Electrohydraulic—The Most Versatile Shaker?

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ABSTRACT

Mechanical shakers are inexpensive, reliable and simple to operate, but unfortunately limited in the types of testing they are able to perform. At the opposite extreme, electromagnetic (EM) shakers are more versatile and expensive, and therefore generally limited to aerospace testing. This article discusses the less well known, but highly versatile electrohydraulic shaker and its application for vibration and shock test needs.

INTRODUCTION

Advanced technology in products and the ever increasing requirements for product reliability have created the need for both advanced vibration test techniques and additional vibration testing of existing products. Many of these test techniques are described in such documents as MIL-STD-810C and MIL-STD-781C. These vibration tests are also used as guides for a number of commercial manufacturers looking for increased product reliability. The equipment available and the application of this equipment is of extreme importance today. It must be capable of reproducing the required test accurately while still offering the versatility required to perform many different types of tests. Basically, three different approaches to the problem of vibration testing exist. I will attempt to objectively look at the uses and limitations of each.

MECHANICAL SHAKERS—PRO AND CON

Mechanical shakers are inexpensive, reliable, and easy to operate. They are reasonably satisfactory for certain tests, most notably for simulating long-term, steady vibration found in certain locations, such as aboard ships. However, their nominally sinusoidal, fixed-displacement, single-frequency-at-a-time vibration is not good simulation of "real world" complex vibrations. Also, their useful frequency range (typically 10 to 60 Hz) is severely limited. They cannot develop variable strokes needed for realistic simulation or the higher frequency capability needed for most testing. And, finally, their "nominally sinusoidal" displacement forcing function is often badly distorted with the acceleration response looking much worse.

ELECTROMAGNETIC SHAKERS—PRO AND CON

Electromagnetic (EM) shakers have accomplished much valuable testing, and have contributed greatly to the present reliability and success of our aircraft and aerospace programs. These shakers are almost without peer for very high-frequency vibration testing and calibration of accelerometers. When driven by ultralow distortion amplifiers, they produce nearly pure sinusoidal motion and strokes of a microinch or less are possible.

Electromagnetic shakers are not limited to nominally sinusoidal, one-frequency-at-a-time motion, as are mechanical shakers, but rather:

1. can be used to synthesize random vibration;
2. can be used to reproduce vibration time histories that have been stored on magnetic tape, as is popular in the automotive industry; and
3. can be used to perform certain shock tests.

The difficulty with testing large items at frequencies above 1000 Hz when item dimensions approach 48 inches (1.2 m) (or one-quarter wave length at the propagation velocity within the item) is that resonant responses are so complex that motion cannot be controlled. This difficulty has led many laboratories to attempt vibration control with multiple accelerometers and additional electronic controls that:

1. select the largest accelerometer signal; or that
2. compute an average acceleration value for control purposes.

Many MIL-STD test procedures were intended to apply only to components and small assemblies. Upper test frequencies of 500 Hz and later 2000 Hz seemed appropriate. But as test item size increases, the frequency ceiling should drop. Acoustical environment testing becomes appropriate when large test items must be tested to high frequencies. (More will be said about intense noise environmental testing combined with low frequency vibration testing later in this article).

EM shakers have some drawbacks which should be considered:

1. High cost per pound force:
   System costs per pound force, when a high-powered, low distortion amplifier is included, are very high.
2. Limited stroke:
   Strokes of only one inch (25 mm) are generally available.
3. Limited force:
   At very low test frequencies, available force may be insuffucient. Also, waveforms are apt to be poor.
4. Armature cooling presents problems.
5. Stray magnetic fields (both alternating at shaker frequency and direct) adversely affect some test items.
6. EM shakers are very heavy and hard to move from place to place between tests.

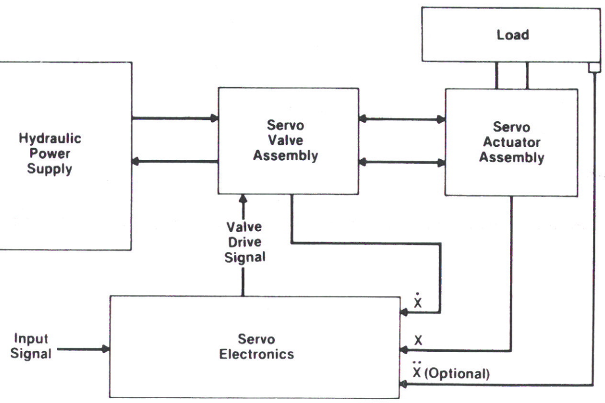

Figure 1. Block diagram of typical electrohydraulic shaker system.

ELECTROHYDRAULIC SHAKERS— HOW THEY WORK

Nearly every vibration textbook over the past century has described how mechanical shakers work. Nearly every text since 1950 has described EM shakers and pointed out their similarity to loudspeakers. Although electrohydraulic (EH) shakers have been in use since the early 1950's little has been said about how they work or their capabilities. The EH shaker system functions similar to the EM shaker system in that an electrical command signal is converted into mechanical force or motion that is used for vibration testing. Figure 1 shows a typical block diagram of an EH shaker system.

The servo-controller is used to monitor the variable system parameters (null position, piston position, power valve position, force, acceleration, etc.) and sum them with the command signal to generate the error signal which then drives the servo valve.

Figure 2 shows a cutaway of the valve/shaker itself to illustrate how this electrical signal is converted into the required motion of the piston rod. The electrical signal is used to drive the electromagnetically actuated pilot valve. The oil flow output of this valve is proportional to the electrical drive signal. On applications where this flow rate is not enough to reach the required system performance, a large power valve is used as a hydraulic flow amplifier. Flows of these power valves range from 30 to over 500 GPM (114 to 1890 l/m).

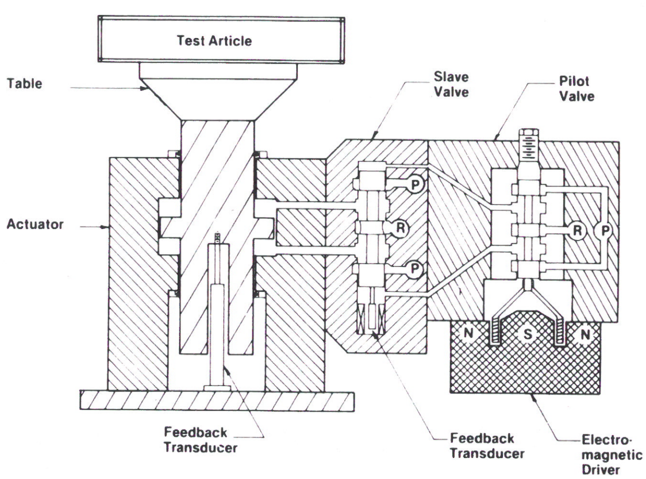

Figure 2. Cutaway of servo valve and electrohydraulic shaker.

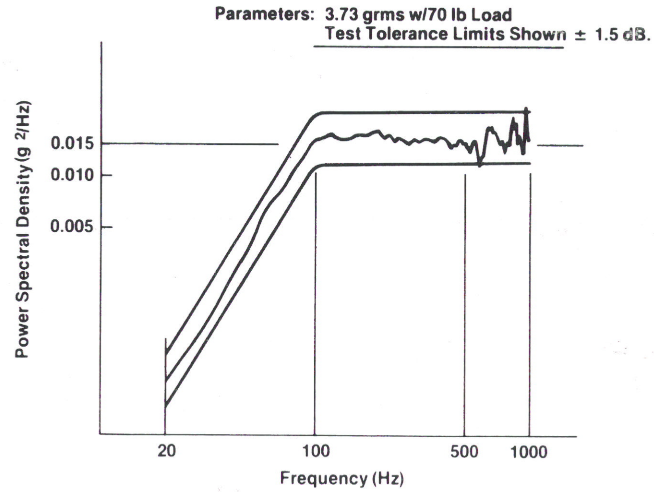

Figure 3. Example of power spectral density output from electrohydraulic shaker system.

The actuator piston (and any attached table/specimen) is driven back and forth by the differential pressure acting first on one side of the piston head and then the other. The valve assembly (pilot or pilot/power combination) is always mounted as close to the cylinder as possible to minimize the oil volume between the valve and piston head. This is because the oil is compressible and appears as a spring in series with load.

ADVANTAGES OF ELECTROHYDRAULIC SHAKERS

EH shakers have a number of advantages over both mechanical and EM shakers:

- Stroke capabilities range from 1 inch (25 mm) to over 20 feet (6 m), with the most common stroke length in the 2- to 6-inch (51 to 152 mm) range.
- High forces and high velocities are available. 80,000 lb. (36287 kg force) units have been built for testing heavy specimens and systems with velocities of up to 350 in/sec (9 m/sec) have been supplied for testing of smaller specimens. These shakers also have the capability of very low frequency vibration (.001 Hz) and ability to vary the null point about which they are vibrating.
- The usable frequency range extends from 0 to 1000 Hz. The upper frequency limit is affected by the stroke of the actuator. Oil compressibility causes the motion of the actuator to be attenuated at frequencies above the first system resonance. The first resonance frequency is reduced as actuator stroke is increased.

EH shakers are used in simulating such vibration environments as:

Transportation effects on packaged products
Roadway effects on automobiles, trucks and components
Earthquake effects on structures.

Very low-frequency (less than .2 Hz) and long-stroke (10 inch/25 cm) systems with low acceleration distortion are also possible and find application in gyro and motion sensor calibration.

EH shakers are able to perform all types of vibration tests; sinusoidal, pure random, shaped random, shock and motion histories inputed from magnetic tape. Figure 3 is an example of a power spectral density made with a typical hydraulic shaker system.

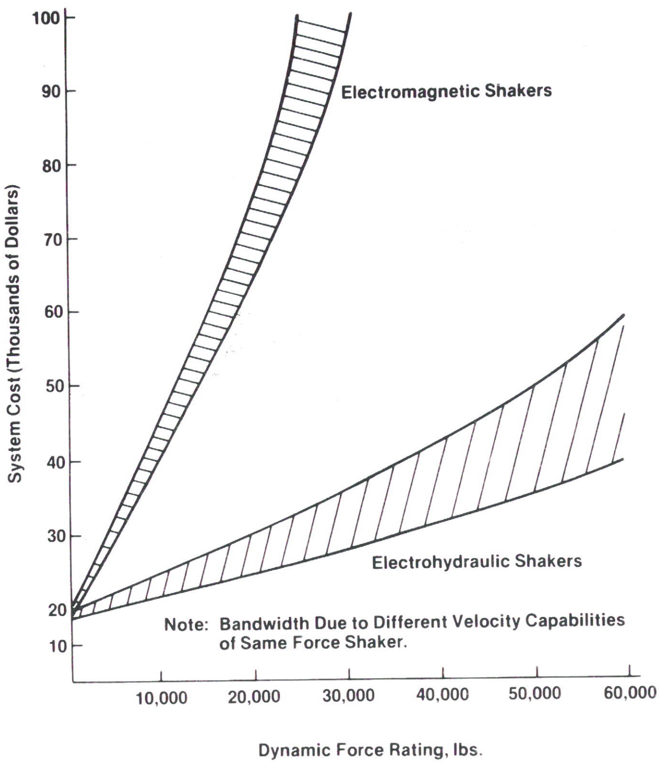

Figure 4. Shaker system cost vs. shaker force output.

This test was controlled with one of the new automatic digital vibration control systems presently available.

Figure 4 gives a graphic display of system costs vs. shaker force. The scaling of this graph is such that the common force ratings of mechanical shakers (100-1000 lbs/45-454 kg) does not show up, but these units are priced below both the EM and EH shaker systems. It is clear from this graph that the system costs of EH shakers fall between those for mechanical and EM shakers. It is very apparent that there is a significant difference in price for force ranges of 10,000 lbs (4536 kg) and over. The variance of dollars in this graph is due to the fact that one particular force shaker may be supplied with different velocity capabilities.

COMBINING VIBRATION WITH INTENSE NOISE TESTING

Earlier I stated that high-frequency vibration testing of large packages is seldom appropriate. There is no way that the shaker can control high-order response modes. The shaker may vibrate, but at many frequencies the vibration does not penetrate far into the test item.

We know that vibration of up to 10,000 Hz has been measured inside flight equipments, but at these frequencies most structures appear as isolators and at least part of the energy transmission path was acoustic. Increasingly, therefore, intense noise testing is gaining popularity.

At least two laboratories have combined practical low frequency vibration generated by hydraulic shakers with intense noise while varying temperature and/or altitude and humidity. The launch phase simulator at NASA's Goddard Space Flight Center, Greenbelt, Maryland was the first to use this approach.[1] Three EH shakers for low-frequency vibration have recently been added to the acoustic environmental testing of missile guidance packages being done at the Navy's Pacific Missile Test Center, Point Mugu, California.

SUMMARY

The vibration test equipment available today seems to be somewhat self-sorting by both application and system costs. On the low end of the scale, both in capability and system costs, are the mechanical shakers. These would appeal to those involved in limited testing at fixed frequencies up to 60 Hz. On the high end of the scale are the electrodynamic shaker systems. These are typically used to perform military/aerospace testing up to 2000 Hz with a maximum displacement of 1-inch (25 mm). In the middle are the electrohydraulic shaker systems with virtually unlimited stroke capability and forces up to 80,000 lbs (36287 kg). These shaker systems appear to offer the most versatility for the investment. ■

Reference

1. Simpson, M., "NASA's Unique Environmental Test Facilities," *J. of Environ. Sciences, XX,* 1977, p. 11-15.

Bruce Huntley has recently taken over the marketing and sales activities at TEAM Corporation. He has worked in both design engineering and applications engineering at TEAM. Mr. Huntley graduated from California State University, Fullerton with a B.S. in Mechanical Engineering. He is a member of the IES, Fluid Power Society and the ASQC. ■