MIRA

NEW TECHNOLOGY 2003

MIRA

NEW TECHNOLOGY 2003

MIRA

Historical development of high performance **multi-axis vibration test systems**

by Clyde Harman, Team Corporation

The use of vibration testing to identify structural weaknesses is a widely accepted method to improve product quality. Vibration testing using a sinusoidal input, a random input or a replication of a deterministic waveform has proven to be a critical step in successful product improvement. Though long recognised that multi-axis testing provides a more realistic representation of actual field conditions, historically, single axis testing was the method of choice. Primarily the lack of economical and effective multi-axis test hardware and control software was the cause. Significant advances have been made in both arenas resulting in test system designs that permit the application of multiple shakers and testing in multiple axes simultaneously.

Almost no published standards have been written requiring multi-axis testing. One exception is the nuclear power industry, and vibration testing standards such as IEEE-344. Some specifications, such as MIL 810-F, allow for multi-axis testing but few require it. The result is that testing requirements have not pushed the replacement of single axis testing with multi-axis testing.

The automotive industry is one industry where the lack of published multi-axis testing procedures has not prevented its application. The quest for improved product quality has led to the use of several different configurations of multi exciter test platforms. Team Corporation has been involved in the development of many of these test platforms. This article explores some of the engineering developments Team has used that come from the vibration testing community outside the automotive industry, and how they offer much improved testing capabilities.

In the late 1960s and again in the early 1970s, Team helped develop two electro-dynamic, multi-axis vibration test systems. The first system was for White Sands Missile Range (WSMR), developed in 1969, and the second system was produced for the French nuclear testing agency CESTA two years later.

Prior to Team's involvement, White Sands' first two development attempts proved the feasibility of such a system, but they had serious drawbacks that limited their use as a testing tool. Severe resonance and high distortion attributable to the drive links between the electrodynamic shakers and the test table were the source of the problems. WSMR contracted with Team Corporation to design a system using hydrostatic spherical couplings. These couplings use a very thin film of pressurised oil to separate the surfaces of the coupling, as shown in figure 1. The volume of trapped oil is quite small and the bulk modulus of the oil is relatively high, therefore the spring rate contributed by the oil film is virtually negligible in calculating the overall stiffness of the coupling. The couplings have very high transmissibility and are relatively well damped. The Team hydrostatic couplings solved the resonance and distortion problems.

The CESTA system was also successful, with the use of hydrostatic spherical couplings being the key. This system is able to reproduce the measured vibration environment of missile and aircraft flight as well as ground transportation. The system has proven to be durable, and is still in operation after its original installation in 1971.

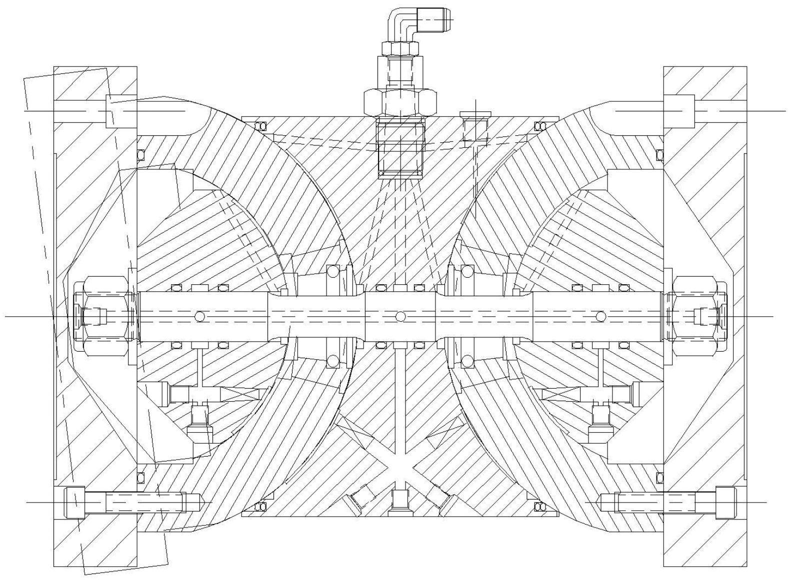

Figure 1: Double hydrostatic spherical coupling with +/- 6 degrees of deflection on both ends.

	WHITE SANDS MISSILE RANGE	CESTA
System Criteria	No resonance below 500Hz	Vertical force 133.5 kN
	Usable to 2,000Hz	Horizontal force 49 kN and 80 kN
	25 mm DA	20 to 2,000Hz, Sinusoidal
	1m square test table	5 through 2,000Hz, Random
	90 Kg Load to 10-g	40-g bare table (sine) 23-grms bare table (random)
	Capable of simultaneous as well as sequential excitation in each axis	Maximum test weight = 227 Kg

Table 1: System performance criteria for WSMR and CESTA.

After these initial successes Team continued to provide a number of high frequency and high force multi-axis vibration test systems, both electro-dynamic and servo-hydraulic. Then, in the early 1990's, Ford Motor Company awarded Team a contract to develop a ride simulator for subjective ride studies at Ford's Scientific Research Laboratory.

Within the passenger compartment, low frequency road noise is largely attenuated by the suspension of the automobile. Passenger compartment excitations attributable to the engine and transmission play a significant role and have a broader frequency band. When subjective ride quality tests are performed, it is critical to accurately reproduce this higher frequency content, which is at very low acceleration levels. Ford measured the acceleration time-histories from six vehicles used in test track studies and found the frequencies of interest to lie between 3 and 200Hz. The acceleration amplitudes at higher frequencies were quite small, as low as 4mg in the longitudinal axis. The use of long mechanical links and conventional actuator rod end bearings in most available 6 DOF systems limited their ability to reproduce frequencies much above 50Hz. Although road data has significant frequency content over 100Hz, reproduced data was typically limited to an upper frequency range of about 50Hz to correspond with hardware restrictions.

Team Corporation's solution to this limitation in frequency response was to use Team's Voice Coil Servo-valve, hydrostatic couplings and hydrostatic bearings in a patented integrated servo-hydraulic actuator. The man-rated vehicle vibration simulator developed for Ford Motor Company is pictured in figure 2. This simulator was the basis of a production version, 6 DOF vibration test system, the CUBE®.

This full 6 DOF device permits testing to 250Hz in sine in all axes. That bandwidth can be extended to 500 Hz controllable random in the vertical axis. Figure 3 shows a cut-away view of the interior. Within the movable "box" of the CUBE®, the yellow portion in the drawing, are six servo-hydraulic actuators with hydrostatic bearings connecting the actuators to the box. Ford's evaluation of the CUBE® found that the background acceleration noise on all channels could be reduced to less than 2 mg through careful management of hydraulic fluid temperature and pressure.

The success of the CUBE® (24 installations to date) resulted from the application of the technical knowledge and experience gained in those early multi-axis systems mentioned above. In the last several years Team has begun to apply that same knowledge and experience to

Figure 2: Vehicle Vibration Simulator used for subjective evaluation of ride quality. Photo courtesy of the Ford Motor Company.

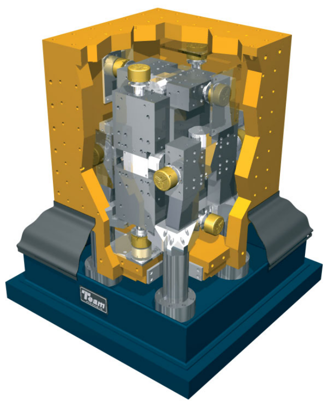

Figure 3: Team Corporation's CUBE®. Interior view shows servo-hydraulic actuator arrangement.

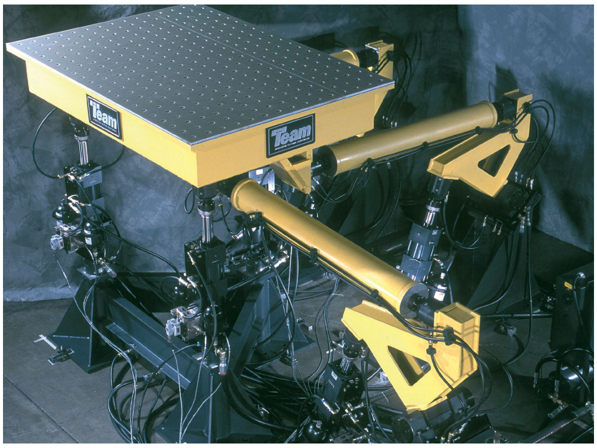

Figure 4: The Mantis™ multi-axis shake table. Hydrostatic bearings are located at the ends of actuators, connecting rods and at the bell crank base mounts.

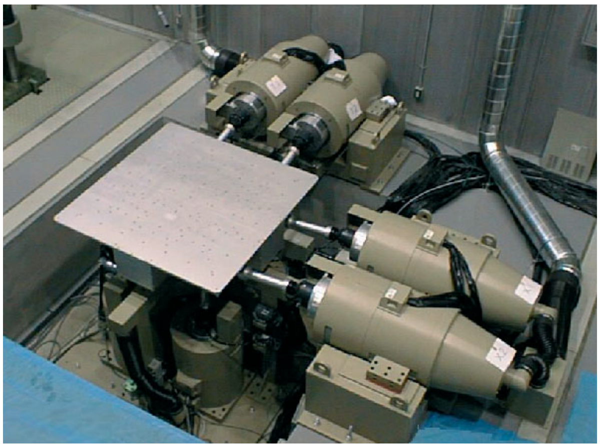

Figure 5: University of Tokyo Seismic 6 DOF System, Engineered and Installed by IMV in 1999

other 6 DOF solutions with higher performance in both acceleration and frequency response. Team Corporation is now producing two of the latest developments in 6 DOF test systems, the Tensor™ and the Mantis™. Incorporating voice coil servo valves along with linear, spherical and angular hydrostatic bearing designs these systems offer the best solution for creating a controlled, high frequency, 6 DOF vibration environment.

In an innovative adaptation of the actuator-to-box hydrostatic connection used in the CUBE, the Tensor™ inverts the physical arrangement by clamping the specimen table between pre-load pistons. This allows for vibration testing to the full capability of the shaker, and since the shaker is now on the outside of the specimen table, it can be either an electro-dynamic or servo-hydraulic shakes.

In the case of the Mantis™, Team has employed its unique hydrostatic, spherical bearing, the Hydraball at both ends of the actuators, at both ends of the mechanical links, and a rotary, hydrostatic, journal style bearing for the bell cranks (see figure 4). Team's advanced hydrostatic bearing technology provides for a multi-axis, zero backlash connection between the shaker and the test table. This translates directly into higher frequency performance bandwidth and eliminates the noise generated by conventional rod and cylinder bearing connections.

Parallel to the 6 DOF, servo-hydraulic development work going on at Team Corporation, IMV Corporation of Japan, an electro-dynamic shaker manufacturer has been applying Team's proprietary hydrostatic bearing and coupling technology to produce multi-axis systems. IMV have applied their long-stroke, ED shakers to create 6 DOF systems used as automotive ride simulators and to model seismic events. Figure 5 shows a 200mm stroke, 300 Hz seismic shaker system installed at Tokyo University.

Replication of real world environments demands the use of systems that realistically reproduce actual field conditions. Multi-axis vibration environments require multi-axis systems to replicate them. Historically, the lack of effective multi-axis hardware and control software has limited the availability and capability of multi-axis test systems. By applying lessons learned in other vibration test environments and using time proven technologies in innovative ways, Team Corporation has created a suite of multi-axis test systems that accommodate a range of test articles with different physical and test environment needs for use in automotive product testing. ■

Performance Characteristics	Mantis™	CUBE®	Tensor™ (Servo-hydraulics)	Electro-dynamic Systems
Degrees of Freedom	6	6	6	6
Frequency Bandwith	100Hz	250Hz	700Hz	2000Hz
Displacement Pk-Pk	150mm	100mm vert. 50mm horz.	13mm	Shaker Dependent
Payload, typical	50-2000Kg	25-500Kg	5-50Kg	Shaker Dependent
Max. force rating	315 kN	62 kN	36 kN	Shaker Dependent

Table 2: General performance data for multi-axis systems.