

## Multi Axis Shake Tables (MAST)

### Multi Axis Shake Tables

With many years experience in the vibration and shock testing field, Servotest are able to supply a range of vibration testing equipment, developed to exceed other manufacturers in the market place. Servotest supply an unbeatable range of dynamic test equipment that covers the whole spectrum of testing needs required of a modern manufacturing organisation. By offering equipment in a number of bespoke ranges and complementary accessories, we can offer the variety of testing forces, sizes and orientations needed. Modular power units are then configured to the environment needed. International service is reliably supplied through a series of satellite offices and partner organisations. Turnkey facilities including planning, upgrading, installation and maintenance are available and can be individually designed to suit specific needs. New technologies are continually introduced into the hardware, instrumentation and software to keep the equipment at the forefront of the industry. All the equipment complies with International Standards including CE, MIL, ASTM, IEC, ISO and BS.



### A world of experience...

Servotest is a World Class Test and Motion Simulation Company, with experience of operating around the globe, for multi national corporations, smaller specialist companies and Government Departments. Since the 1950's our engineers and equipment have been at the forefront of our industry. Product and Service quality is maintained by a program of continuous training and development of our engineers and equipment.

We operate in all of the key industry sectors for our marketplace, including Automotive, Marine, Civil Engineering, Aviation, Defence, Aerospace and Traction. The company holds both ISO14001 and 9001 Quality accreditation marks and is a member of many national and international trade organizations.

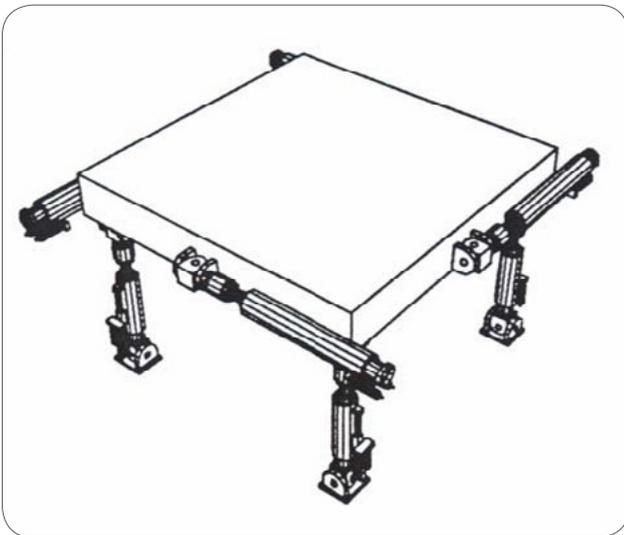
# MAST – Introduction

Multi Axis Shake Table “MAST” allow test structures to be excited under numerous configurations from single direction “Slip Table” to simultaneous six spatial degrees of freedom “6-DOF MAST”. Servotest MAST systems offer the chance to realistically simulate a broad range of anticipated load events.

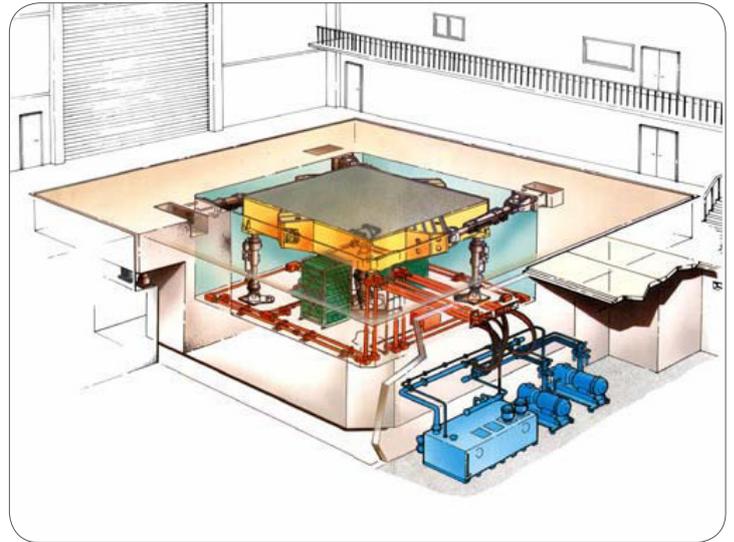
Principally, the multi-axis simulators are designed for experimental verification of the safe functioning of large components and subsystems under seismic conditions.

Servotest MAST Systems are recognized to surpass common testing in other fields of quality audit such as:

- Vibration tests on structural models.
- Simulation of transportation motion.
- Simulation of dynamic loading of systems in the aerospace industry.
- Automotive component validation and durability testing.



The functional capability of components and systems under seismic and other dynamic conditions (random, shocks, vibrations) has to be ensured in many engineering sectors to verify experimentally the safety and reliability of large components or structures under dynamic load conditions.

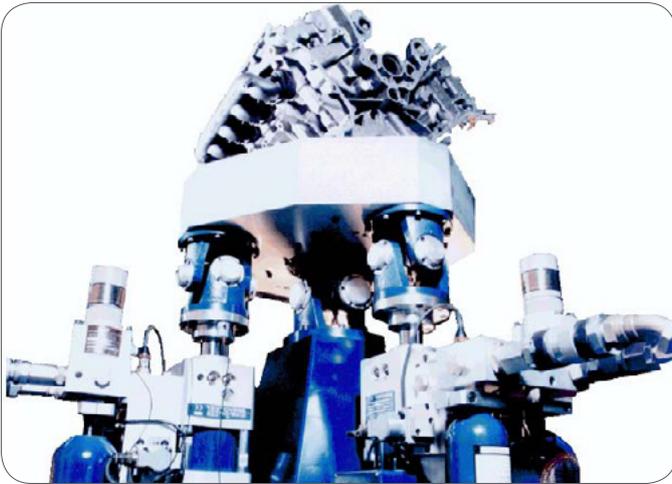


In order to minimise scaling errors, specimen parts will normally be large, driving the seismic simulation table size and weight larger to support large components or structures weighing at least up to 60 Tonnes.

Servotest MASTs size vary from 0.5mx0.5m to 6mx6m with a dynamic force capability of up to 1000kN vertically and 600kN horizontally. The frequency response of the actuators extend from 0.1Hz up to more than 20Hz in all degrees of freedom which provides a test facility of enormous flexibility and capability.

Servotest prides itself on providing with turnkey facilities including palnning, upgrading, installation, and maintenance are available and can be individually designed to meet the needs of individual customers.

## MAST – Automotive Applications



Servotest exhaust test systems (pictured above) enable high frequency vibration to be reproduced in either a dummy or live engine manifolds to simulate engine vibration.

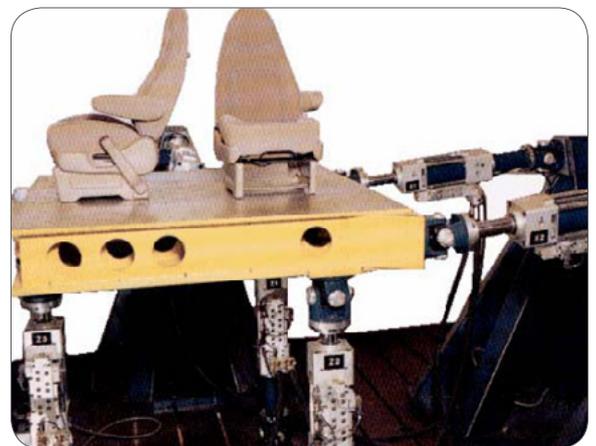
Two models are available – one to provide vertical vibration, the other giving roll and pitch vibration.

Noise, vibration and harshness testing is a prerequisite in the automotive industry. Car dashboards, instrument consoles etc need to be checked thoroughly before being approved for inclusion in passenger cars. Simultaneous multi axis tests or vertical/horizontal tests can be carried out without having to remount the specimen. The whole system (Right hand side picture) is controlled using the powerful Servotest MAST software designed to ensure complex tests can be performed with relative ease.

Also available is the Jounce & Squirm test system, which allows manufacturers to evaluate fabric wear by simulating the actions of people in the seat during normal driving conditions. It also simulates the repetitive bouncing actions similar to those that occur in normal driving conditions, providing evaluation of the cushion spring. The 'jounce' and 'squirm' tests can be run independently or simultaneously.

For a MAST to operate at high frequencies (typically >80Hz), the table must be exceptionally stiff and light – often two conflicting requirements. For synergistic applications, Servotest have designed a completely new type of circular table, as opposed to the traditional square configuration. This is due to a combination of actuator layout, space constraints, and balancing mass versus useable working area.

This test rig enables high frequency vertical vibration to be reproduced at a small table to simulate engine vibration for testing exhausts systems. Frequencies up to 400 Hz can be generated and resonance tracking software is utilised to endurance test the exhaust system locking on the exhaust system key resonant frequencies. The vertical motion is produced by a short stroke high frequency linear actuator mounted on the customer's or Servotest supplied bedplate.

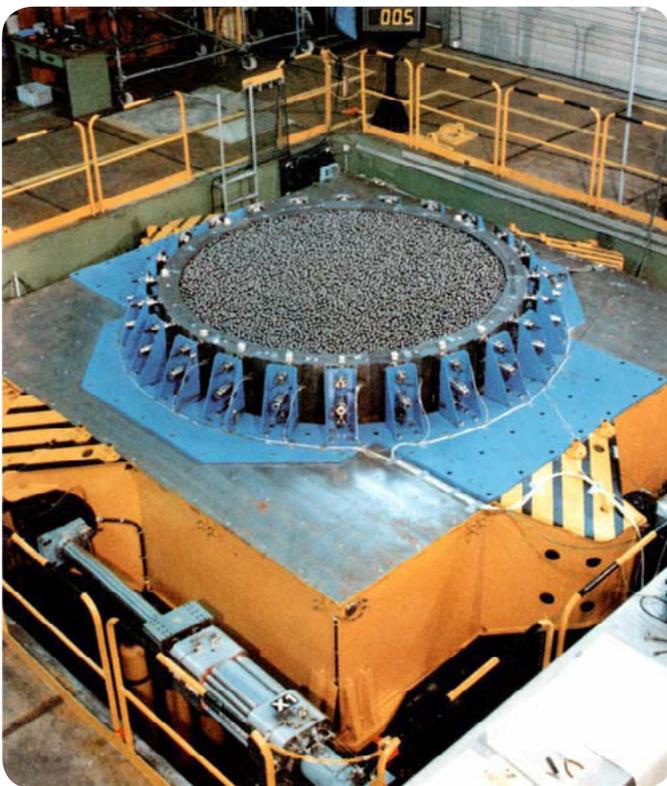


## MAST – Seismic Applications

Research into safe structures is a growing sector, especially in the developing World. Accurate reproduction of actual seismic conditions allows research institutes, power companies and construction manufacturers to put a structure on top of a table, and see how it bears up to a simulated earthquake.

Servotest seismic MAST systems are designed to precisely reproduce actual seismic conditions to test the ability of the specimen to withstand earthquake inputs. In addition to earthquake reproduction, random time history generation, shock pulse generation and multichannel sine sweeps can be created quickly and easily.

MAST seismic systems require huge dynamic force capabilities to be able to simulate earthquakes. In addition to this the building that houses the system, and its foundations, have to be specially reinforced to cope with the stresses.

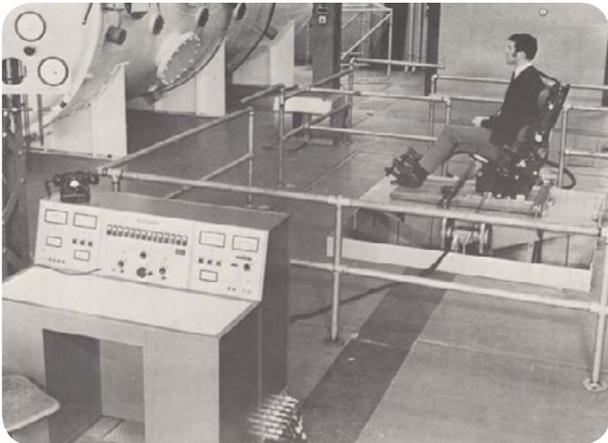


# MAST – References

## Experience

Servotest experience in low frequency, low distortion motion systems goes back to 1970 when we built the first low distortion motion system for the Royal Aircraft Establishment. Stroke 500mm with pitch, heave and surge degrees of freedom.

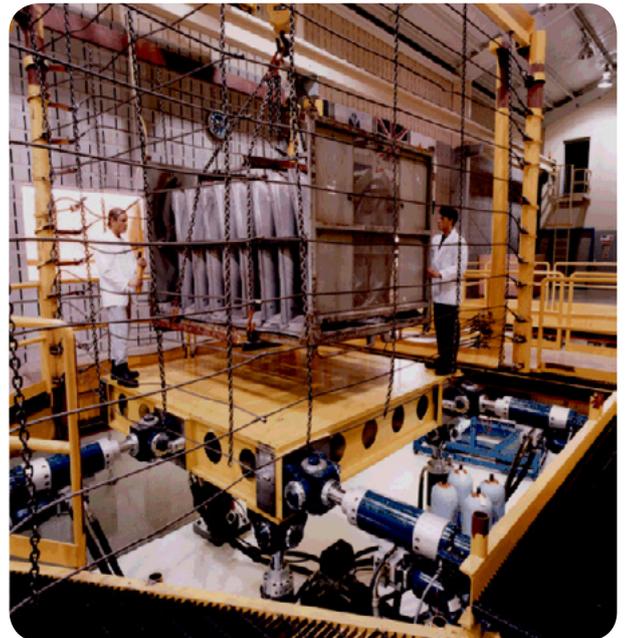
It incorporated man rated safety together with acceleration harmonic distortion requirement better than 15%. This project incorporated new Servotest design concepts of our hydrostatic bearing actuators, self aligning bearings, pressure controlled snubbers and three stage Servovalves.



## Packaging Testing – MAST System

This particular system was developed for a major automotive manufacturer who became increasingly concerned about the proportion of their components which were damaged during transit by rail to their factories. They commissioned Servotest to build a MAST system (pictured below) to exactly reproduce the conditions on the train, thus enabling them to find the weaknesses in their packaging. The performance of the system is designed to enable up to 6g vertical vibration at velocities in excess of 1.2 m/s.

This research was so successful that the savings made from the findings of their experiments, covered the cost of the whole test facility – in just 3 months.



# MAST – References (cont.)

## 1 –DOF Slip Table Seismic System

The seismic slip table is an effective method of reproducing seismic vibrations, without the complexity and expense of a full multi-axis system. Servotest differ from its competitors, by placing the actuator under the table. This offers the most compact and convenient solution when testing large structures within a confined space.

The system has been designed so the actuator can be removed without removing the table. In addition, the bespoke-engineered hydrostatic bearing actuator is the most reliable servo-hydraulic actuator on the market today, and will function perfectly for years before servicing is needed. A Servotest actuator delivered in the late 1980's has now seen over fourteen billion cycles after only two services.

The actuator is mounted at either end by Servotest Cardan joints. This unique product was specifically engineered to meet the low backlash, high axial load requirements of the testing industry – not offered by other joints. Inside, a combination of precision taper roller element and thrust bearings, offer incredible durability and low friction. Out of hundreds supplied, not one failure has been recorded on a seismic test system; such is their reliability.



## Aircraft Cabin Simulation

Servotest was commissioned to design and build a cabin crew training system to help ensure the safety of cabin crew. This simulates heave, pitch and roll motions of the fuselage and was incorporated with environmental effects to recreate the dramatic conditions of a crash landing or other emergency.



The system uses three actuators with very long strokes to create the desired heave motion, pitch and roll. The actuators provide input to a motion platform, on which a customer supplied dummy fuselage sits. The system is designed to carry realistic in-flight loads for the section under test, and conforms to the fuselage height as it would be seen from the ground.

As safety is paramount in simulations such as this, the system was designed with a number of features which ensured that no harm could come to the crew, such as limiting acceleration and building in interlocks in case of system shut down.

## MAST – References (cont.)

### **Reproducing Motion Seen by Large Structures**

Concern over the reliable operation of nuclear power stations built in seismically active regions has involved Servotest in extensive development of Multi Axis Shake Tables over the last two decades.

To avoid scaling errors, parts are normally tested full size in order to classify their ability to withstand vibration. Components as well as building structures need to be assessed in terms of reliability. Motion systems of this type tend to require large platforms suitable to support large components or structures weighing many tons. The frequency response normally extends from 0.1 Hz to 100 Hz in three to six degrees of freedom.

- Payloads: Upto 100,000 kg
- Table Sizes: 1m<sup>2</sup> - 36m<sup>2</sup>
- Degrees of freedom: 1-6
- Frequency: Up to 200 Hz
- G levels: Up to 10g



**Chongqing Highway Research Institute, China**

## MAST – References (cont.)

### MAN Rated MAST Systems

Over the past three decades Servotest Ltd have accumulated considerable experience in the design, manufacture and installation of vibrators especially designed for scientific investigation of human perception thresholds, comfort tests, biodynamic measurements, and the effect of vibration on health and performance.

All Servotest MAN rated MASTs fully comply with International Standard BS EN ISO 13090-1:1998 (International Organization for Standardization, 1998) in any failure condition. The standard specifies that in the event of a failure of the operator, the electrical or mechanical components of the device, or the software in programmable systems, the subject shall not be exposed to sustained or transient acceleration.

This type of installation usually incorporates a number of features which makes it different from vibrators designed for other purposes.



### Acceleration Levels

Limited Acceleration Levels – accelerations of the order of  $0.1\text{m/s}^2$  are significant in this type of applications. Upper set limits of acceleration for other applications vary from  $20\text{m/s}^2$ -max for transportation applications, and  $100\text{m/s}^2$  – max for aerospace applications.

### Acceleration Distortion

Human beings are remarkably sensitive to the shape of acceleration waveforms. Exact simulation of conditions involved, for example in transportation, involve the exact reproduction of signals, including their frequency and amplitude as well as their harmonic distortion.

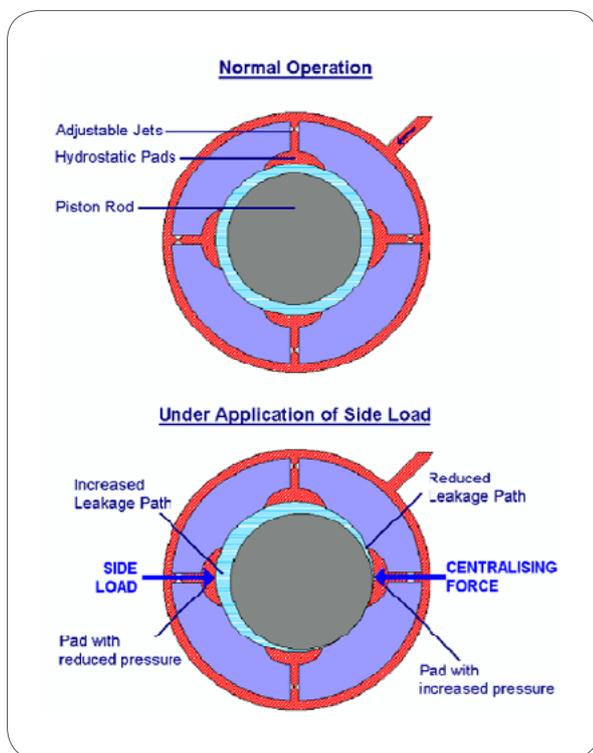
### Safety Features

Where people are being used as experimental subjects, increased emphasis must be placed on the provision of safety devices and failsafe systems. SERVOTEST systems are fully protected by a unique combination of mechanical, hydraulic and electronic safety systems.

# Precision Made Equipment

## Servotest Hydrostatic Bearing Actuators

The hydrostatic bearing actuators are fatigue rated for continuous operation and long trouble free life in excess of 50 x 10<sup>8</sup> cycles. They are easy to maintain, the only items requiring periodic attention are the oil filters and low pressure seals. The filters can be replaced on site by the customer without any need to dismantle the actuator. One of the low pressure seals can be reached without any dismantling and the other is made easily accessible by removing the transducer housing.



## Actuator Range

Based on years of experience and development Servotest 050, 065, 080, and 0100mm rod dia. type actuators are of low aspect ratio design to give high flexural rigidity and low stress levels. The three different piston rod sizes are double-ended, fatigue rated hydrostatic bearing actuators.

## Construction

A hydrostatic bearing actuator consists of a hollow hard-chromed alloy steel piston rod, housed inside a steel cylinder, which is machined to close tolerances. Internal and external threads are provided at the upper rod end for attachment of vibration tables, load cells or mounting fixtures. Pressure equalising grooves are machined into the piston and no piston seals are fitted, giving friction free movement. High strength aluminium alloy front and rear bearing heads incorporate hydrostatic bearing pads, which provide a self-centring force on the rod and prevent metal-to-metal contact so that side load capacity is increased and friction is eliminated.

Hydraulic snubbing sections are also incorporated into the bearing heads to prevent damage to the actuator in the event of piston rod overtravel, resulting from a system failure or incorrect usage.

Low-pressure seals, constructed from Nitrile based material, are fitted at each end of the actuator, to retain the oil leakage from the hydrostatic bearings. This oil is collected in annular galleries and returned to the system either through internal oilways to the return ports or through a special drain hose, depending on the actuator design. A range of servo valve manifolds enables the use of up to six Moog 76 series two stage valves, or 3 stage servovalves for large flows depending on the actuator performance required. The valves and associated manifold are mounted directly on the actuator cylinder, to minimise the volume of oil between valve and piston and hence reducing the compressible volume and maximise the hydraulic resonant frequency.

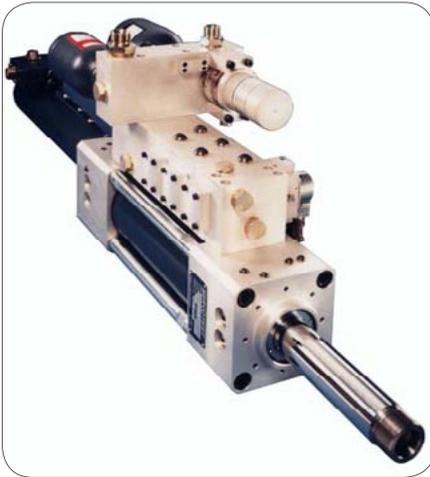
## Mounting Methods

Several mounting methods are available, depending on the test application. Servotest actuators can be freely supported by self-aligning bearings, trunnion mounts, gimbal mounts, or flange mounts and mounted in load frames, vibration stands or incorporated directly into a special test rig.

## Precision Made Equipment (cont.)

### Preload Section

For many components or structures the loading pattern comprises of two components, a mean load, or preload, and an alternating load. The preload can either be a tensile or compressive load and is usually constant.



All servo-controlled actuators have the capability of exerting a load composed of both these components, providing that the sum of the two components does not exceed the maximum rating of the actuator. However, in applications involving high velocities and high levels of mean load, the preload actuator can reduce by as much as half the size of the hydraulic power supply and the energy consumed during a test.

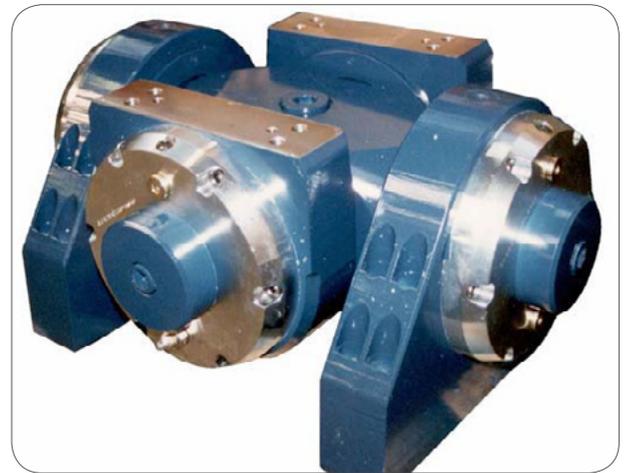
In these cases a compressive pre-load is fitted by applying pressure to the base of the piston. This pressure is maintained at a constant value with large accumulators, controlled via a pressure feedback.

### Self Aligning Bearing

The functionality incorporated into the self aligning bearings offered for this application is as follows:

- Efficient force transmission at angles up to 55
- Fatigue rated
- High axial stiffness
- Very low friction
- Zero backlash
- Minimum weight

Servotest self aligning bearings are low friction, no backlash and accommodate large angles possible on long stroke motion systems.



### Hydraulic Power Supply

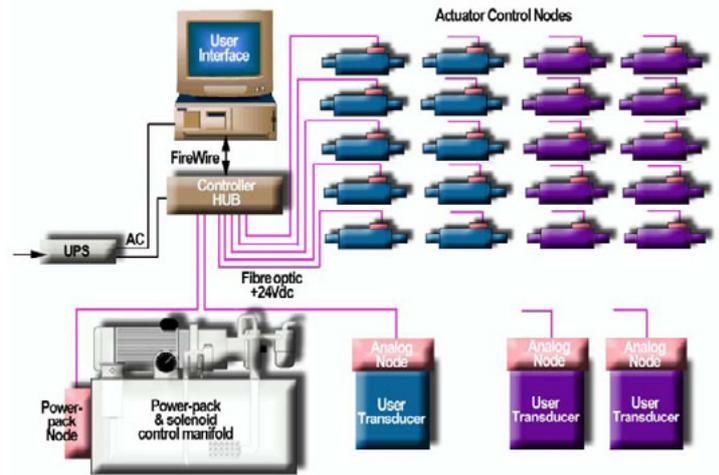
The hydraulic supply provides filtered oil at a chosen pressure to provide force and a chosen flow to provide velocity. The product of pressure and flow is power. Certain decisions have to be taken when selecting the size and type of hydraulic power supply based on test methods employed.



Oil Pressure - 21 MPa, 28 MPa, or 14 MPa (for Man rated systems) with adjustments available on the system between 5 and 28 Mpa to cope with a large range of payloads.

# PULSAR Digital Controller

The Servotest MAST (Multi Axis Shake Table) control system incorporates 'Total Degree of Freedom' software that leads the marketplace with its innovative design and functionality. The system, pioneered by Servotest, gives Engineers highly accurate control over the test, together with the ability to reproduce time history files faster and more simply than ever before. All Servotest MAST systems are shipped with this unique solution as standard.



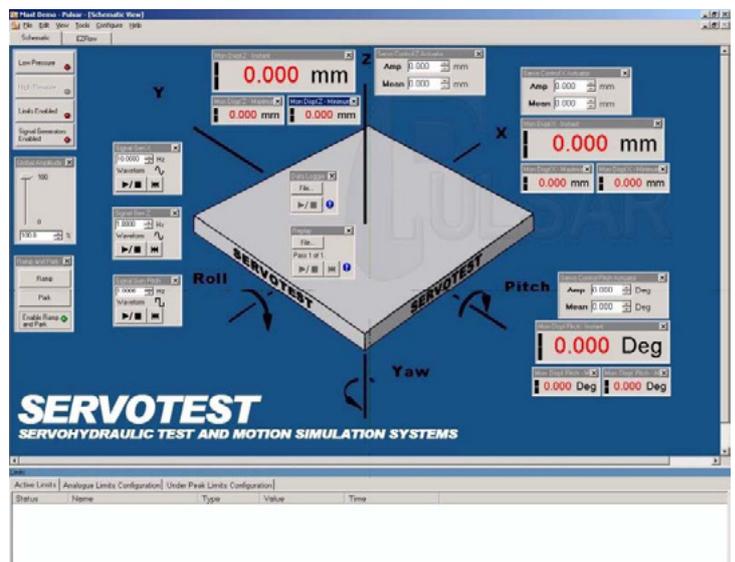
# PULSAR Software (MAST)

The Mast module has been developed to allow the control of multi axis shake tables to be easily achieved using the Servotest Pulsar Digital Control System.

The module contains a series of control panels, each relating to a particular aspect or group of functions for the test system. Also, a graphical representation of the shake table is given, labelling the available axes of movement.

In common with the other software modules within the Pulsar system, the Mast module uses the in-built databases to configure the software module to match the test system being controlled. Additional functionality includes an origin panel to allow the operator to specify various centres of motion for the table.

Time history reproduction can be accomplished with the addition of the optional ICS analysis software module. The main window from a typical configuration of the Mast multi axis shake table control software is shown below:



# PULSAR ICS Analysis

Servotest's Iterative Control System (ICS) was developed to provide simulation control capabilities to test rigs that are required to reproduce accurately the dynamic response that is present when a test specimen is subjected to actual service conditions. The simulation control software carries out the reproduction of the test specimen response, from the same transducers used to measure the service conditions. ICS analysis employs an iterative process that creates a drive file for the test rig controller, which reproduces the desired test specimen response. ICS Analysis makes use of advanced system modelling techniques and an intuitive user interface to provide the user with a system that produces accurate results without the need to understand the complexities of simulation testing.

The drive file produced by the ICS process can then be played to the rig by Servotest's Replay. In the case of fatigue or endurance testing the file will be played a set number of times using EzFlow.

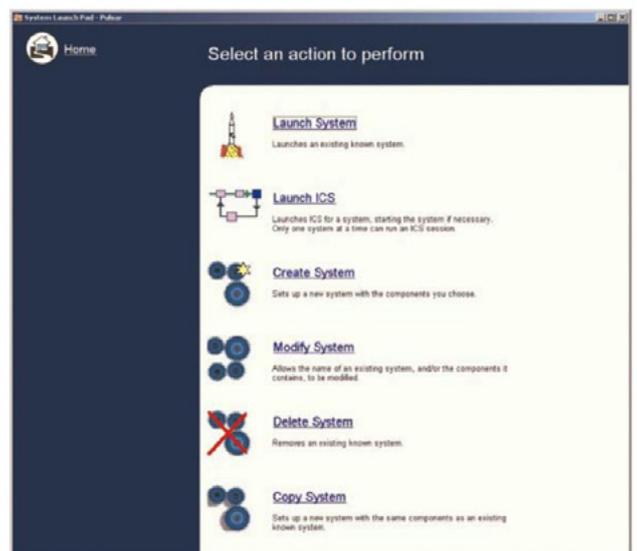
The ICS Analysis package provides the user with the necessary tools with which to re-produce time history files from track data. The software has been designed specifically for ease of use and in view of this, ICS interacts with Replay and Datalogger either automatically or with a degree of control from the user. Included is a set of tools for analysing the results and generating filters and white noise files. Although generated around the SBF format, ICS can support various formats including RPCII and ADF.



## ICS Analysis Auto-Iteration Mode

Usually the iterative process, once started, does not require any more user intervention until it is completed. Furthermore, when the desired files are very long or the process necessitates many iterations, the whole operation can be time consuming. For these reasons it was important to introduce an automatic mode into ICS.

Once the system matrix is correctly determined the user can select the auto-iteration mode and set the performance criteria which will be used to decide when to stop. The ICS session stops when all response channels meet the criteria or when any of them starts diverging. This, for example, can allow the process to run over-night, unmanned and in a safe manner.



## Specification

	<b>From</b>	<b>To</b>
<b>Table size</b>	0.5m	6m x 6m
<b>Table mass</b>	50Kg	37,000Kg
<b>Resonant frequency</b>	2000Hz	120Hz
<b>Vertical force</b>	10kN	1000kN
<b>Horizontal force</b>	5kN	600kN
<b>Vertical stroke</b>	50mm	300mm
<b>Horizontal stroke</b>	50mm	300mm
<b>Hydraulic power</b>	35kW	1550kw

# ***SERVOTEST***

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