



#12648

Challenges and Considerations When Using Hydraulic Modal Shaking in Large-Scale Modal Testing IMAC-XL

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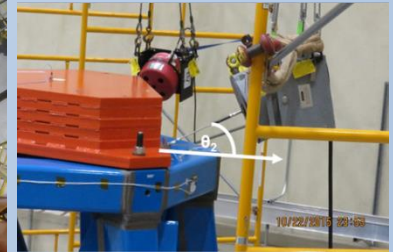
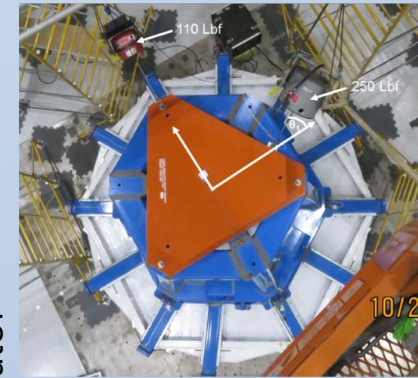
Motivation 1



- Modal tests have traditionally utilized electrodynamic modal shakers.
 - Very good linearity characteristics.
 - Versatility
 - Relatively easy to set up.
- However, utilizing electrodynamic modal shakers on dimensionally larger and more massive test articles, combined with the need for higher excitation levels in order to identify their nonlinear characteristics, can be problematic.
 - Longer stroke, higher velocity, and higher force level requirements.



MPCV Orion
LAS Ogive



MPCV Orion CMLAS Simulator



MPCV Orion
CMA Simulator

Motivation 2

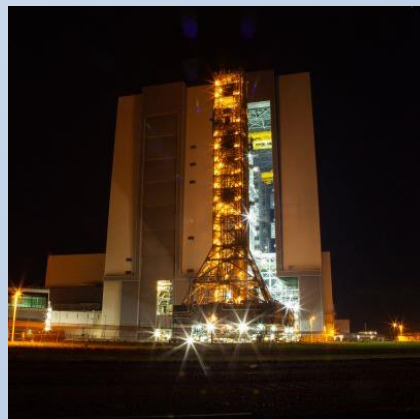


- Hydraulic modal shakers become attractive on larger-scale modal tests since they can generate higher force levels at lower unit cost with a smaller spatial footprint and can better meet the longer stroke, higher velocity, and higher force requirements.
 - Four hydraulic modal shakers were used in modal testing NASA's 327 feet tall and 1.8 million pound Ares I-X Flight Test Vehicle (FTV) inside the Vehicle Assembly Building (VAB) in 2009.
 - More recently in June 2019, five inertial hydraulic modal shakers were used in modal testing the Space Launch System (SLS) Mobile Launcher (ML), which is over 360 feet tall and weighs more than 10 million pound, inside the VAB.

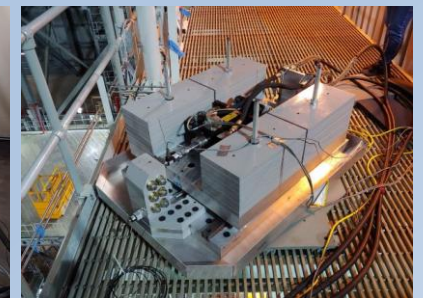
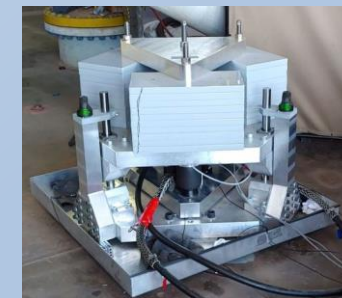
Ares I-X FTV Modal Test



Mobile Launcher (ML)



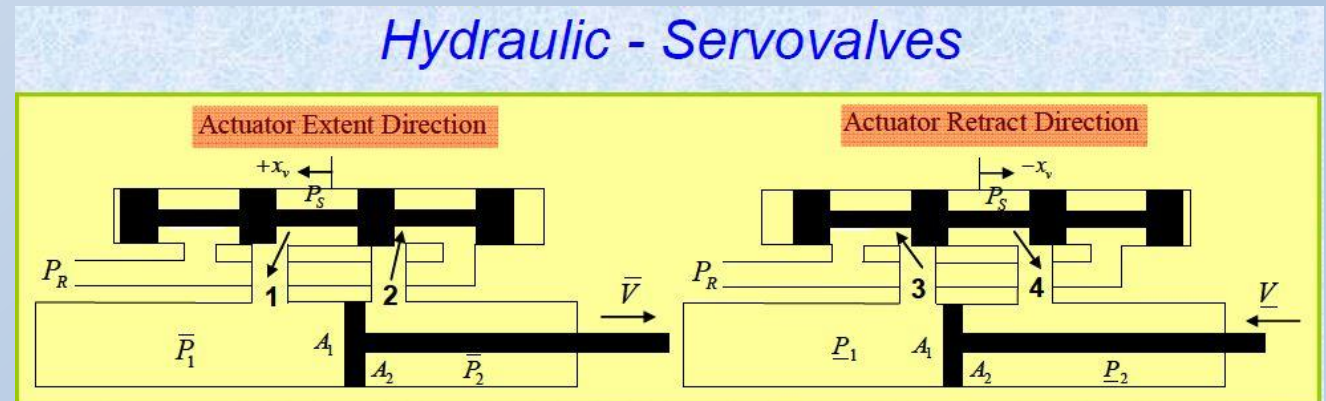
ML Modal Test Inertial Hydraulic
Modal Shakers
Vertical Horizontal



Hydraulic Actuator Configuration



- Hydraulic actuators are comprised of a piston in a housing with pressurized hydraulic fluid used to exert a pressure to the face of the piston to generate motion and/or force.
- Hydraulic actuators used for vibration and shock testing use a stiff double acting double ended (i.e., double rod) hydraulic actuator with a high frequency response electrohydraulic servo valve.
 - Push/pull forces and/or extension/retraction of the actuator is achieved by changing the pressure differential across the piston.



Servo Controller 1

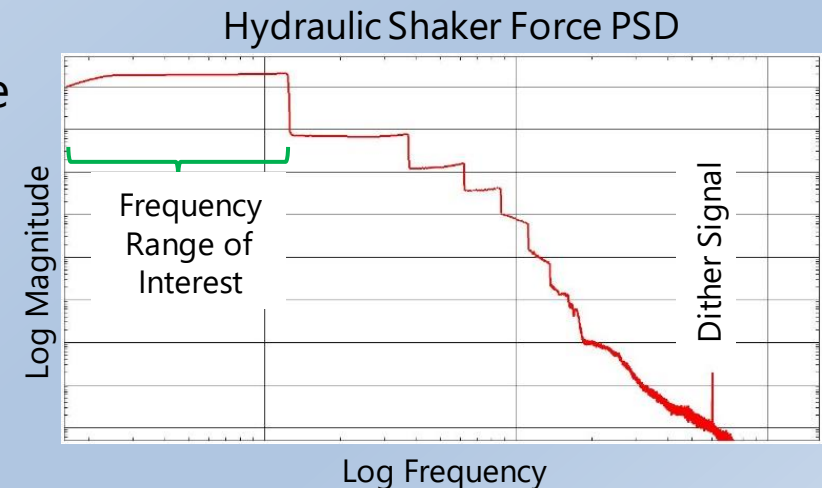


- A servo controller sends an electrical command signal to the electrohydraulic servo valve that positions the servo valve and hydraulic actuator piston at the desired starting position (usually mid-stroke).
- The servo controller uses position feedback of the servo valve and the hydraulic actuator piston, usually measured with a Linear Variable Displacement Transducer (LVDT).
- Hydraulic actuators are inherently unstable and the servo controller is required to set the desired hydraulic actuator piston position.
 - Without the servo controller, the hydraulic actuator piston would end up drifting off to one side or the other reducing the useful stroke limit and potentially impacting its mechanical stops and incurring damage.
- The servo controller, its electrical command signal to the electrohydraulic servo valve, and the hydraulic actuator and servo valve position signal feedback is often referred to as the "inner control loop".
 - The "inner control loop" does not prevent the hydraulic actuator from reaching its stroke limit.

Servo Controller 2



- The servo controller in addition to generating the electrical command signal for the servo valve to move the hydraulic actuator piston, based upon the shaker controller's drive signal, also generates a high frequency dither signal.
 - The dither signal produces very small amplitude oscillations in the servo valve to prevent it from sticking.
 - Dither signal frequency should be well above the modal test frequency range of interest, typically an octave or more above the resonant frequency of the servo valve resonant frequency where the system transfer function has minimal gain.
 - The dither signal may produce local responses in the test article, particularly in the vicinity of the shaker drive points, and therefore may affect the data acquisition system (DAQ) full scale settings.
 - Recommend at least one set of data be acquired at a sampling frequency high enough to capture the dither signal and the test article's response to it while the shaker drive signal to the servo controller is off.



Hydraulic Actuator Stroke Limits

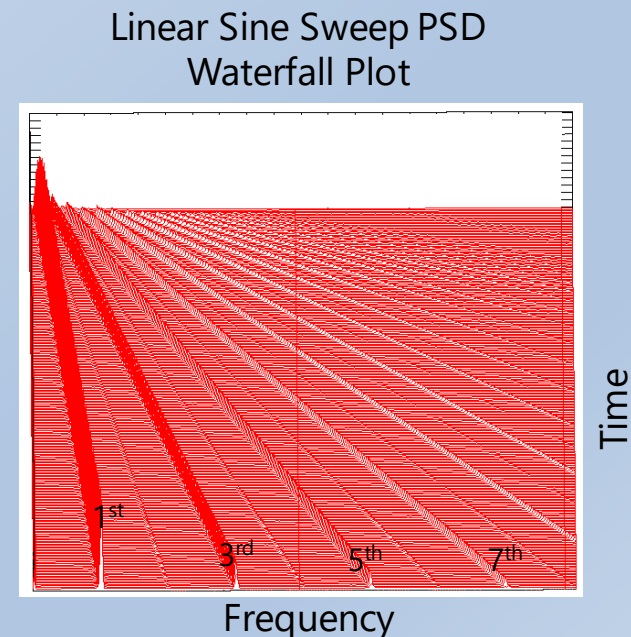
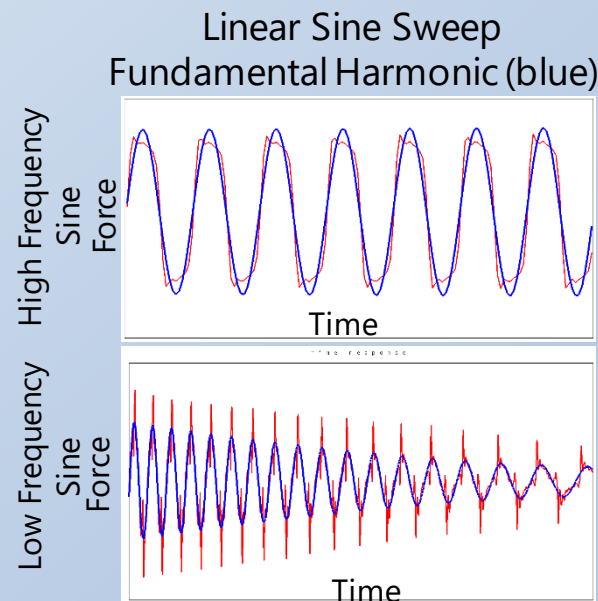
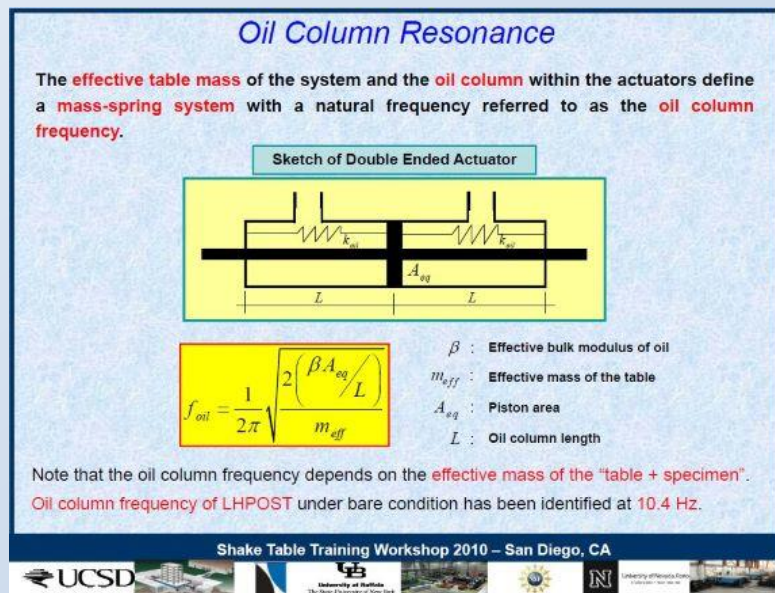


- Hydraulic actuators have a dynamic and a mechanical stroke limit.
- When the hydraulic actuator reaches its dynamic stroke limit, the piston starts to engage its dashpots that begin to bleed off the hydraulic fluid that is applying the force on the piston in order to try and reduce the piston's velocity prior to reaching its mechanical stroke limit where it impacts the housing's mechanical stops.
- Hydraulic actuators should not be driven to exceed their dynamic stroke limits for two reasons:
 - Engaging the dashpots introduces more nonlinear distortion in the hydraulic actuator force.
 - The distance between the dynamic and mechanical stroke limits is relatively small, so exceeding the dynamic stroke limit likely means the mechanical stroke limit will be reached. Repeated high velocity contact with the mechanical stops can result in permanent damage.

Hydraulic Modal Shaker Force Nonlinear Distortion 1



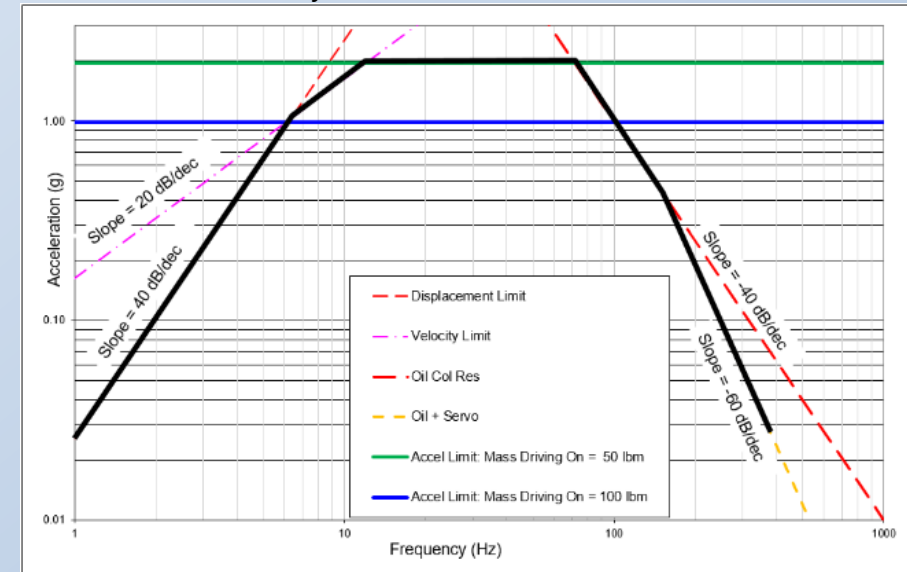
- Hydraulic modal shaker forces can have significant nonlinear distortion.
 - Servo valve nonlinear flow response.
 - Hydraulic actuator oil column resonance.
 - Effective bulk modulus of a hydraulic fluid is a function of pressure and amount of entrained air.
 - Formation of air bubbles in the hydraulic fluid can lead to cavitation in the hydraulic power supply hydraulic pumps, which can cause them to fail.



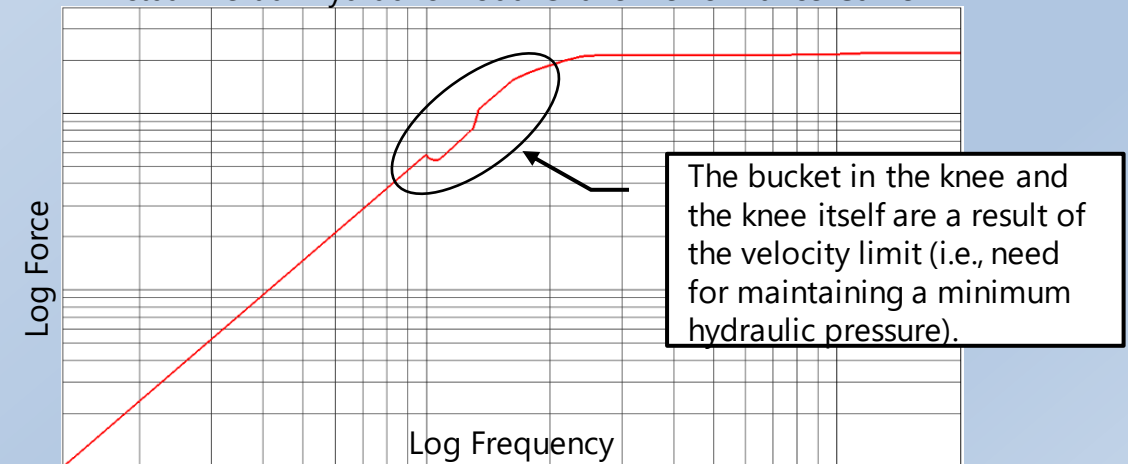
Hydraulic Modal Shaker Performance Limits 1

- Hydraulic modal shakers performance limits are defined by:
 - Peak displacement (i.e., equal to or slightly less than dynamic stroke length limit).
 - Peak velocity (dependent upon hydraulic power supply maximum flow rate).
 - Peak dynamic force.
 - Oil column resonance frequency.
 - Servo valve corner frequency.

Theoretical Fixed Hydraulic Modal Shaker Performance Curve



Actual Inertial Hydraulic Modal Shaker Performance Curve



Hydraulic Modal Shaker Operational & Safety Concerns 1



- When using hydraulic modal shakers and their associated hydraulic power supplies and hydraulic hosing, safety procedures should be followed to protect personnel, test article, and facility.
- Potentially high force transient events can be caused by a major failure in the servo controller or in the feedback signals.
- Loss of the command signal to the servo controller will cause the hydraulic modal shaker to use all its available force to remain stationary.
 - Personnel should not be touching or near a hydraulic modal shaker when the servo controller is on regardless of whether the hydraulic power supply is on because there can be significant stored energy in the hydraulic system.
 - Needs to be considered when sizing the hydraulic modal shakers, in the selection of the shaker attachment hardware, and in selecting the drive points.
- Uninterrupted Power Supply (UPS) backups to the servo controllers are highly recommended to ensure the servo controllers remain under power in the event of a power outage to minimize any transient forces into the test article.

Hydraulic Modal Shaker Operational & Safety Concerns 2



- Of fundamental importance is that the pressure rating of the actuators, bearings, and supply lines are documented and that the hydraulic power supply is not allowed to exceed these maximum pressure limits.
- Safety issues related to spillage and leakage need to be considered in the test planning, preparation, and execution.
- Safety procedures for inspection and detection of leaking/cracked hydraulic hoses should be implemented to prevent potential contamination of the test article with hydraulic fluid.
- Personnel safety procedures should be followed to prevent personnel from being exposed to the hazards from operating hydraulic systems:
 - Sprayed by the hot hydraulic fluid.
 - Hit by flailing hydraulic hoses.
 - When handling hoses the potential of having hydraulic fluid injected under the skin, which can have grave medical complications.

Hydraulic Modal Shaker Operational & Safety Concerns 3



- The hydraulic power supply consists of a hydraulic fluid reservoir tank, hydraulic pump, heat exchanger to maintain the hydraulic fluid temperature, and filtration to maintain the cleanliness of the hydraulic fluid.
- It is estimated that at least 75% of hydraulic system failures and maintenance activities are the result of contaminated hydraulic fluid.
- Proper filtration and temperature control are essential for maintaining the quality of the hydraulic fluid and the health of the hydraulic actuator.
 - Hydraulic fluid cleanliness should be tested on a regular basis based on system usage and any time there is a major component failure such as a damaged bearing or valve.
 - When the system is idle, it is highly recommended that hydraulic fluid be continually circulated through the filtration system and that a near operational temperature be maintained.
 - The hydraulic power supply heat exchanger needs to be capable of properly maintaining the temperature of the hydraulic fluid.
 - Hydraulic fluid contamination due to the introduction of water must be prevented.



End