Team

Vibration Testing Equipment

Bearings & Couplings

For Vibration Test Systems

Systems & Solutions

Engineered vibration testing solutions for improved product quality.

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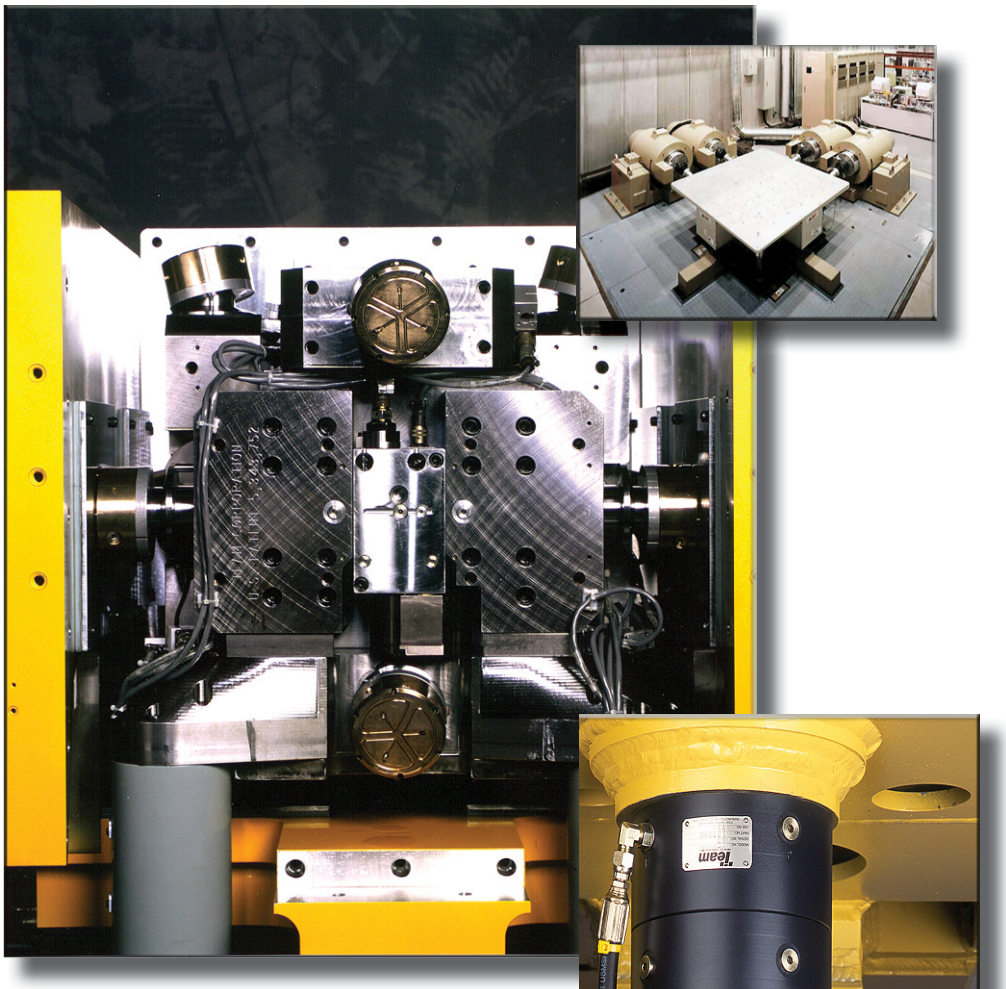
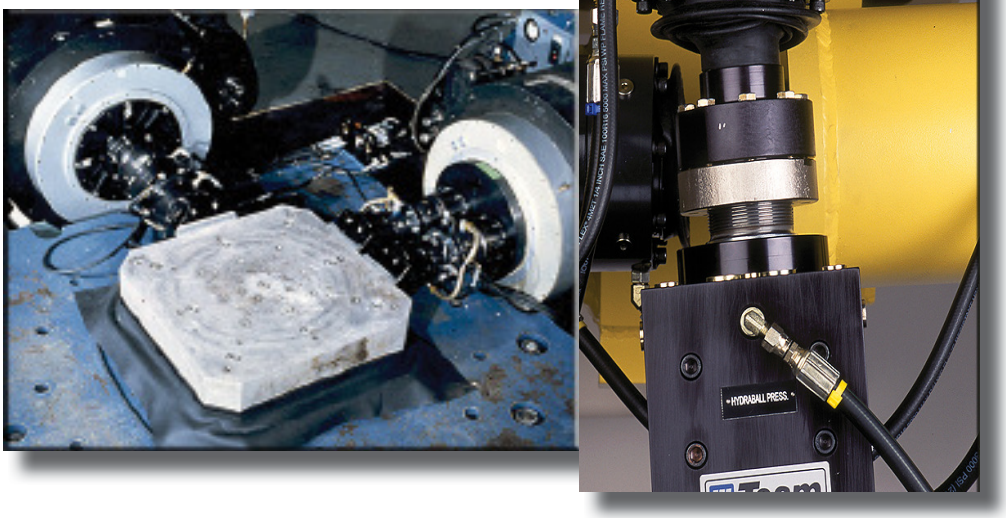


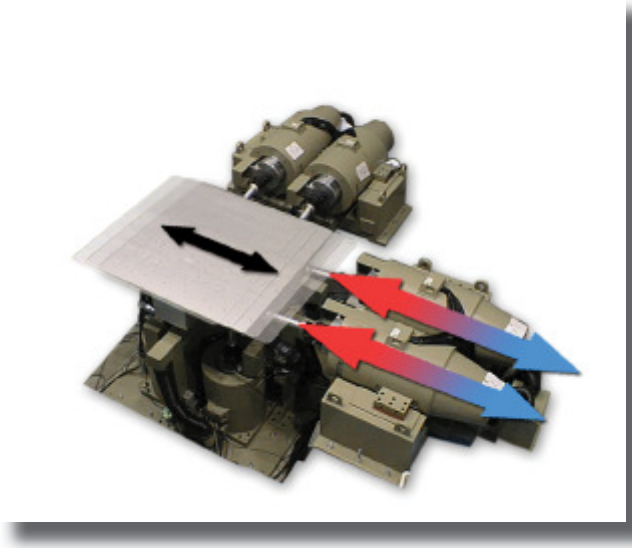


Team Corporation is a Leader in Multi-Shaker/Multi-Axis Systems Incorporating Hydrostatic Bearing Technology

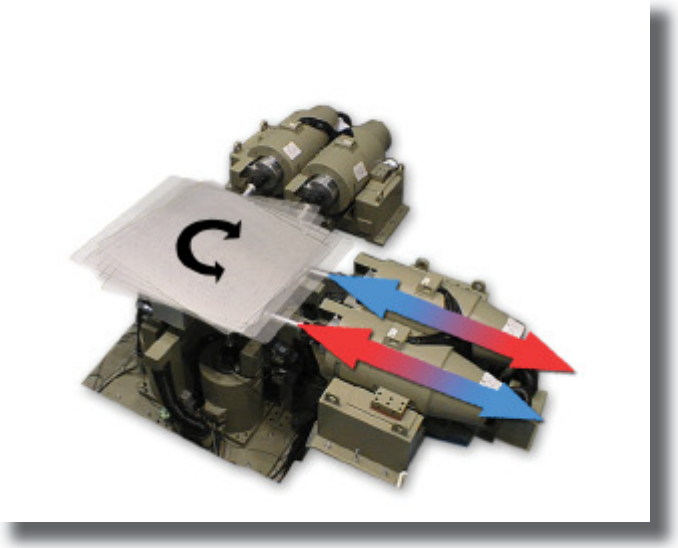
One of the challenging design issues for creating high-performance test systems using multiple exciters is producing the desired motion while restraining all others. *Team* Corporation has engineered a wide variety of system solutions resolving the needed degrees of freedom with the appropriate degrees of restraint.

Vibration testing has proven to be a critical step in the successful development of robust products. Traditionally, vibration tests have been conducted by sequentially applying uni-axial excitation to test articles along three orthogonal axes, using a linear shaker and rotating the test load after each test. Although the vast majority of uni-axial vibration testing uses a single vibration exciter, some conditions exist where a single shaker is not appropriate for the task at hand.

Using more than one exciter to provide input force in a single direction is known as Multiple Exciter, Single Axis (MESA). Two considerations are critical for a successful MESA design: one, how to accommodate angular deflection due to table dynamics or if the shakers go out of phase and two, how to control cross-axis motions. Not accommodating angular deflection can result in very large moments being applied to the test object and/or shaker. Generating pure linear motion in a single direction means effectively constraining unwanted cross-axis motions. Similar challenges must be faced when the goal is a test system capable of simultaneous motions in several directions.



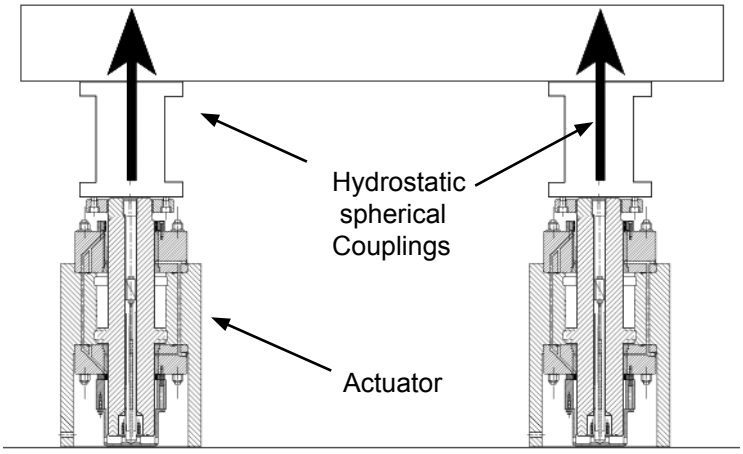
Shakers IN-PHASE create translations.



Shakers OUT-OF-PHASE create rotations.

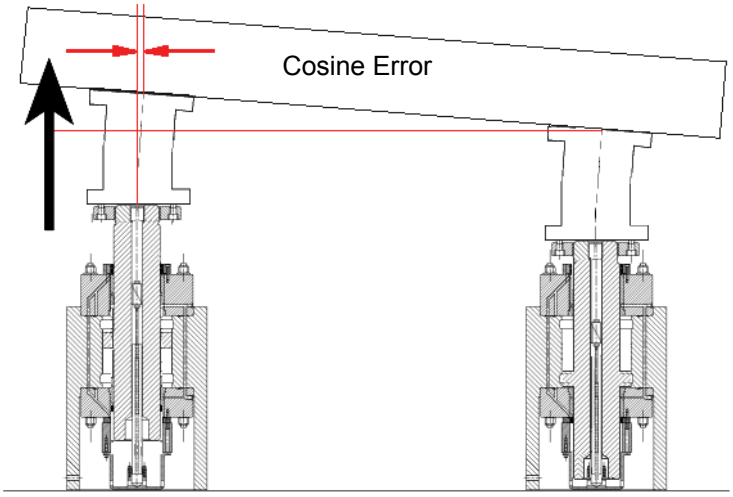
In any multiple degree of freedom vibration system it requires a pair of actuators to generate both a translation (a linear movement along one of the three axes of motion) and a rotation. Six Degrees of Freedom (6 DoF) requires three pairs of actuators, each pair associated with one of the three axes X, Y and Z. In-phase they produce a translation; out-of-phase they produce a rotation.

These three figures illustrate several of the conditions that can occur when using more than one exciter to provide input force in a single direction. Hydrostatic spherical couplings eliminate damage to either the actuators or the test object in the first two illustrations.



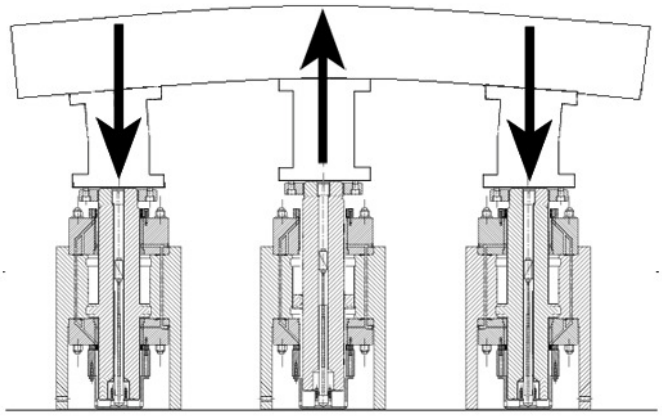
In-Phase

The first figure shows a pair of actuators attached to a beam. When operated in phase, no bending moments are translated to the exciters and relative distance between the attachment points remains constant.



Out-Of-Phase

When the same pair of actuators is operated out of phase two things occur. One, if the beam is not allowed to pivot with respect to the centerline of the actuator, bending moments will be applied to the actuator shaft. Two, a foreshortening of the distance between the attachment points occurs, often referred to as “Cosine Error”. Depending on the relative stiffness of the beam and the exciters, this can impose large lateral loads on the exciters. Application of single and/or double Hydrostatic Spherical Couplings can eliminate the first condition and compensate for the second.



Over-Constraint

The third figure illustrates over-constraint. Hydrostatic Spherical Couplings will prevent the actuators from being damaged in this example, but the test specimen (beam) will see bending moments due to the out-of-phase relationship between the actuators. Depending on the force applied and the strength of the specimen, damage can occur.

It has long been recognized that multi-axis testing provides a more realistic representation of actual field conditions. However, mechanical design challenges become increasingly difficult when simultaneous multi-axis motions are required. Termed Multiple Exciter, Multiple Axis (MEMA) systems, the complexity of the kinematics become the focal point of the mechanical design. Producing high fidelity, repeatable motions in more than one direction simultaneously has been the focus of much of *Team* Corporation´s research over three decades. A brief discussion of the kinematics defining multi-exciter multi-axis test systems will illustrate these challenges.

An object´s motion in space is completely defined by six degrees of freedom (6 DoF). A degree of freedom is simply a direction of motion, either a linear translation or an angular rotation. For a rigid body, there are three translations – lateral, longitudinal and vertical; and three rotations – pitch, roll and yaw. To accurately recreate real world motion, all 6 DoF must be controlled. The optimum number of exciters needed to reproduce 6 DoF is six; if more than 6 are used, the system will be over-constrained, if less than 6 are used, it will be impossible to produce the complete range of motion.

Over-constraint is a situation where more than one actuator has authority over a single degree of freedom. This is easily illustrated by the familiar knowledge that two points define a line. Assume each point represents the attachment of an exciter with a double pivot coupling to a beam (representing the line). By randomly cycling the two exciters in and out of phase, the beam will either translate vertically or rotate (pitch). In other words it will exhibit two degrees of freedom. Importantly, the beam will never be subjected to moments by the exciters. Now, add a third exciter to the beam. If all three exciters are allowed to randomly cycle, at some point one exciter will work against the other two, introducing moments into the beam and potentially causing damage. This is the condition of over-constraint.

The issue of over-constraint is exacerbated in a MEMA system, with the increased number of actuators, and consequently the number of degrees of freedom. An important aspect of *Team* designs for multi-exciter systems is the elimination of over-constraint.

After defining the fundamental arrangement of actuators to eliminate over-constraint, the next challenge is designing the connection device used to attach linear actuators to a rigid beam or table with multiple degrees of freedom. Consider again the illustration of two exciters attached to a rigid beam. As the actuators are cycled out of phase, a rotational connection is needed to accommodate both the angular and lateral misalignment of the beam relative to the axis of each actuator. The obvious solution is some type of spherical bearing providing the pivot. Hydrostatic Coupling Technology is the Basis of *Team* Corporation Multi-Exciter Test SystemsCorporation has developed a family of hydrostatic spherical bearings and couplings, proven to be ideally suited to the demands of high performance vibration test system.

A pair of HydraBalls attached to a 6 DoF MAST table. The HydraBall in the foreground connects an actuator directly to the table, providing vertical excitation with compensation for lateral and longitudinal translations, as well as for any rotation.

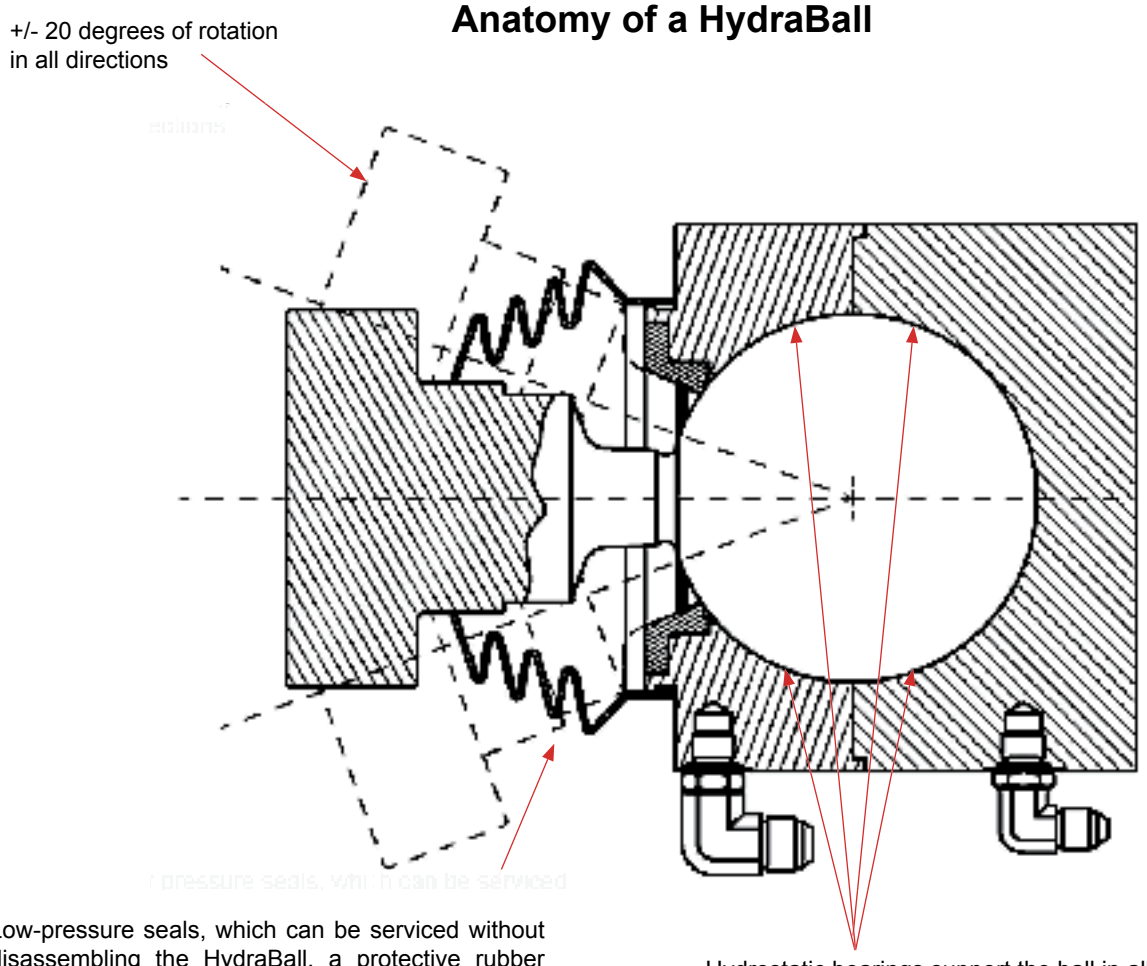
Hydrostatic Coupling Technology is the Basis of *Team* Corporation Multi-Exciter Test Systems

Hydrostatic bearings are well-accepted as the best choice for reacting and transmitting loads in high-frequency vibration test systems. *Team* Corporation has pioneered the use of hydrostatic bearing technology in multi-degree of freedom couplings, creating the world´s most capable multi-exciter test systems.

The ideal swivel or pivoting connection for a vibration test system has neither mechanical backlash nor friction. Backlash degrades transmission of force through the coupling; friction causes non-linear response to load and wear on adjacent surfaces. The elimination of backlash while simultaneously minimizing friction is very difficult to accomplish in conventional spherical couplings.

By design, these couplings have mechanical clearance that result in poor force transmissibility. To reduce mechanical clearances, a coupling is preloaded, which adds friction and hysteresis or “stick – slip” behavior. By carefully tuning the preload on mechanical couplings, generally acceptable performance can be achieved in systems operating below 50 Hz.

Anatomy of a HydraBall



Low-pressure seals, which can be serviced without disassembling the HydraBall, a protective rubber boot and negative drain pressure from system HCM virtually eliminate oil leaks.

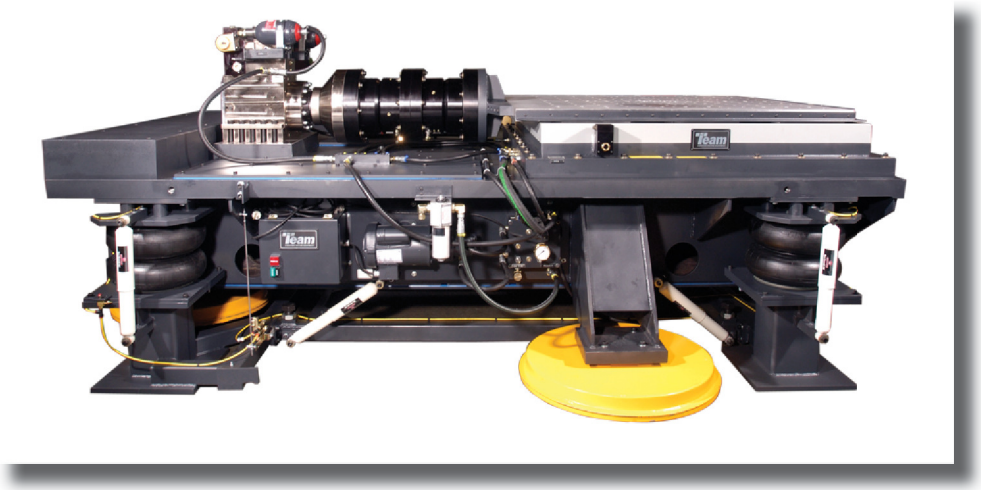
Hydrostatic bearings support the ball in all directions and offer zero backlash transmission of force.

Team Corporation produces a complete line of hydrostatic spherical couplings specifically designed to be the ideal connection for vibration exciters. With all articulating surfaces supported by a hydrostatic film, *Team* couplings have the highest possible transmissibility of force. The hydrostatic film also eliminates virtually all friction, minimizing wear and reducing maintenance. *Team* Corporation´s family of hydrostatic spherical couplings is available in a range of differing load capacities and in number of pivots. They have been applied in single axis, multi-axis and specialty test systems, supporting extremely massive payloads on a frictionless, hydrostatic film of pressurized oil.

One of the most versatile hydrostatic couplings produced by *Team* Corporation is called the HydraBall. Designed to be a direct replacement for spherical rod bearings used in a wide variety of low-frequency test equipment, the HydraBall provides all the benefits of hydrostatic coupling technology in a simple to apply and robust design. A standard HydraBall has a dynamic load capacity exceeding 10,000 lbs. yet weighs only 25 lbs. Essentially a “ball and socket” type of design, the HydraBall can deflect 20 degrees in any direction from the neutral position and still provide a direct load path from the test specimen to the actuator shaft.

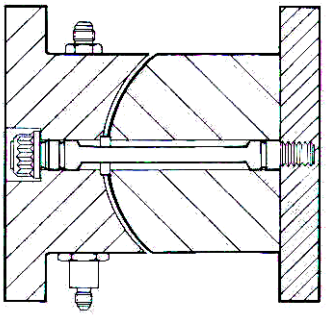
The outstanding features of the HydraBall provide a means to create multi-axis test systems with long stroke and high frequency capability. By separating two HydraBalls with a rigid, lightweight strut, very large orthogonal displacements can be accommodated with minimal interference from structural response.

For high force, high frequency multi-exciter systems with relatively short displacement, *Team* Corporation has designed a family of Hydrostatic Spherical Couplings that can carry upwards of 100,000 lbs of load. Termed the 420 Series, these high load couplings are available in single or double pivot designs with either +/- ½ degree or +/- 6 degree angular deflection. As with the HydraBall design, the 420 Series are fully supported on a hydrostatic film of pressurized oil separating all articulating surfaces. They are remarkably stiff in both compression and tension, are friction-free and provide a direct load path throughout the full range of deflection.

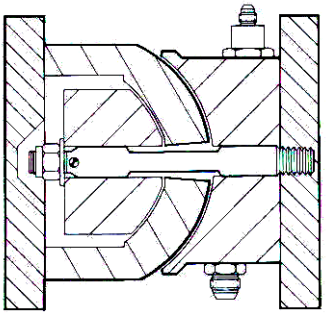


Dual 422.40 Hydrostatic Spherical Couplings connect the shaker to the slip table in this unique repositionable system used both horizontally and vertically (see application example bottom of page 14). The actuators are protected from load induced bending moments by the coupling pair.

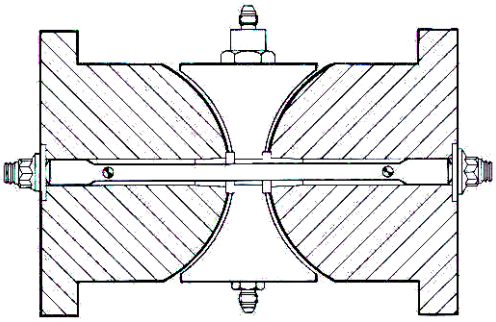
420.xx
Provides a single pivot with +/- 0.5 degrees of rotation which will allow for angular misalignment.



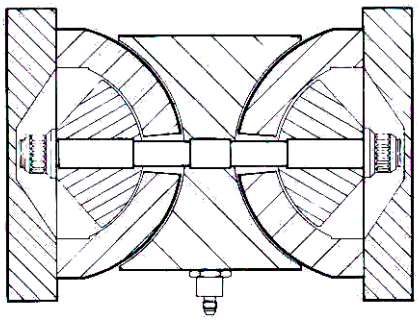
421.xx
Provides a single pivot with +/-6 degrees of rotation which will allow for angular misalignment



422.xx
Provides a double pivot allowing correction for angular and lateral misalignment. Angular capability is +/-0.5 degrees at each pivot.



423.xx
Provides a double pivot allowing correction for angular and lateral misalignment. Angular capability is +/- 6 degrees at each pivot.

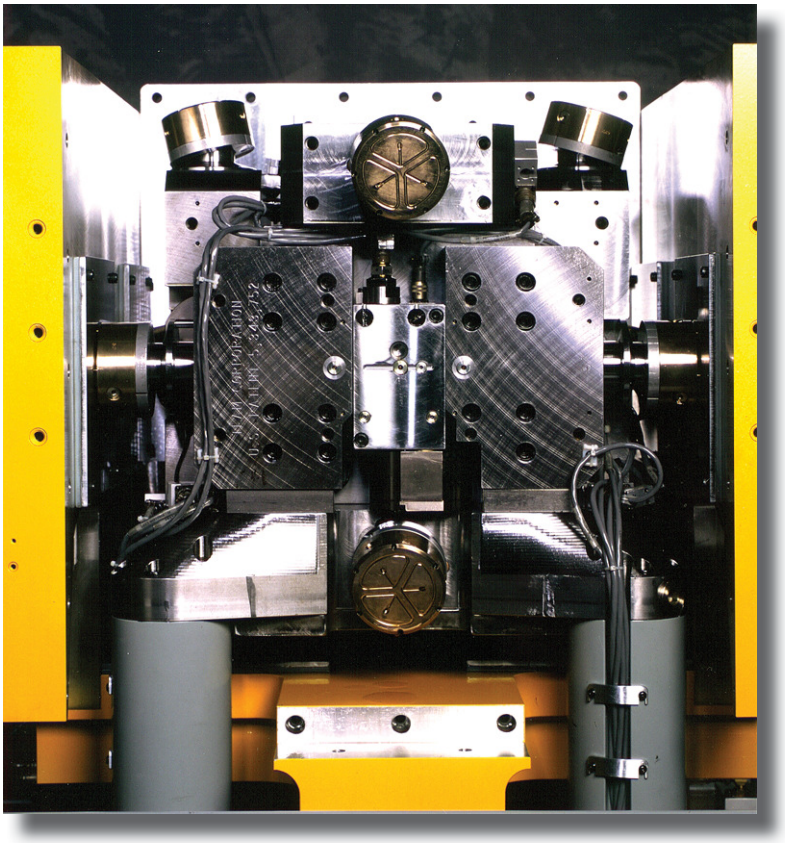


Team Corporation´s 420 Series Family of Hydrostatic Spherical Couplings

Restraining Off-Axis Motions without Adding Moving Mass has been Solved

Hydrostatic Spherical Couplings are proven to be the best solution to accomodate angular deflection. Guiding a payload and reacting extreme overturning moments without imposing a weight penalty is the purpose of *Team* Corporation Pad Bearings.

Use of *Team* Corporation Hydrostatic Spherical Couplings eliminates the danger of imposing moments to the actuator and/or table by providing the needed degrees of freedom when using multiple exciters. However, in single axis excitation, the desire is to restrain 5 DoF; in other words to permit motion in only one direction while controlling all other motions. This requires some external guidance and reaction mechanism to counteract any undesired motions without influencing the testing direction. *Team* Corporation solved this challenge by designing a line of hydrostatic Pad Bearings specifically suited for the task.

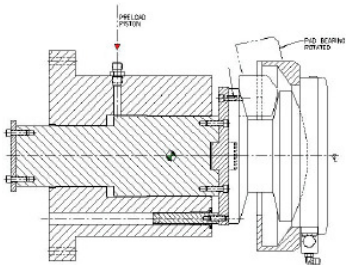


An interior photo of Team´s CUBE™. Hydrostatic spherical bearings can be seen on the ends of four of the six actuators that make the CUBE a 6 DoF vibration test system.

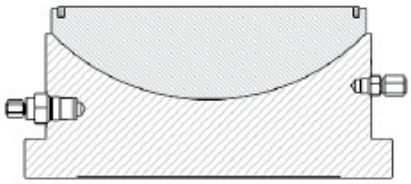
Pad Bearings have all the features that make hydrostatic bearing technology the choice for high-force, high frequency excitation – namely, no backlash and no friction. Their unique design facilitates the creation of test systems having extremely large overturning moment capacity without adding moving weight to the total payload. Pad Bearings also ease the manufacturing tolerances, being able to compensate for both as-built variations in dimensional accuracy as well as the dynamic responses of the table structure.

Pad Bearings are used in opposing pairs, with one Pad Bearing creating a compressive preload on the opposite Pad Bearing anchored to a rigid reaction mass. The compressive preload is maintained by using an accumulator to provide a constant hydraulic pressure to the preload piston in the Pad Bearing. This capability to accommodate linear motion as well as angular deflection is provided by two hydrostatic surfaces in the Pad Bearing, a planar surface bearing against the guided table backed by a spherical surface allowing angular deflection in the plane of motion.

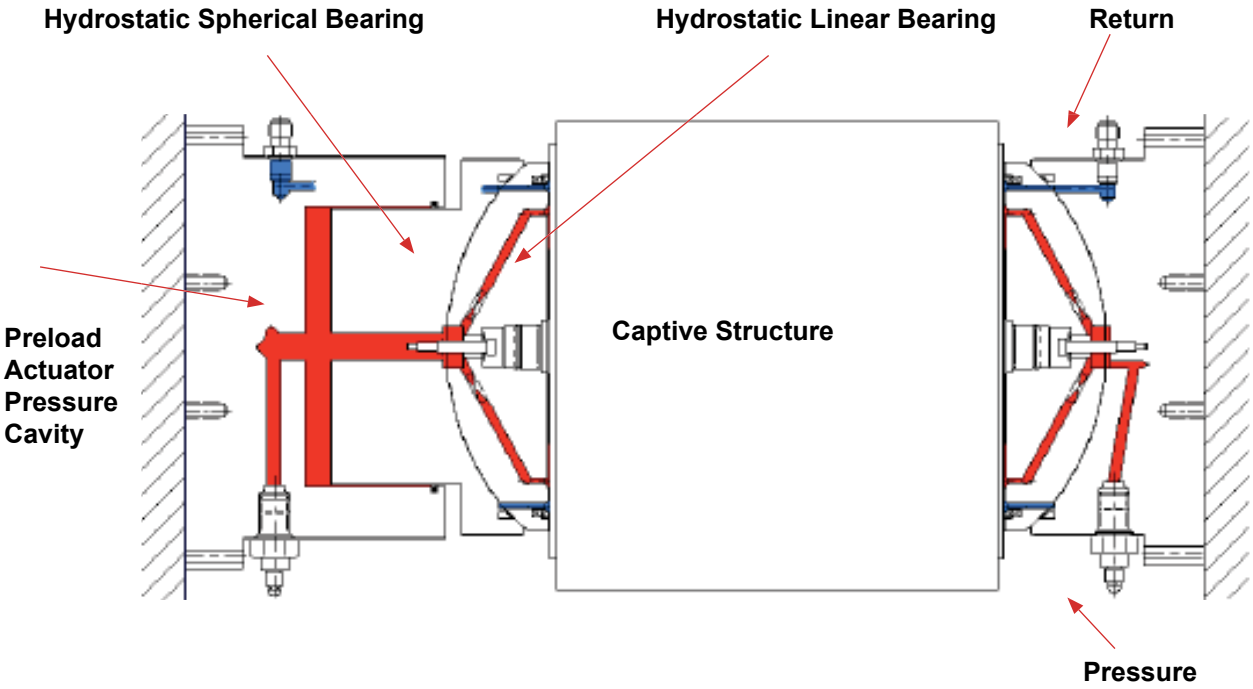
The development of the Pad Bearing has allowed *Team* Corporation to create very innovative multi-axis test systems. By placing Pad Bearings at each end of our patented



Assembly illustrating both the preload ability and the rotational ability of the assembly.

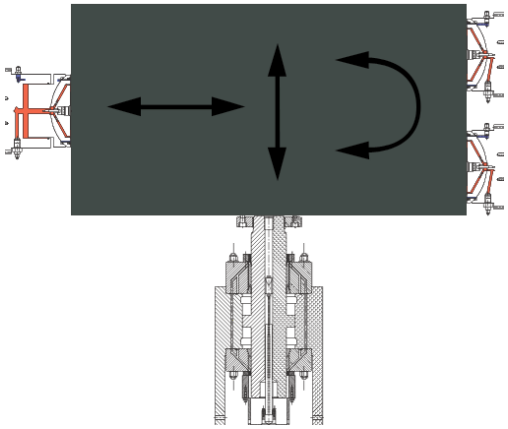


A typical Pad Bearing, which incorporates a hydrostatic spherical bearing and a linear bearing.



The captive structure in this illustration is free to move vertically, in and out of the plane of the page, and to rotate within the limits of the hydrostatic spherical bearings. It is constrained in the horizontal direction.

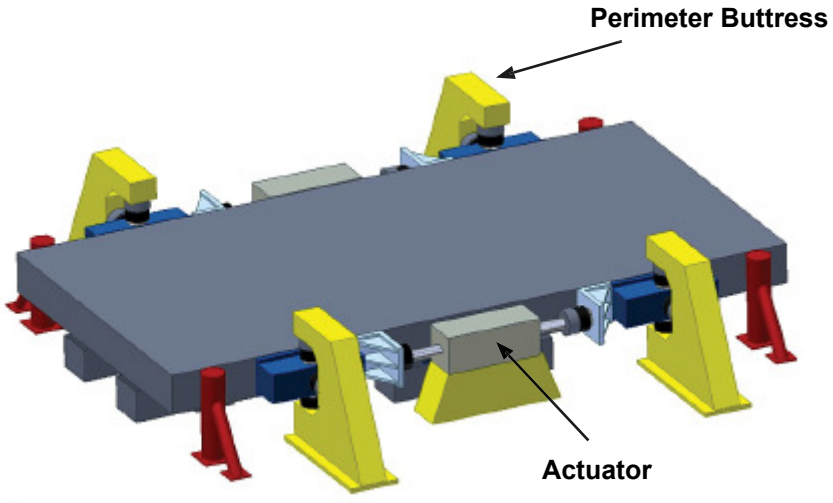
By adding two bearings, rotation within the plane of the page is eliminated. The number of constrained degrees of freedom is equal to the number of bearings used.



Integrated Actuator, *Team* Corporation has produced systems where the actuators become an internal component of the shaking table. In systems with shorter stroke length, controllable response to 500 Hz is commonplace. Perhaps the best example of this type of system is *Team* Corporation´s CUBE™, the highest performance full 6 DoF system available on the market. Another unique application where the Integrated Actuator is considered the only choice for test professionals is in geotechnical centrifuge research. Incorporating our Integrated Actuator with Pad Bearings into single and multi-axis shaker tables mounted on a centrifuge bucket, seismologists have accurately reproduced earthquake simulations on earthen models in highly elevated g fields.

The capability to support extremely massive payloads is valuable to full-scale seismic research. *Team* Corporation´s 4 DoF Earthquake Simulator at the University of California, Irvine has 20 inches of longitudinal stroke, 10 inches of vertical stroke, and can excite payloads ranging to 20 tons. *Team* Corporation is now pioneering the use of Pad Bearings in electrodynamic multi-axis systems with very high frequency response.

Large hydrostatic spherical Pad Bearings mounted on the ends of actuator and preload piston assemblies react the large inertia moments and high forces generated in a seismic simulator.



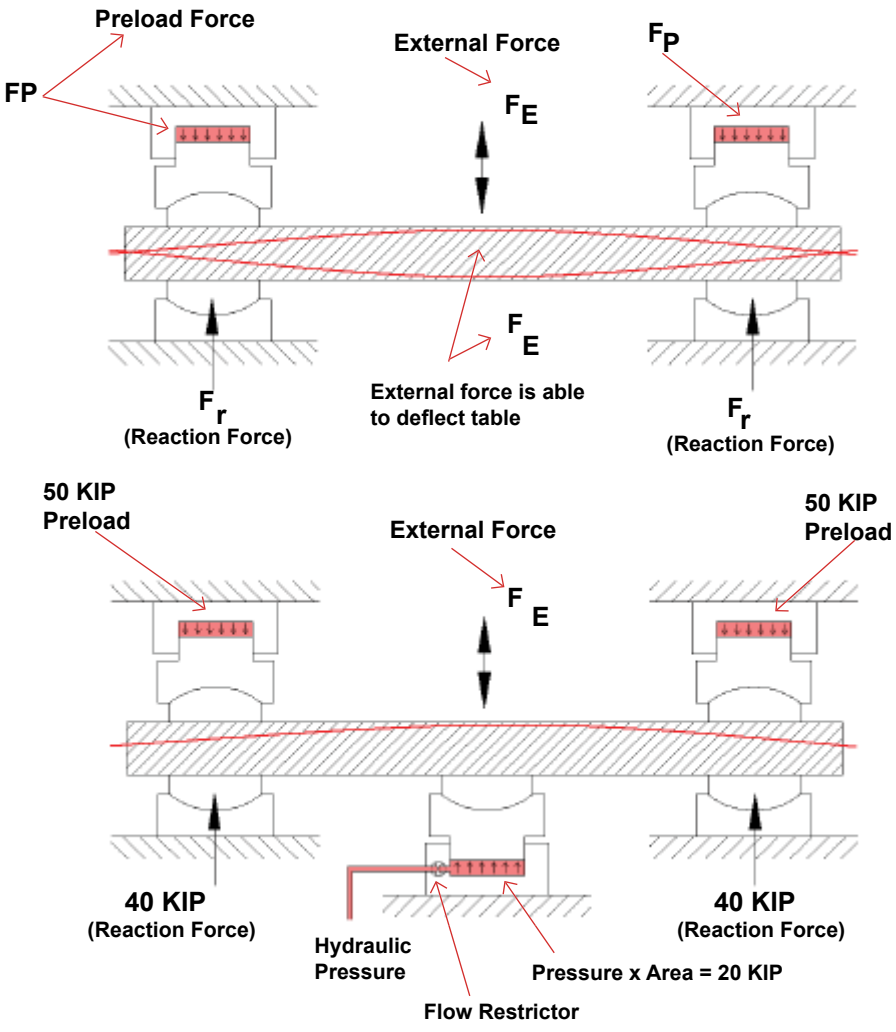
Large displacement seismic table

The **top sketch** shows a large single axis table supported on an array of Pad Bearings under the table and guided by Pad Bearings on perimeter buttresses. This design is for a table 40 ft x 20 ft (12.2m x 10.1m) with a maximum test specimen weight of 400,000 lbs (181,488 kg), a maximum velocity of 2m per second and a total actuator stroke of 48" (1.22m).

The **middle sketch** shows a diagram of the Pad Bearings located around the edge of the shake table. The force required to lift the shake table off the Pad Bearings FE must be greater than the preload force, 2FP. However, without a preload to the table at mid-span, for any force FE table deflection will occur. If the expected force is large, the table must be made very stiff to avoid deflecting an unacceptable amount.

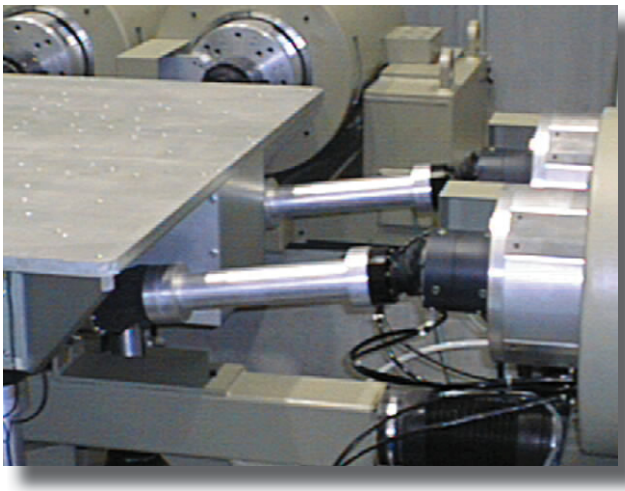
The **bottom sketch** shows a diagram of what happens when preload bearings are applied in an array along the mid-span of the table. They "preload" the table, effectively increasing apparent stiffness by taking up some of the deflection. The total preload force on the table remains unchanged from the concept shown in the first figure however the distribution of force is changed.

The self-adjusting preload Pad Bearings are charged with sufficient hydraulic pressure to create some known force in the middle of the table span. This force is determined by table design and established by piston area and system pressure. Now a payload can generate an upward or downward external force (overturning moment) without creating any vertical movement as long as the preload force is not exceeded. A restrictor in the hydraulic supply line severely limits hydraulic fluid flow from the pressure chamber. This makes the bearing very stiff in the downward direction, yet permits slow response to a steady state change in table position.



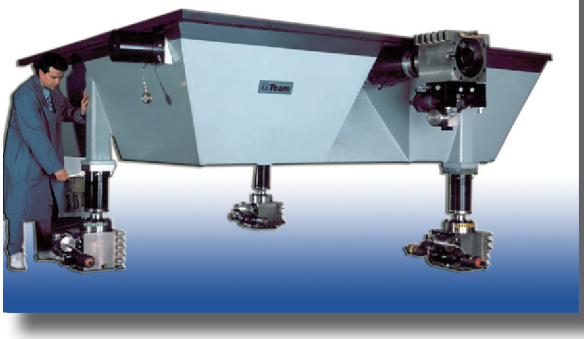
As long as preload force exceeds external force, no deflection occurs.

Applications



University of Tokyo

A 6 DoF shake table built with long stroke electrodynamic shakers. This system consists of eight electrodynamic shakers driving a single table. It is capable of 8 inches of total displacement in all three axes and +/- 15 degrees of pitch roll and yaw. HydraBalls on each end of mechanical struts deliver shaker force to the table with zero backlash.



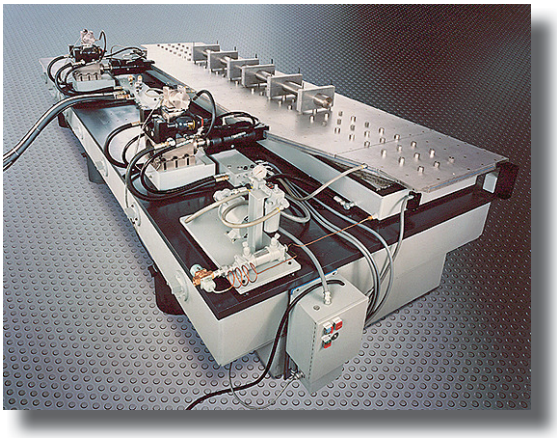
Phalanx System

Built for General Electric, Pittsfield, MA this 4 DoF system was designed for multi-axis vibration screening of General Electric´s 18,000 lbs Phalanx Weapons System. Capable of 66,000 lbs force vertically and 46,800 horizontally, the system had an upgrade path to a full 6 DoF. Dual pivot Hydrostatic Spherical Couplings between each actuator and the specimen mounting table accommodate rotations and off-axis load paths.

CES/CESTA

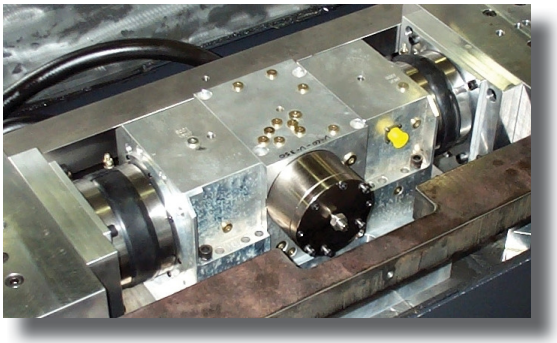
Built in 1973 for the French nuclear regulatory agency this 3 DoF system had a vertical force capability of 30,000 lbs., a horizontal force capability of 11,000 lbs in one axis and 18,000 lbs in the other. Hydrostatic Couplings can be seen attached to the right hand actuator in a pair to prevent rotation around the vertical axis.

Applications



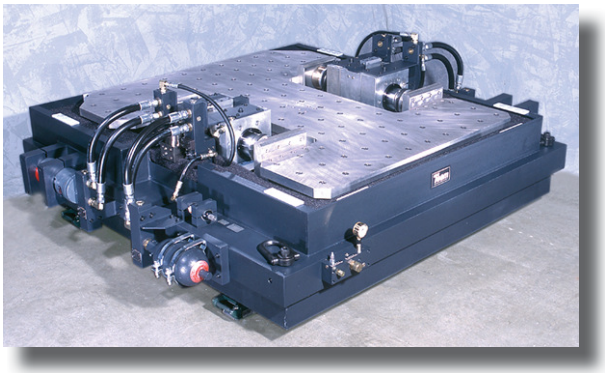
Schlumberger

A dual Hydrashaker system providing 2 DoF used to test oil well down-hole electronic logging/drilling tools. The double pivot Hydrostatic Spherical Couplings allow for angular misalignment while providing a backlash free, direct load path between the Hydrashakers and the shake table.



Geotechnical Centrifuge Shaker

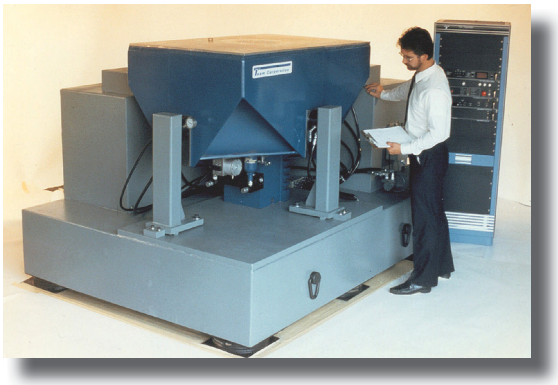
An ultra compact, high frequency Hydrashaker used to perform soils testing on a centrifuge in a high gravity field. Patented design using Pad Bearings permits bi-axial table performance.



Computalog

Another dual Hydrashaker system providing 2 DoF used to test oil well down-hole electronic logging/drilling tools. In this design the Hydrostatic Spherical Couplings are integrated into the actuator itself. Capable of 60 g's with a 600 lbs payload, hydrostatic bearings and couplings insure a direct load path between table and shaker while accommodating payload inducted inertial moments.

Applications

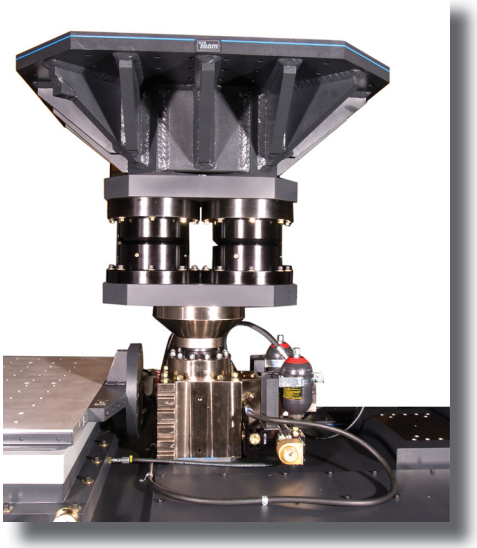


Magnavox

A large, guided head expander constrained to a single degree of freedom (vertical only) designed for testing large shipboard cabinets with off axis centers of gravity.

UC Irvine

Typical earthquake spectra have large displacements, relatively high velocities and massive test specimens. This requires the generation of high forces and creates large inertial moments that must be reacted by the table mechanism without introducing distortion into test results. Hydrostatic bearings, both spherical and linear, are mounted at the end of large actuators to accept these loads.



NSWC Dalgren

A large shaker system for testing missiles to Naval transportation standards. There are two identical systems which can be repositioned on air bearings. Used in tandem with the payload bridging both shakers, they can shake a missile up to 32 feet in length, along with its canister, one axis at a time. Hydrostatic Couplings eliminate bending moments generated by the payload´s overturning moment from reaching the Hydrashakers.

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.

A test system is only effective if it can be used when needed. Periodic maintenance must be anticipated and carefully planned to minimize program interruptions. *Team* Corporation test systems, using hydrostatic bearings, eliminate the most common sources of periodic maintenance. No longer is it necessary to adjust swivel preload or replace spherical rod ends. What has been a bi-annual service requirement on typical systems is now fully eliminated.

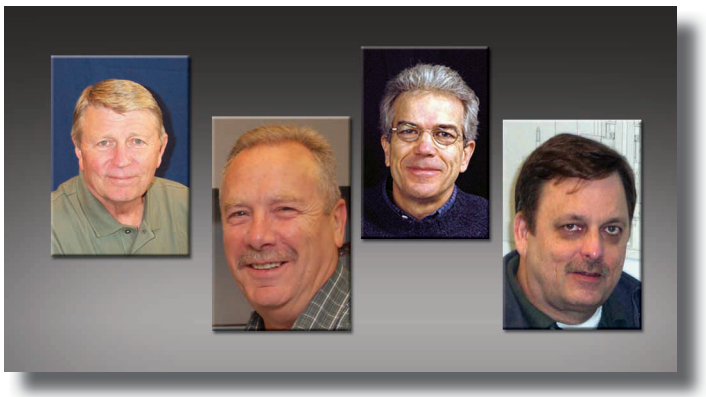
First and foremost, *Team* Corporation offers annual maintenance contracts to ensure a consistent level of system availability. In the event of unanticipated service requirements, *Team* can dispatch service engineers to provide more extensive maintenance as needed. To augment our customer support function,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



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

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