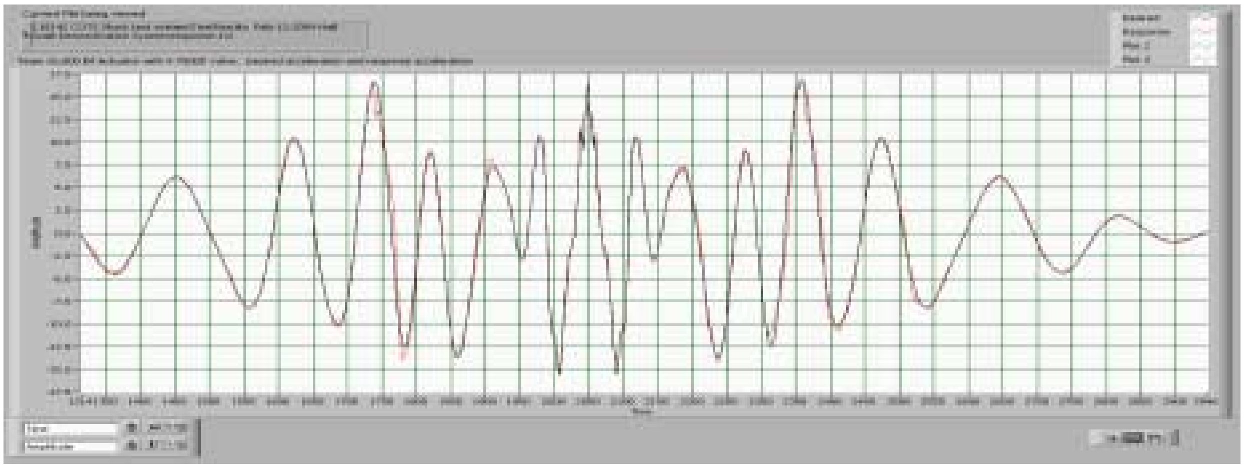

Figure 6. Acceleration Measured on SSTS overlaid on the reference waveform

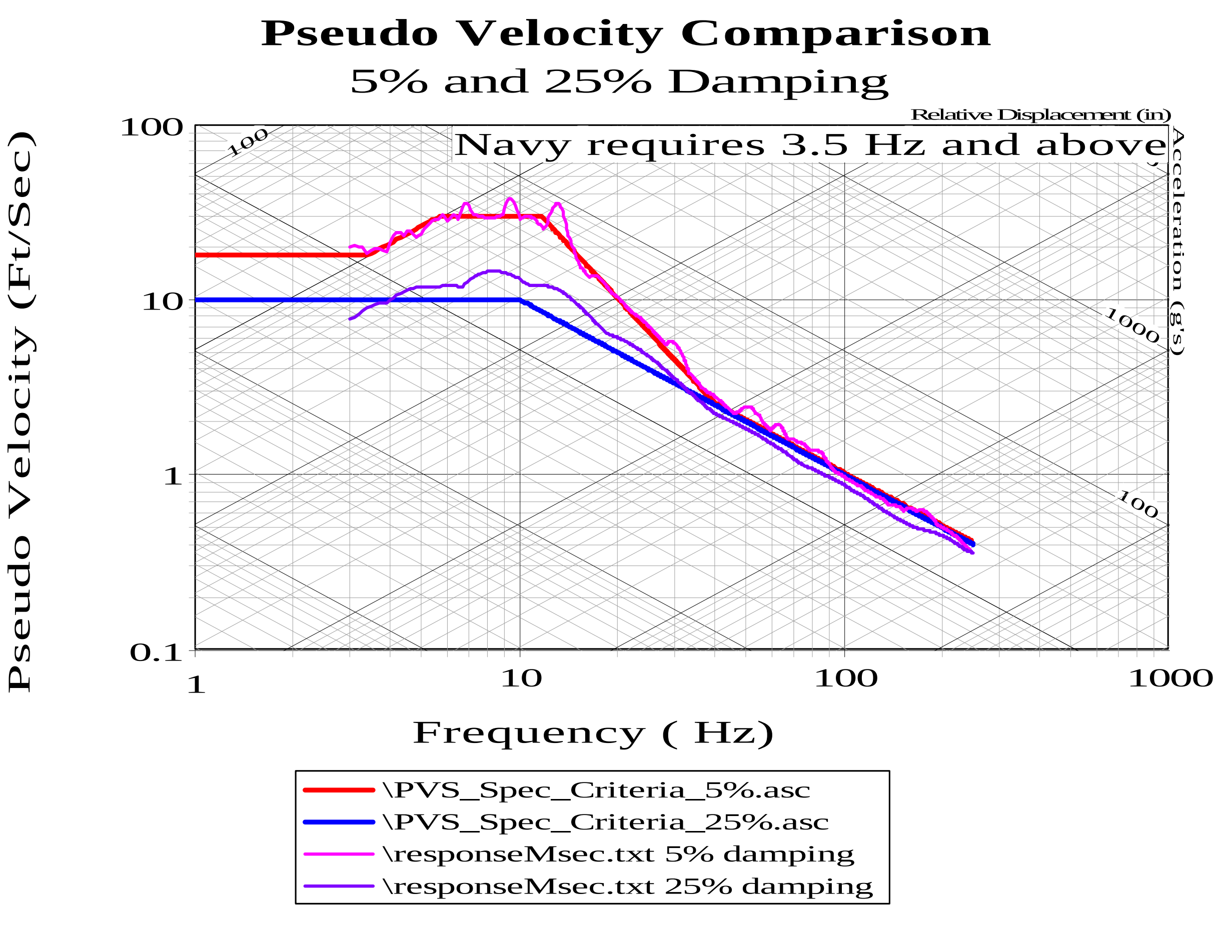

Figure 7. 5% and 25% Damping Pseudo Velocity Spectrums of Measured Acceleration with PVS criteria

Modified Pseudo Velocity

These results were very encouraging, and the Navy was interested to know if the SSTS could envelop a worst case PVS, based on current knowledge. We demonstrated we could meet that PVS quite nicely.

Comments made by UERD personnel indicated that upcoming requirements would have more energy in 40 to 80 Hz band. We undertook to demonstrate that the system had the frequency response, dynamic range and controllability to add the needed energy in the 40 to 80 Hz band. We arbitrarily generated a new PVS by boosting the velocity at 60 Hz. The match between the new acceleration waveform and that measured on the SSTS as well as the spectrum match are shown.

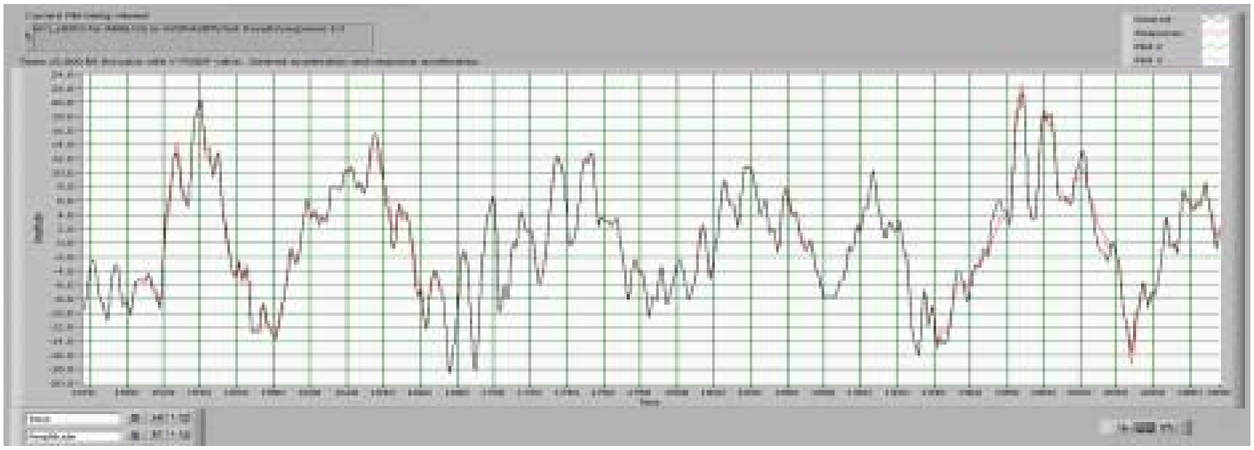

Figure 8. Time waveform match of measured Acceleration overlaid on the target waveform.

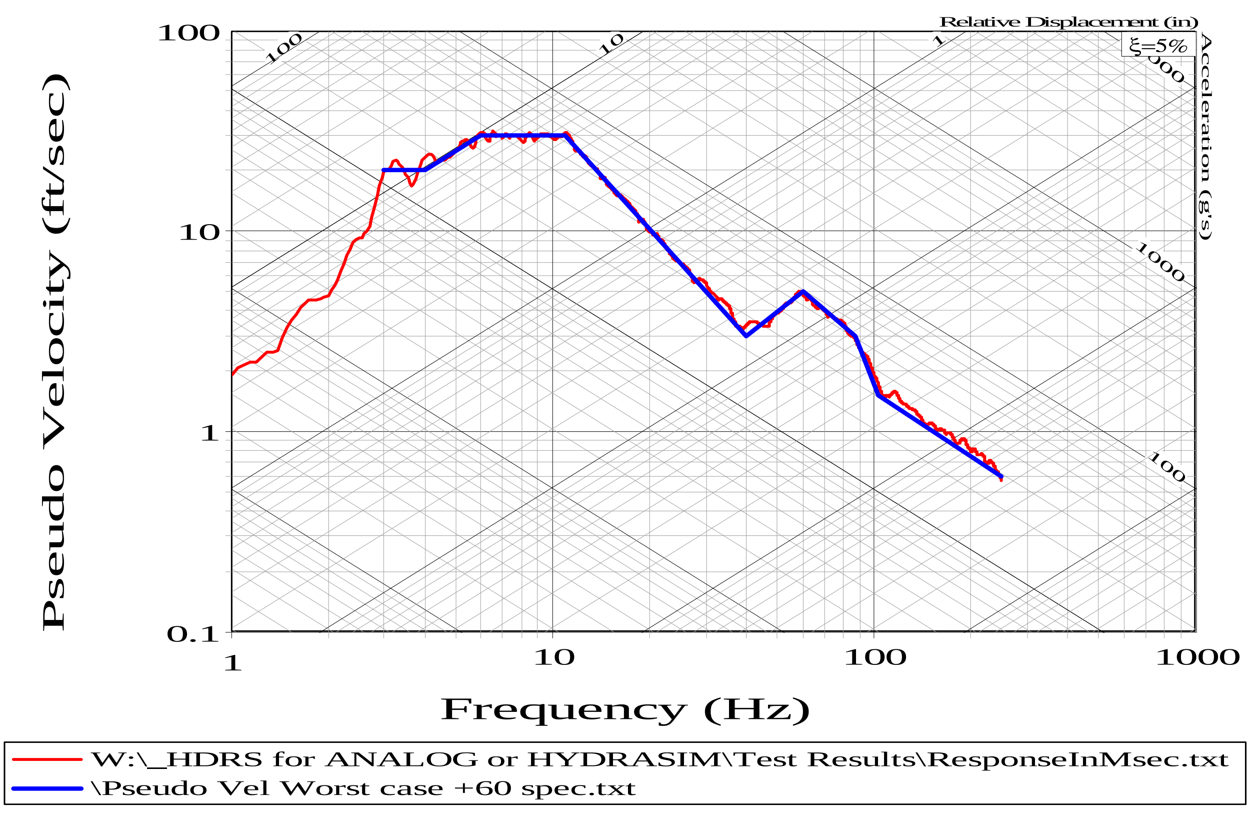

Figure 9. Pseudo Velocity Spectrum Target and Measured PSV on Demo SSTS

UERD Preferred Waveform

These excellent results were achieved with a 2 second random waveform whose energy distribution gave the necessary PVS. But, the waveform used does not resemble the actual shock waveform in terms of acceleration transients versus time. UERD felt that it may be important to have more energy in an initial pulse, followed by an energetic bubble pulse. They developed such a waveform that had the desired PVS and asked us to run it on the demonstration SSTS.

Waveform from UERD

UERD's waveform as delivered needed more stroke than our demonstration SSTS has, and was deficient in the frequencies from about 15 Hz to 30 Hz. We filtered the original waveform to reduce the stroke, and added some energy in the 15 to 30 Hz range. The graph in Figure 10 shows the original waveform in red, the filtered waveform in green and the SSTS response in blue.

The UERD preferred shock Acceleration – Time waveform, the filtered version, and the measured acceleration response of the SSTS are shown in Figure 11. The original is Red, the filtered is green and the response is in blue.

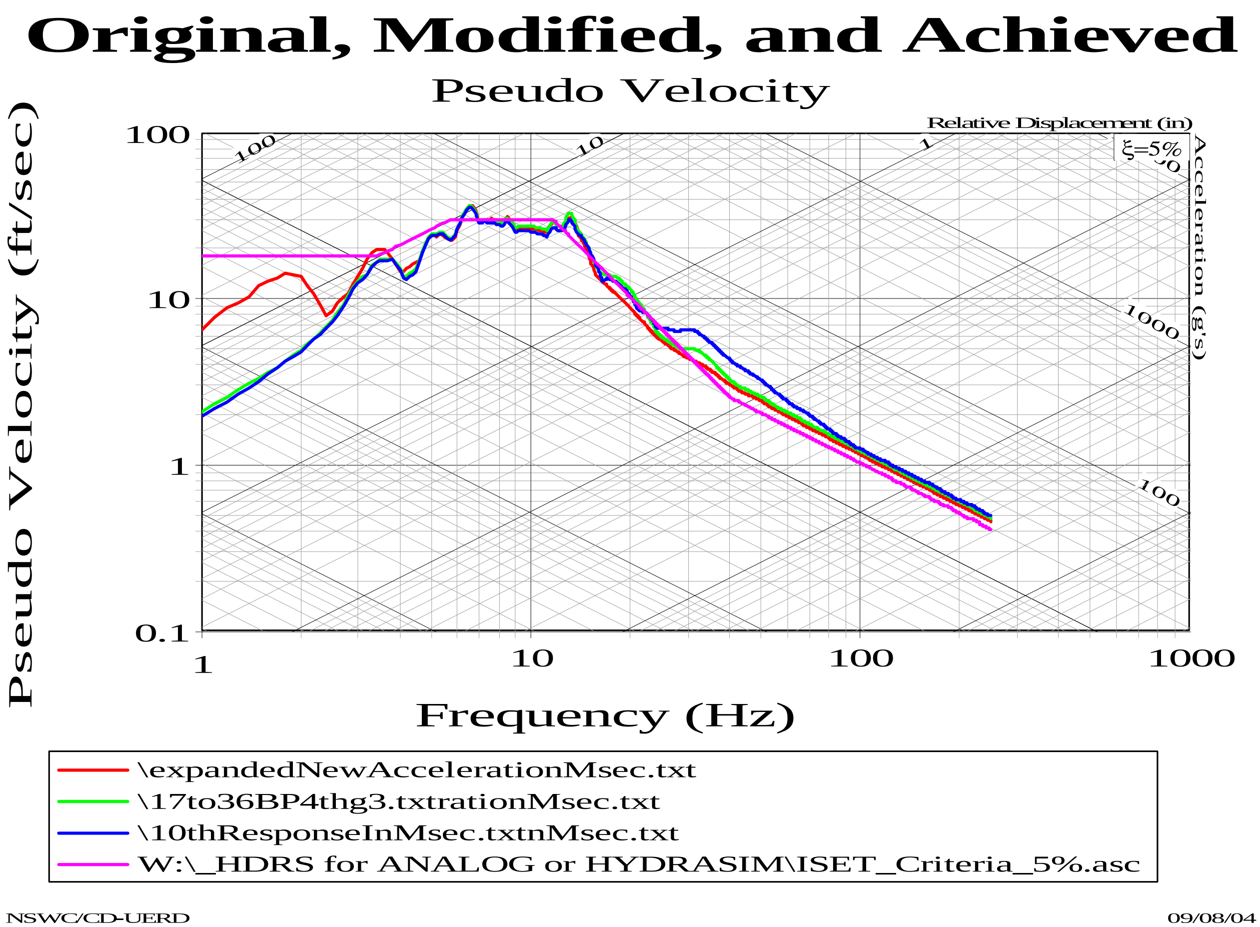

Figure 10. Pseudo Velocity of UERD preferred waveform, filtered waveform, and SSTS response

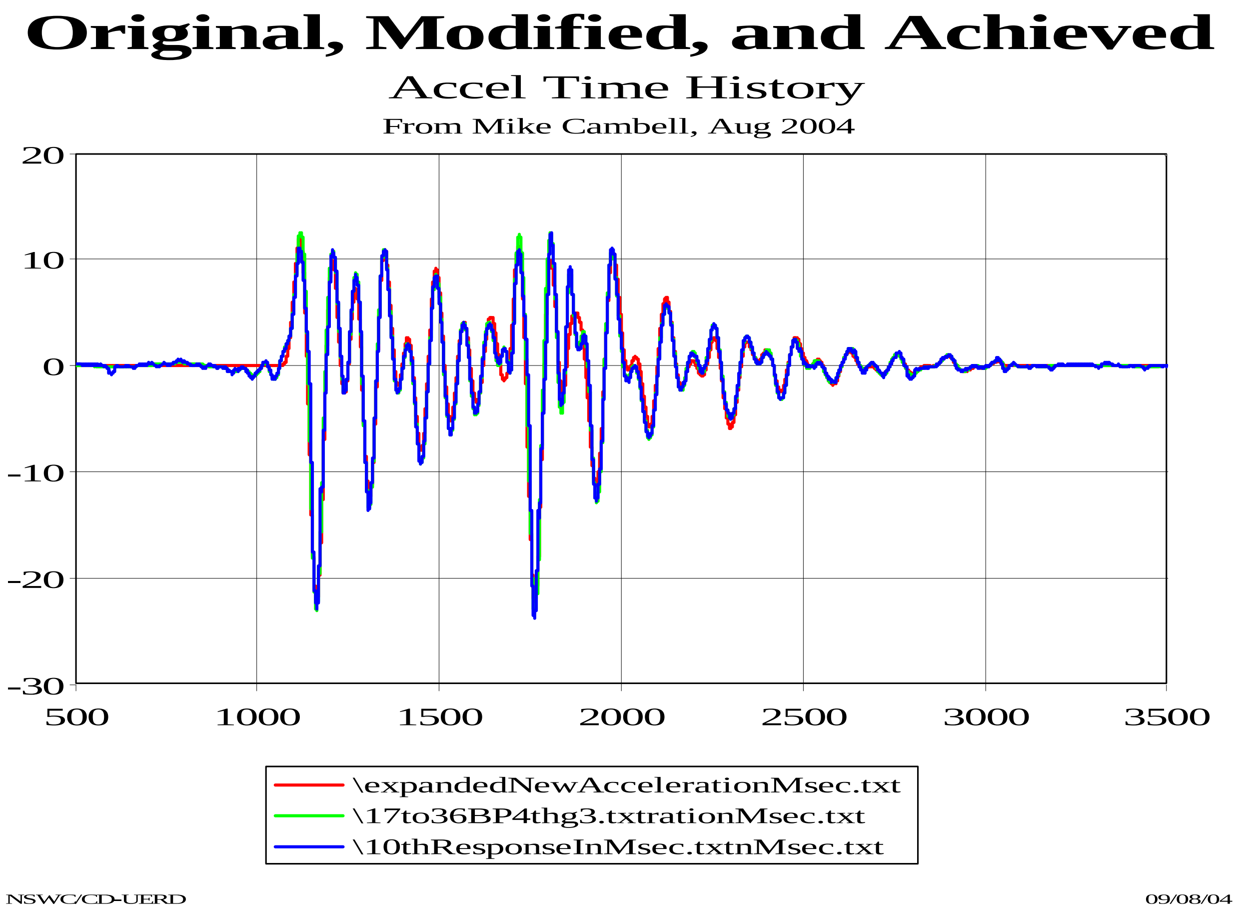

Figure 11. Acceleration Waveform of UERD Preferred, filtered, and SSTS response

Waveform from another Program

We were approached by another supplier to the Navy with a request to try their shock waveform on the demonstration SSTS. That waveform has essentially the same characteristics as the UERD preferred waveform. The waveform match by the SSTS and the PVS match are presented in Figures 12 and 13. The Targets are in Blue; the SSTS measured response is in Magenta. In this case we do not know the target PVS, so we can only show the match between the original waveform PVS and the SSTS response PVS.

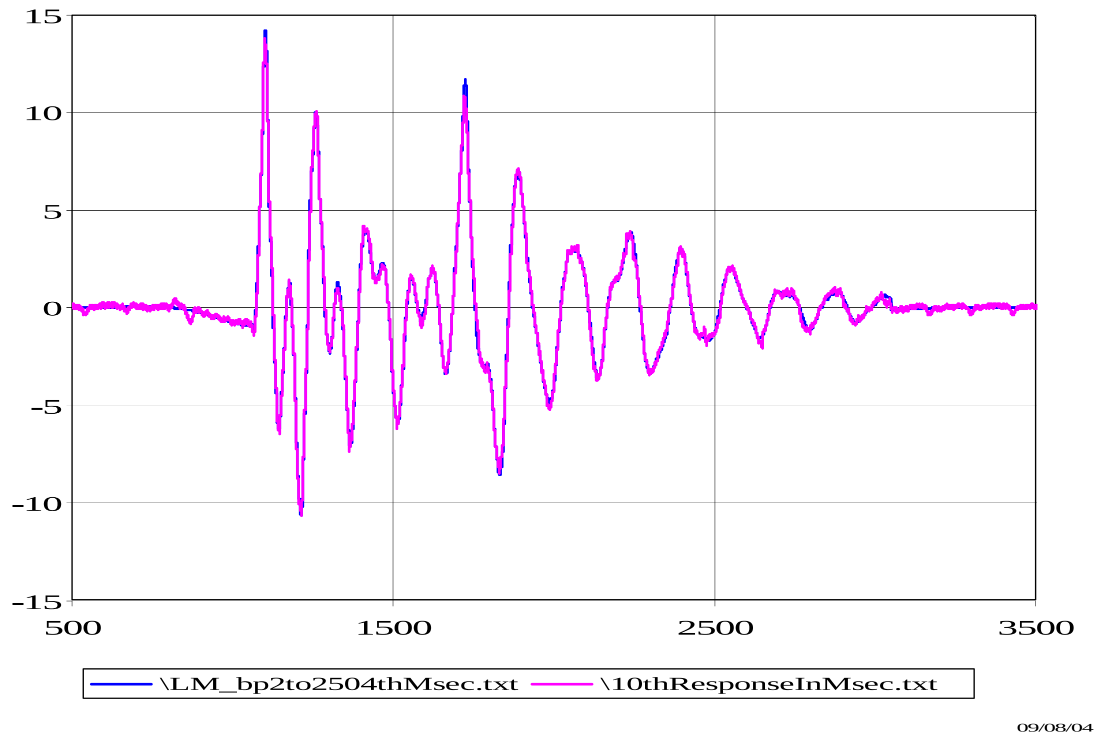

Figure 12. Acceleration waveforms target and SSTS response

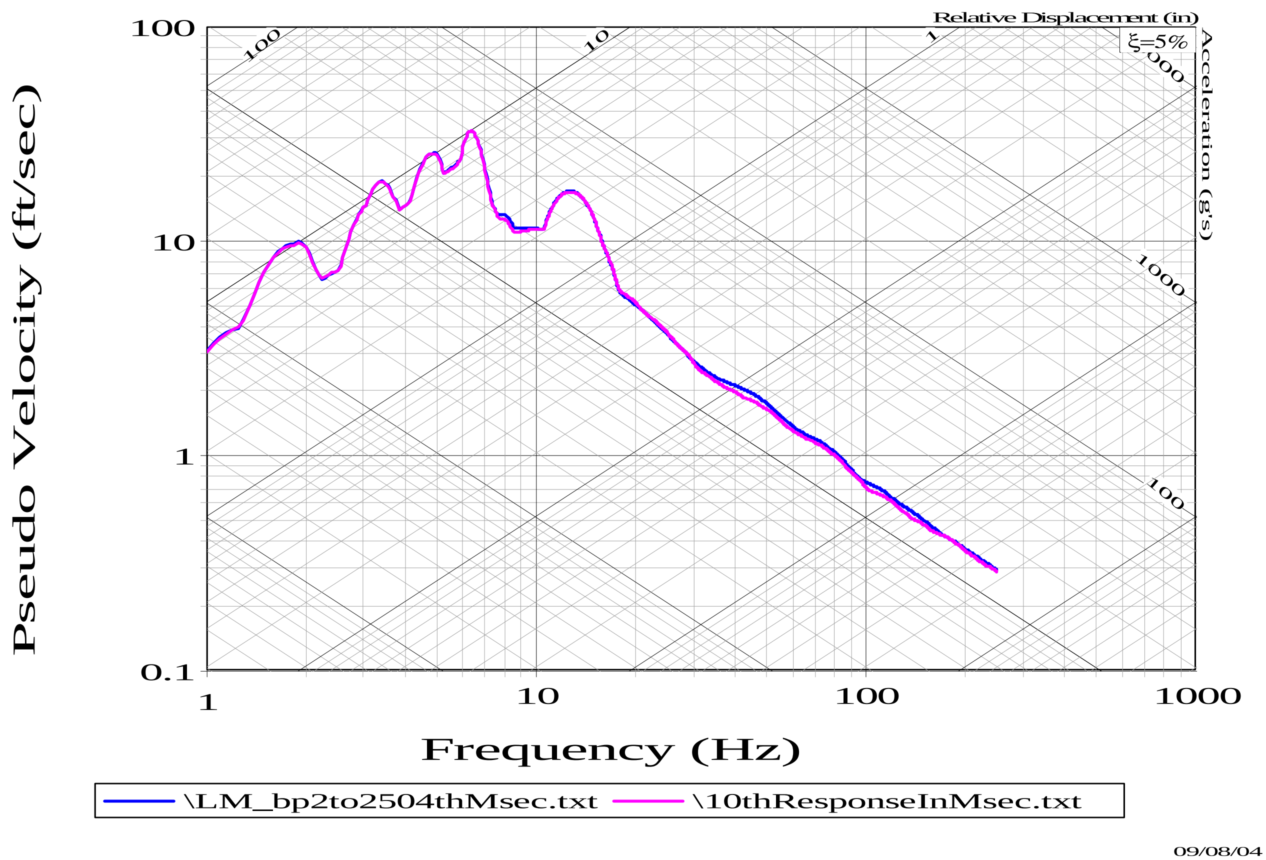

Figure 13. Pseudo Velocity of the target waveform and the SSTS response

Future work

This SSTS system solves the problem of doing type B and C subsidiary component and subassembly shock tests in the lab. The current system has a load limit of 600 lb. We expect that the same approach can be used for more powerful systems to allow testing of heavier loads to higher levels. We are exploring the possibility of increasing the load capacity, the velocity capability, and the stroke to meet more challenging test specifications.

One advantage of using the SRS or PVS to define a shock event is that it could allow different shock pulses to accomplish equivalent tests. That could allow use of longer shock pulses with lower acceleration, velocity and stroke requirements to achieve the desired test goals. The efficacy of this approach will require considerable investigation. Once that is accomplished, the size and cost of the SSTS systems may be reduced.

This approach may also be applicable to multi-axis shock test machines. Team's experience and expertise in designing high performance multi-axis vibration systems predicts that such a multi-axis shock test system is possible. Hydrostatic spherical couplings, hydrostatic pad bearings, and other stock components can make such a system quite successful.

Conclusion

Team Corporation's SSTS produces fine Class II type B and C subsidiary component and subassembly shock tests and gives the user control of the shock waveform and resulting pseudo velocity. The flexibility provided by the HDRS control software ensures the appropriate spectral distribution of energy and maintains the transient time history characteristic of the actual event. The use of Team's HDRS control software provides other advantages as well. Tests can be run rapidly, in succession. Different products, similar in dynamic characteristics, can be tested to the same drive file without the need for the iteration step. This results in considerable timesavings. Different products can easily be tested to different specs with minimal time spent adapting the SSTS to the new set of criteria.

The robust nature of the hardware components has been proven through 1000s of hours of use in the commercial testing market. The components used in the SSTS have been Team Corporation standard products for 3 decades. By using hydrostatic technology throughout the system for all bearing surfaces, dynamic characteristics are improved and mechanical wear essentially eliminated. Proven components provide predictable behavior and hydrostatic bearing technology reduces maintenance requirements, resulting in definable, long-term performance.

The close correlation between predicted behavior and the actual performance of Team's prototype system offers considerable confidence that modeling parameters in HydraSim are accurate. While further investigation is required to define a system with higher payload capacity, the validated modeling tools are in place that will ensure predictable performance.