

Subsidiary Component

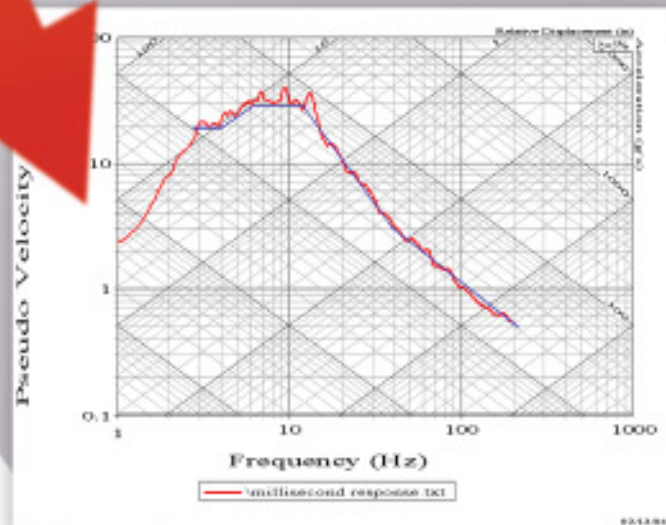
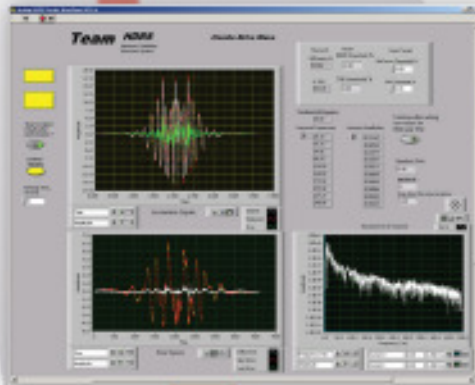
Vibration Test Systems

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Shipboard Environments place extreme demands upon Commercial-Off-The-Shelf components.

The use of Commercial-Off-The-Shelf (COTS) components in US naval vessels has introduced many challenges to suppliers. Developed for typical industrial application, COTS equipment must withstand the aggressive environments encountered during combat operations. Reproducing these environments in the test lab is the goal of the naval qualification community.

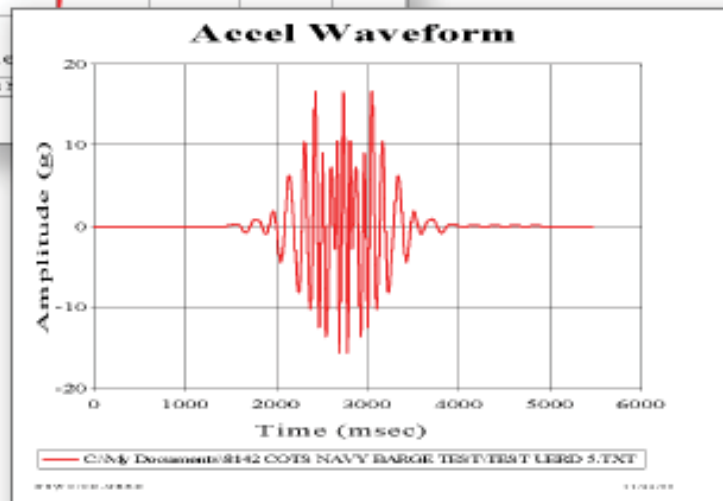
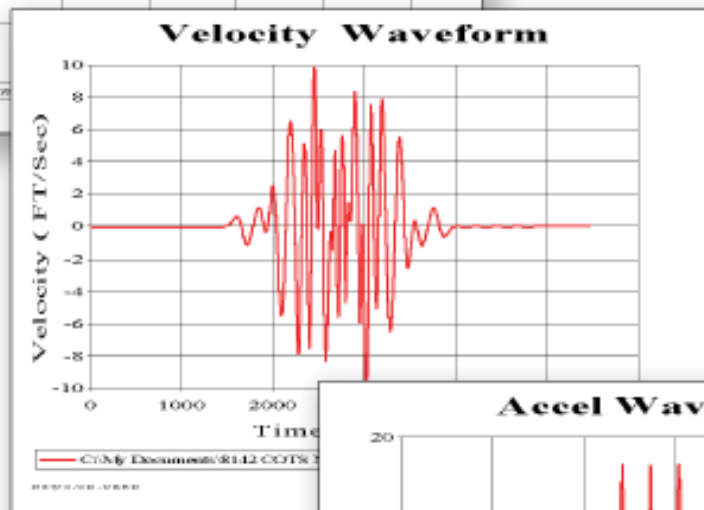
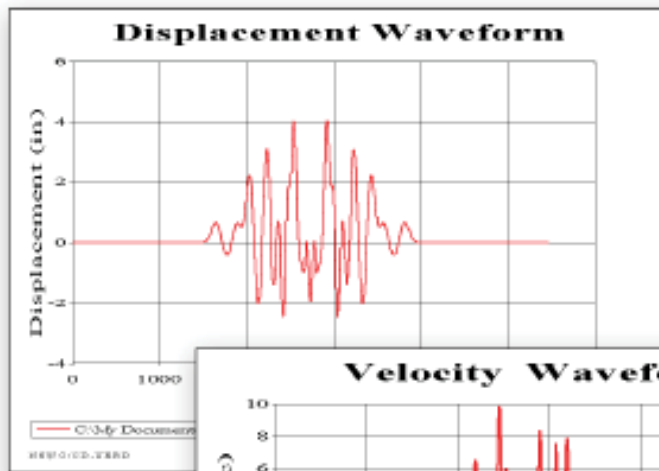
The extensive use of COTS equipment in critical military systems has created a need for greater agility in introducing changes and upgrades into previously qualified equipment. The rapid evolution of COTS technology results in more frequent insertion of new components and new technology into existing, qualified systems. The recent introduction of COTS equipment into naval combat systems has presented particularly difficult challenges.

The effects of near-field underwater explosions on naval combat vessels introduce a severe shock pulse on the vessel hull. MIL-S-901D shock qualification historically was only done for principal units, i.e., items that are installed on the ship. When there were changes in subsidiary components, or items installed within these principal units, the reconfigured principal unit had to undergo requalification. A new qualification approach for COTS based systems was desired, one that can reproduce an environment derived from the shock qualification of principal unit in the test lab. The goal has been the development of a laboratory test system that can reproduce the correct shock environment on subsidiary components repeatably and with minimal time spent in test preparation.

A typical acceleration time-history measured inside a principal unit mounted to the vessel hull through isolators has acceleration peaks between 15 and 20-g's with frequency content up to 250 Hz. When analyzed for displacement and velocity transients, 20 inch peak-to-peak displacements are found and velocity transients of perhaps 15 feet per second occur. NAVSEA Underwater Explosion Research and Development (UERD) has determined that the spectra of the measured environment below $\frac{1}{2}$ of the isolator frequency can be filtered without affecting the damage potential of the waveform. This effectively reduces

the peak accelerations while still maintaining the appropriate shock response spectra. With the reduction in acceleration peaks, a similar reduction in displacement and velocity occurs, namely reducing the peak-to-peak displacements to a more manageable 10 inches and velocity transients to perhaps 10 feet per second. These modified parameters fall well within the capacity of *Team* Corporation HydraShaker systems under production for a number of years.

Team Corporation has demonstrated the ability to recreate the measured environment produced by MIL-S-901D performed on an isolated principal unit. With the cooperation of UERD, *Team* has repeatedly performed a number of tests that satisfy the criteria established by NAVSEA O5P. *Team's* Subsidiary Shock Test System (SSTS) has conclusively shown the ability to reproduce the entire acceleration time-history resulting from the detonation of the test charge. This includes the initial shock pulse from the detonation and the "bubble pulse" that follows in approximately 650 msec. The SSTS has also shown the capability to reproduce the decaying sinusoid that is sometimes measured in the frequency band centered around 60 Hz. A typical measured shock environment has significant energy content extending from about half the isolation frequency of the principal unit through 250 Hz. This broad frequency band has been demonstrated to be well within the capabilities of the *Team* SSTS. Another outstanding feature of the *Team* SSTS is the ease with which new, or modified, acceleration time histories can be implemented. Test results are output in UERD-Tools, a software program developed by UERD that has become the standard for data review and analysis.



Typical parameters of the environment inside a principal unit measured during a MIL S-901D barge test. Raw data has been filtered to remove the excitation below 1/2 the isolator frequency.

The Creation of High Performance Test Systems capable of Reproducing Severe Environments is the Primary Focus of *Team* Corporation

High Performance servohydraulic test systems are a specialty of *Team* Corporation. Utilizing proprietary servovalve technology as well as hydrostatic bearings, *Team* produces very long stroke linear actuators capable of extremely high velocity transients and extended frequency response.

Team Corporation's focus for the last 50 years has been the development and refinement of servohydraulic actuators, high frequency, high flow servovalves and the ancillary equipment needed to complete a functional and robust test system. The unique conditions encountered in naval combat systems require test hardware with a combination of long stroke, high force, high velocity and a broad frequency band. These requirements have been amply demonstrated as typical characteristics of a *Team* HydraShaker system.

Test Controller

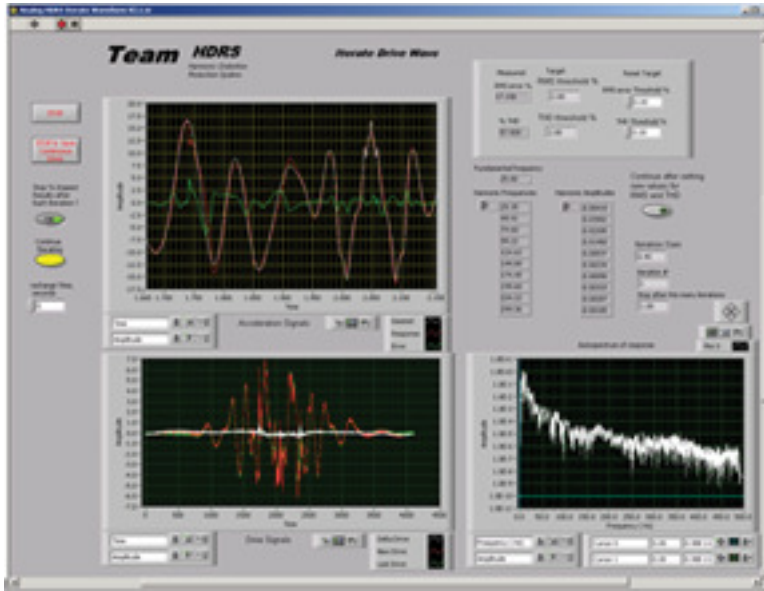
The most important piece of any linear vibration test system is the operator interface, or test controller. The operator interface included with the SSTS is a proprietary system, written in LabView that was developed specifically by *Team* Corporation to optimize the performance of a servohydraulic test system in reproducing a discrete waveform. Other test controllers are based on the essentially linear behavior of electrodynamic shakers; servohydraulic exciters are inherently non-linear due to a phenomena called "oil column resonance". The result of using these linear test controllers with a servohydraulic shaker to reproduce a shock profile is less than ideal performance.

Team Corporation's Harmonic Distortion Reduction Software (HDRS) can accept a drive file, or the desired acceleration time-history, written in a variety of formats, including an Excel table, ASCII,

MatLab, etc. the software package then iterates the waveform to reduce the rms error level. This iteration process is operator-controlled and consists of outputting the drive file at an operator-defined level, for example -12 dB. HDRS uses the control accelerometer feedback to measure the actual response, applies a correction factor and the process is repeated. In practice, this iteration process produces an acceptable response (less than 15% rms error) after 6 or 8 iterations, requiring about 30 minutes of test preparation time. The operator has the option to continue iterations until an even more precise match to the desired profile is reached, or can terminate the iteration process if the first couple of iterations are acceptable.

Once the drive file is iterated in, it can be saved and used again without repeating the iteration process. This assumes the dynamics of the test object remains roughly equal from one test to another. For example, if a principal unit is characterized in a barge test, then the same drive file can be used to test the suitability of a variety of subsidiary components of roughly the same dimensions and weight, i.e. screening a selection of servers prior to insertion into the principal unit. Once a family of drive files are developed for differing test loads, it is quite reasonable to expect the iteration process could be virtually eliminated.

The output from HDRS is read by UERD's software called UERDTools. This software has a variety of sub-routines for presenting the data. Typically, UERD and NAVSEA O5P evaluate test data by reviewing the Pseudo Velocity Shock



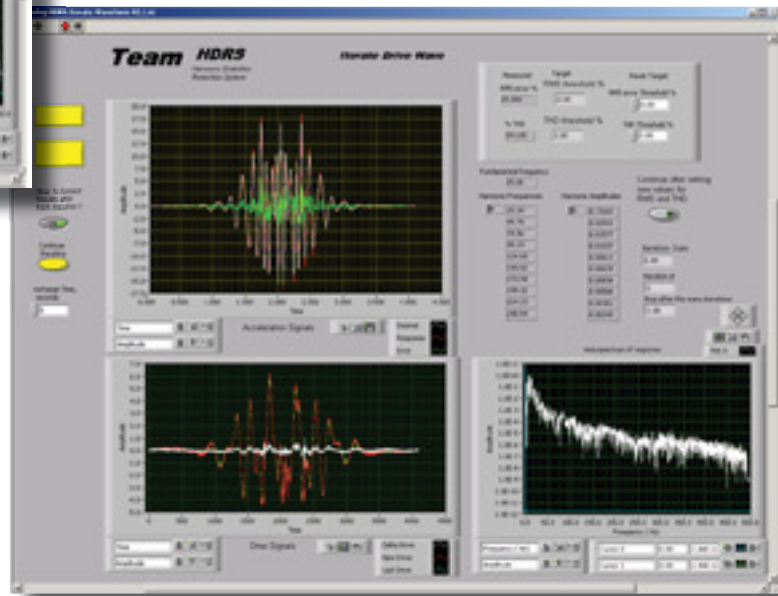
Screen shots of Team's HDRS test controller software. This screen is used for the iteration process with the error between the desired response and the actual response shown in the upper right quadrant.

Response Spectra. Team's HDRS can seamlessly upload the actual response data into UERDTools and then display the data in the format most familiar to evaluating organizations.

HydraShaker

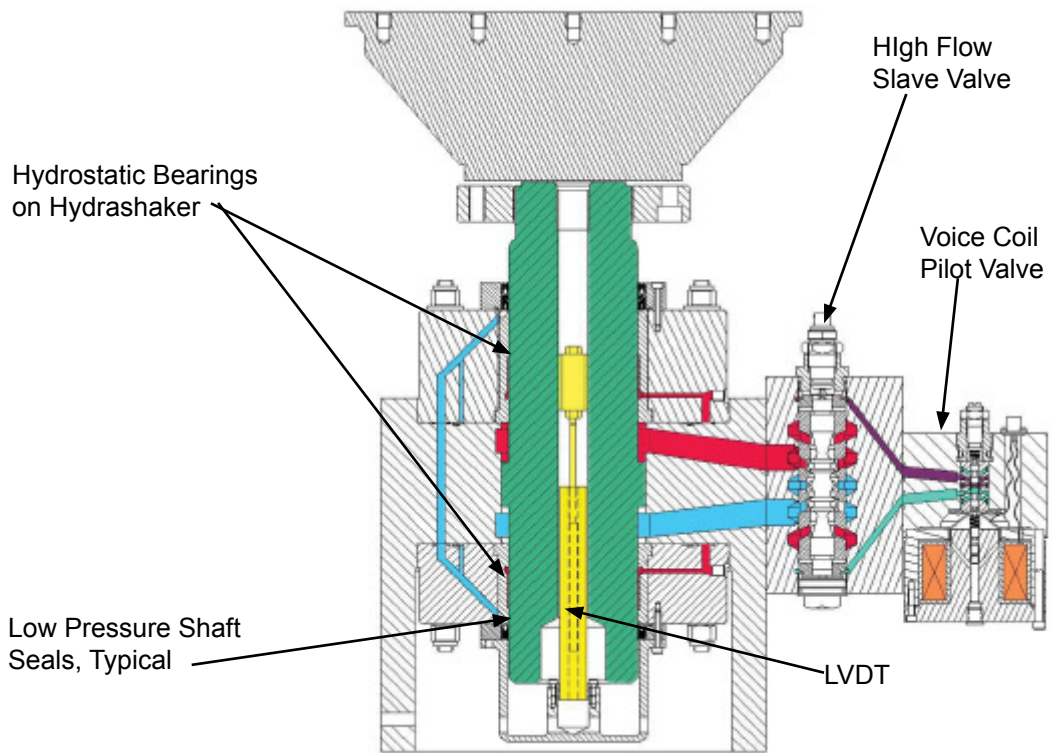
Stiffness is of utmost importance in a vibration exciter; dynamic response of the actuator itself during testing can compromise test results or even result in damage to system components. The HydraShaker was designed from the outset to be both mechanically and hydraulically stiff. This is achieved through the use of an extremely massive body, manufactured from a single billet of steel, with substantial cross-sectional dimensions to minimize deflection and resonance. The piston, or moving element in the actuator, is manufactured from a single piece of high strength steel, with an oversized rod diameter for increased bending moment capacity. Hydraulic stiffness is achieved through minimizing the trapped volume of oil between the servovalve and the piston.

The double ended design of the HydraShaker fully supports the piston with hydrostatic bearings on both ends of the rod as well as the circumference of the piston. Hydrostatic bearings are universally accepted as the optimum choice in vibration testing. Utilizing a thin film of pressurized oil to support adjacent surfaces, friction is eliminated since no metal-to-metal contact exists. Without friction, wear is virtually negligible. The stiffness of a hydrostatic bearing is a function of the volume of oil making up the separating film.



The volume of oil in Team Corporation's hydrostatic bearing design is extremely small, with an attendant increase in bearing stiffness. For example, a typical HydraShaker rod bearing can react dynamic loading that exceeds 1,000,000 in-lbs. applied radially. This design feature has the additional benefit of eliminating any high pressure dynamic seals, the most common source of periodic maintenance. To complete the design, the HydraShaker is fitted with a concentric LVDT (linear variable displacement transformer) to provide very accurate position feedback to the system controller.

The displacement transients in the acceleration time histories that have proven acceptable by UERD and O5P are generally less than 12 inches peak-to-peak. This stroke length matches a standard HydraShaker design proven in similar test systems Team Corporation has produced for a number of years. With this stroke length, it is possible to reproduce the measured environment within a principal unit as well as perform more typical swept sine excitation to 500 Hz, as demonstrated by our Bellcore test systems, produced for the telecommunications industry.

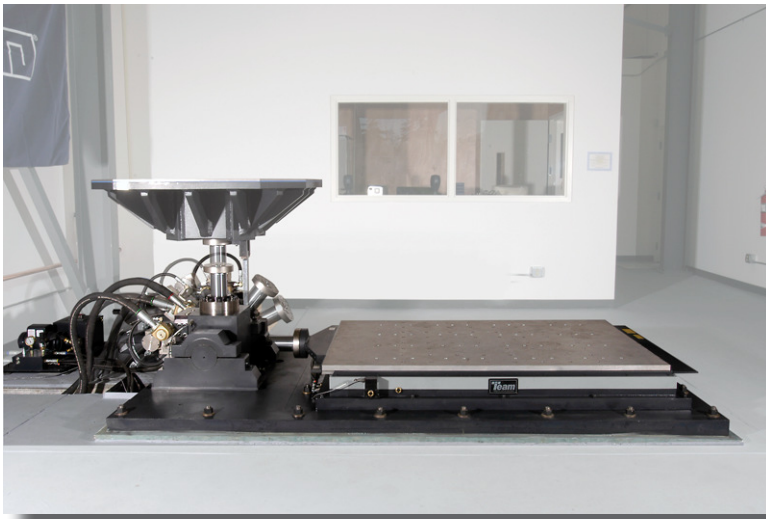


Arrangement of a typical HydraShaker, showing the internal construction of the Voice Coil Pilot Valve, the Slave Valve, and the HydraShaker piston with hydrostatic rod and piston seals,

Servovalve

The key to high frequency response in a servohydraulic vibration system is the ability to control the needed volume of pressurized hydraulic oil to and from the HydraShaker piston. This ability is governed by fluid dynamics and frequency response of the fluid control valve, or servovalve. *Team* Corporation designs and manufactures the highest performing servovalves in the world, specifically optimized for vibration test system conditions.

A typical servovalve assembly mounted directly to the HydraShaker is composed of two separate valves, the Voice Coil Pilot Valve and the Slave Valve. The Voice Coil Pilot Valve accepts the low level drive signal from the test controller and converts it to a proportional valve spool movement. This results in a proportional flow of hydraulic fluid. The Voice Coil Pilot Valve has a very small spool with low mass and inertia, driven directly by a high power voice coil. Providing a very responsive system with wide dynamic range, the Voice Coil Pilot Valve is able to resolve small differences in drive voltage into correspondingly small differences in spool movement. This high resolution provides the sensitivity to achieve superior test results. For example, the V-20 Voice Coil Pilot Valve can provide full flow to over 600 Hz, rolling off as a second order system but continuing to provide useable, controllable flow to 2 kHz.



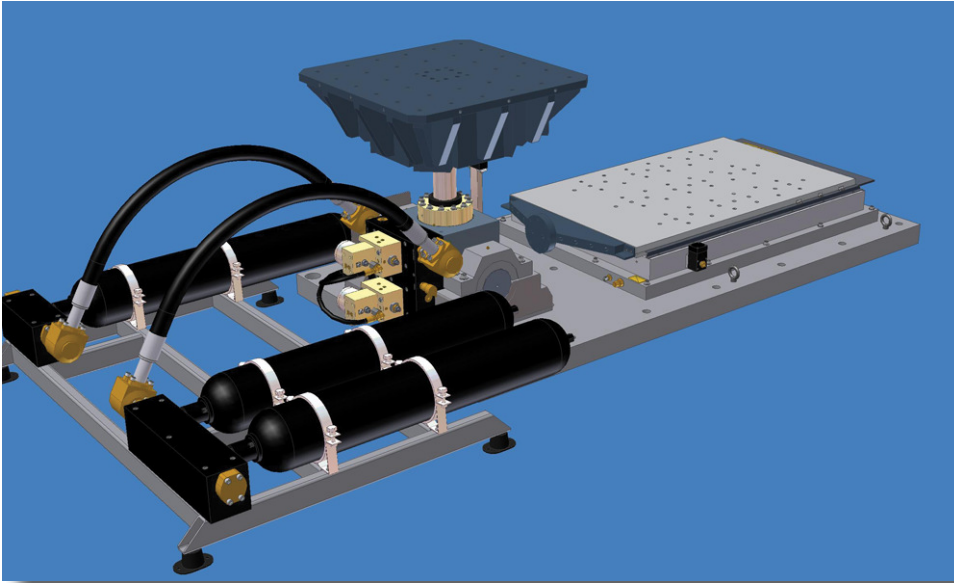
Time-lapse photograph showing the ease with which the HydraShaker can be repositioned from horizontal to vertical.

An example of a large cabinet being installed on Team's SSTS, prior to testing in the vertical direction.

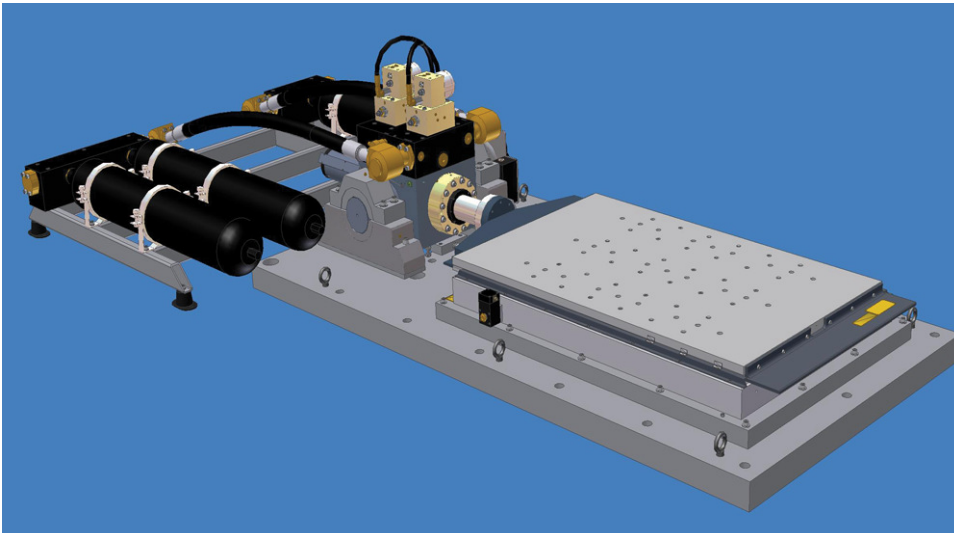


The flow from the Voice Coil Pilot Valve is used to control the Slave Valve. A Slave Valve has a much larger spool with a correspondingly high flow capacity. The Slave Valve controls the hydraulic flow entering and leaving the HydraShaker annulus. With a larger spool and greater inertia, the Slave Valve cannot match the superlative performance of the Voice Coil Pilot Valve; however *Team* Corporation Servovalves have a flow versus frequency that is several times higher than any competing valve. The flow requirements of the SSTS are on the order of 375 gallons per minute to meet the high velocity transients. This is achieved by using a pair of *Team* V-750 Slave Valves operating in tandem on a single HydraShaker.

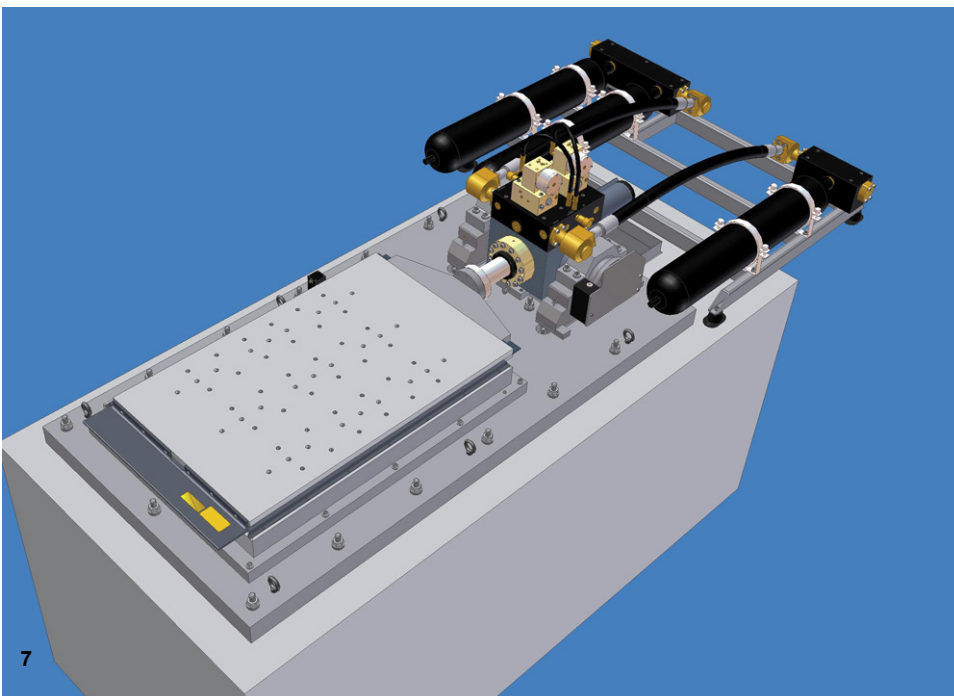
T-Film® Slip Table



The high acceleration levels developed during the reproduction of these acceleration time-histories generate very high moments, particularly when considering the dynamic response of the principal unit. Reacting these moments requires an extremely stiff, robust horizontal table system. A simple oil film table is inadequate for the job and while hydrostatic journal bearing tables have better moment capacity, the availability of 10 to 12 inch stroke journal bearing tables is very limited. *Team* Corporation developed the T-Film® Slip Table to address the deficiencies of other horizontal table designs, with the added benefit of long stroke.



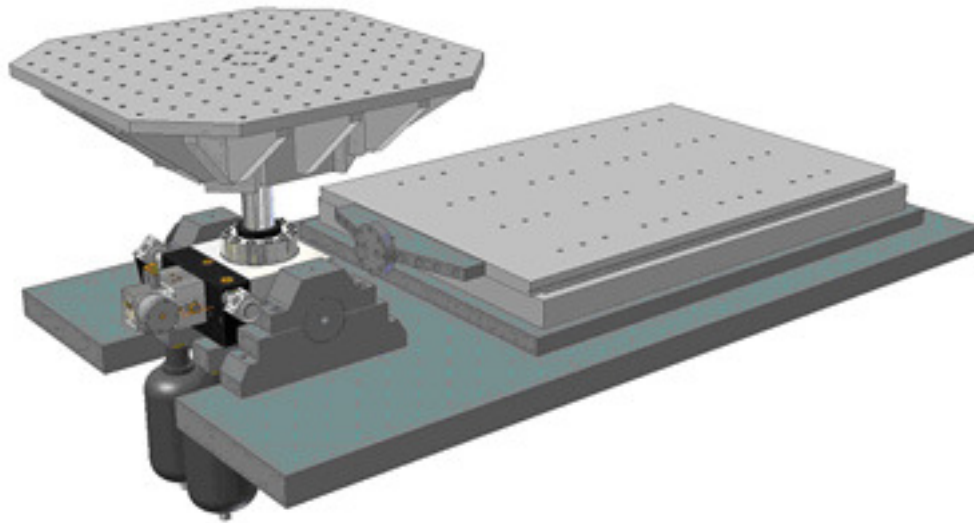
The T-Film® Slip Table uses an array of linear hydrostatic bearings to fully support and guide the slip plate. This provides an extraordinary degree of stiffness in all degrees of freedom other than the line of motion. The design of a T-Film® Slip Table also results in an oil film area about 25% larger than the slip plate, improving stiffness, damping and cross-axis motion control. The oil supply to the T-Film® Slip Table is only 600 psi, reducing heat generation, cost and eliminating any high pressure oil seals. Finally, all oil porting to the bearings is through the base plate, not through the slip plate. This provides considerable flexibility in the placement of threaded inserts for mounting payloads and eliminates any hoses leading to the slip plate from the hydraulic supply.



The T-Film® Slip Table selected for the SSTS has a 48 inch square magnesium slip plate and a total stroke of 12 inches. Four longitudinal rows of bearing elements provide overturning moment capacity of roughly 1.0×10^6 lbs.-in. This capacity permits testing a variety of principal units; including those with a center of gravity located over 60 inches above the table surface.

Vertical Specimen Mount Table

To accomplish testing in the vertical orientation, the HydraShaker is rotated and a specimen mount table is bolted to the rod end through the use of a unique, pre-loaded union. This pre-loaded connection is designed to eliminate backlash, ensuring high transmissibility of force without



Drawing of Team's SSTS illustrating the trunnion mounted HydraShaker, T-Film Slip Table and Vertical Head Expander. All components are mounted on a steel slab to facilitate installation on the reaction mass.

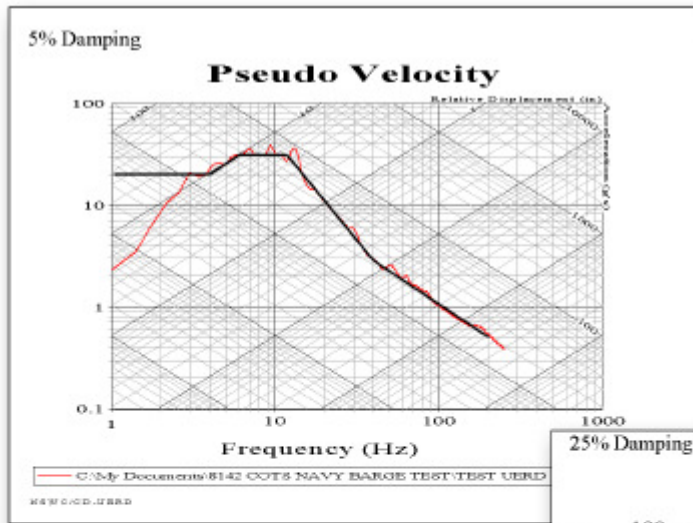
introducing spurious noise to test results. *Team* Corporation's Vertical Tables are designed with very high stiffness and well-damped dynamic behavior to improve the ability to perform severe testing profiles. The large bending moment capacity of the HydraShaker allows testing of a heavy payload without the need for any additional moment support. The Vertical Table used on the SSTS is a magnesium weldment with constrained layer damping, 48 inches square.

Hydraulic Power Supply (HPS)

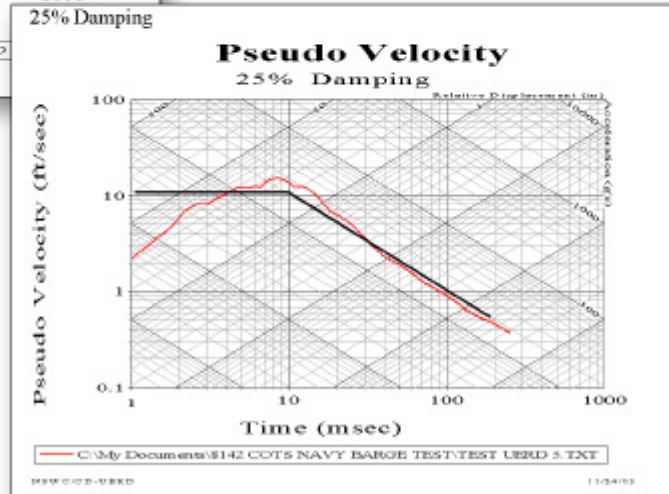
Every servohydraulic linear vibration system requires a continuous supply of clean, conditioned hydraulic oil at the proper temperature and pressure. Oil condition is critical for trouble-free operation. Servovalves and hydrostatic bearings have very tight mechanical tolerances and any contaminants in the oil supply can cause parts to malfunction. Hydraulic oil viscosity varies as a function of temperature; proper viscosity is essential to ensure predictable system behavior. Maintaining the required flow of pressurized hydraulic fluid is essential to achieving maximum system performance in velocity and force. *Team* Corporation is skilled in the design and manufacture of the required HPS to ensure long-term, trouble-free system performance.

The discrete acceleration time-history generated by MIL-S-901D does not require a continuous flow, but rather peak flows to reach occasional high velocity transients. In this case, it is more economical to provide a lower constant flow rate coupled with a stored volume of pressurized hydraulic fluid in an accumulator. *Team* Corporation uses a proprietary modeling program, called HydroSim, to calculate the best combination of continuous versus stored oil supply. The HPS selected for the SSTS is *Team's* HPS-110, with 29 gallons per minute flow rate at 3,000 psi. This flow rate can easily recharge the 15 gallon accumulators in a few seconds, allowing the repetition of the test very quickly. This flow rate will also permit a continuous sinusoidal excitation with 15 inches per second velocity. An advantage of *Team* Corporation's approach to providing the solution for reproducing the desired waveform is our ability to tailor the entire system to satisfy the test criteria, not merely selecting a system from a limited variety of sizes.

Many test facilities have an existing hydraulic power supply available for use. In this case, *Team* Corporation provides a Hydraulic Conditioning Manifold (HCM) to interface with the existing oil supply. The HCM provides the required filtration, pressure control and safety interlocks to ensure high performance and safe oper-



Example of actual test results, displayed in UERDTools, showing the match between the desired Pseudo Velocity Shock Response and that actually achieved. Note the excellent match between the 5% and 25% damping levels.



ation of the *Team*-supplied equipment. Regardless of which type of installation is best suited for customer needs, *Team* Corporation has remote control units located at the test engineer’s station to allow convenient operation and monitoring of HPS and HCM status.

Reaction Mass

Correctly designed and executed, the reaction mass will ensure the majority of the force produced by the exciter will be used to accelerate the test object and the surrounding environment will be protected from an unacceptable level of excitation. All vibration test systems require an inertial mass for excitation of a payload. The inertial, or reaction, mass is often discounted in system design,

considered simply something to “push against”. However, a poorly conceived reaction mass can have dynamic response that makes it impossible to achieve test objectives.

For the SSTS, *Team* Corporation provides the design drawings and a component kit for a competent local contractor to pour in place an isolated reinforced concrete mass embedded in the laboratory floor. The active system hardware is mounted by *Team* technicians to the concrete monolith, grouted in place to ensure uniform contact and pre-loaded through the use of embedded threaded rods. This reaction mass design has been successfully used in a variety of applications with systems having similar stroke lengths and payloads.

Team Corporation's Service and Support Group Ensures Test System Availability

Testing programs can be severely affected by downtime due to system maintenance or repair. *Team* Corporation provides the customer with unmatched reliability. In the event of a breakdown, *Team's* dedicated service engineers are able to provide effective support in a timely and cost effective manner.

Team Corporation's Service and Support Group ensures test system availability

Testing programs can be severely impacted by downtime due to system maintenance or repair. Friction-free hydrostatic bearings require no periodic mechanical adjustment, which provides the test lab with unmatched reliability. In the event of a breakdown, *Team's* dedicated service engineers are able to provide effective support in a timely and cost effective manner.

First and foremost, *Team* Corporation offers annual maintenance contracts to ensure a consistent level of system availability. In the event of unanticipated service requirements, *Team* can dispatch service engineers to provide more extensive maintenance as needed. To augment our customer support function, fully capable service is available locally at select sites.

The only regular maintenance consists of hydraulic filter element replacement. *Team* has established a policy to provide filter element model numbers as defined by the filter manufacturer, allowing the customer to procure these items locally. Of course, *Team* also maintains an inventory of these items to ensure continual availability for the customer's convenience.

Tell Team Corporation Your Needs

Personal and confidential service is the cornerstone of *Team* Corporation's commitment to systems excellence. Contact *Team* Corporation directly to see if one of our standard designs is right for your application.

Your system needs will be reviewed by our staff of engineering experts. With over 35 years of experience dealing with multi-axis test system solutions, *Team* brings a wealth of knowledge to the discussion, suggesting alternative design options to maximize your system capabilities. Let *Team* become your partner in system solutions.



Team servo valve spool and sleeve assemblies.



L to R: Bill Woyski, VP of Research & Development; Doug Lund, VP of Engineering; Bob Tauscher, CEO; Bruce Huntley, General Manager.



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