Comparison of Fatigue Test Systems: Servohydraulic, Servopneumatic,

Single Phase & Multi-Phase Linear Motor Driven

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Fatigue testing has undergone several major technology changes over the last two decades. Prior to 1990, almost all fatigue testers used servohydraulic principles to apply load to the test specimen. Servohydraulics had been used since the mid-1950s and was the de facto standard technology when building material, automotive, aerospace, and large structural testers. In the 1990s, manufacturers started experimenting with other drive technologies including servopneumatics and linear motors. While most 21st century medical device testing applications leverage linear motor technology, each technology possesses unique characteristics that make it indispensable to medical device testing.

Servohydraulics (SH)

When most people think of a servohydraulic test system, they usually think of MTS Systems. MTS Systems introduced the first servohydraulic test system when it was the Material Test Systems Division (aka MTS) division of Research Incorporated back in in the mid-1950s. MTS employed servovalve and hydraulic cylinder technologies designed for aerospace flight control systems and applied them to fatigue testing. Prior to that time, fatigue tests were either done on rotary bend machines or resonance (spring/mass) tests systems. The advantage of the new servohydraulic approach was that the loading "R" Ratio could be controlled to something other than -1.0. Additionally, the applied loads could be scaled from several kilonewtons to several meganewtons, and the number of loading channels was scalable as well. For example, a simple fatigue tester might have only one loading actuator while an airplane wing test rig might have 30 to 40 actuators. As the market for servohydraulic tests systems matured, other companies entered the market. Today, the suppliers of servohydraulic tests systems include MTS, Instron, Saginomiya, Shimadzu, Shore Western and Zwick.

MTS Bionix Axial Torsion System

Servohydraulic System Advantages:

- Servohydraulic actuators can be sized for just about any loading requirement.
- The actuator can be designed with almost any stroke although the most common stroke lengths are 100mm, 150mm or 250mm.
- Servohydraulic actuators are also relatively easy to design so that if you have a special stroke and force requirement, a new custom actuator can be designed in a matter of hours.

So if servohydraulic technology was the standard for so many years, what were the disadvantages that caused people to look for alternate approaches to applying load to a test specimen?

Servohydraulic System Disadvantages:

- The minimum practical force rating that a SH actuator can be designed to is about 5kN. For loads less than 5kN, the friction of the oil seals causes problems with the system resolution.
- Another issue people have in the medical device area is cleanliness. If the SH actuator seal leaks during the test, you can contaminate the test specimen.
- SH actuators are designed to last tens of millions of cycles without fatigue failures or seal leakage. While this level of longevity works well for the typical orthopedic test which lasts 10 million cycles, it's not durable enough for cardiovascular device tests that typically run 400 to 600 million cycles.
- SH systems require significant infrastructure and maintenance. The SH system requires a high power (minimum 5HP) hydraulic pump with an oil supply that needs to be changed out on a regular basis. Additionally, excess heat is usually dissipated using a heat exchange system that uses tap water run to a drain for cooling.

Servopneumatic (SP) Test Systems

An SP test system is similar to the hydraulic test system except that it uses compressed air instead of hydraulic fluid as the driving media. EnduraTEC introduced these systems to the orthopedic market in the early 1990s as a lower cost alternative to the SH systems. While the SP systems held promise for making an impact in this market area, they did not catch on for several reasons:

- Performance frequency of the SP systems is not as high as the SH systems because of the compressible nature of air.
- Customers performing orthopedic testing usually had already made the investment in the infrastructure required to run hydraulic systems. Consequently, there was no compelling reason for them to change over to the SP technology.

EnduraTEC SP Test Instrument

For lower force (i.e., less than 1kN) and moderate test frequency (10 Hz or less) applications, SP systems represent a viable alternative to SH systems. The only manufacturer that supplied SP systems was EnduraTEC.

Single Phase Linear Motors (SPLM)

Single Phase Linear Motors generate a force that is proportional to the amount of electrical current applied. In the mid-90s, EnduraTEC began delivering tests systems with voice coils for stent and wire testing. Patent 5,670,708 represents a stent graft tester that was developed using two voice coils as the driving means. Voice coils were later replaced with a moving magnet linear motor developed by Bose Corporation. The moving magnet design was superior to the voice coil approach because it eliminated the flying leads which were prone to fatigue failure, was easier to cool and had a lower moving mass. The moving magnet motor was also

Bose ElectroForce Test Instrument

employed in the ElectroForce Fatigue Test Instruments supplied by EnduraTEC (later Bose and then TA Instruments).

SPLM Advantages over SH and SP Technologies:

- Their low output force range is ideally suited for testing small medical devices developed for the intravascular market.
- The flexure bearing system and moving magnet design provide extremely high longevity. MDT currently has SPLM-based test systems that have been running continuously for the better part of 15 years.
- The power required to drive a SPLM is quite low compared to the power required to drive an SH or SP system.
- Test frequencies 60Hz and higher are easily obtained due to the low moving mass.

SPLMs Disadvantages:

- A disadvantage of SPLMs is their low force capability although in recent years Bose ElectroForce designed linear motors with 15kN force output.
- The amount of stroke that can be applied is generally limited and is dependent on the size of the SPLM. For example, a 200N SPLM has a 12.5mm stroke and a 2000N SPLM has a 25mm stroke.
- The ability to readily customize SPLMs is almost non-existent due to the nature of the components used. A moving magnet linear motor is comprised of a moving magnet armature assembly, coils for creating the magnetic field, laminates for conducting the magnetic fields and a flexure assembly which allows the magnets to move without crashing into the laminate assembly. It is difficult to design these components for one-off applications.

There is currently only one supplier of test systems which utilize moving magnet SPLMs, and this is TA Instruments.

Multi-Phase Linear Motors (MPLM)

The first MPLM tester was introduced and patented by MTS Systems in 1998. That system featured a horizontally-mounted linear motor that had a 100mm stroke with an air bearing support system. It was designed for precision low force fatigue applications in the semiconductor and medical device testing industries. Despite its advanced design, it did not make much of an impact in the market most likely because it was a new technology that did not fit within the SH paradigm of MTS's culture. After the successful introduction of the SPLM test systems by EnduraTEC in the early 2000's, Instron and MTS decided they needed to offer an electric test system alternative. In the late 2000s, Instron introduced its ElectroPuls Series and in 2014 MTS introduced its Acumen Series of all-electric test instruments. Both systems feature a crosshead-mounted multi-phase linear motor with a moving voice coil or magnet armature that is

Instron ElectroPuls 3000

supported on a linear ball bearing system. The multi-phase design of the linear motor enables it to provide higher loads and a longer overall stroke. For example, whereas the smallest TA ElectroForce Test instrument is rated at 200N and has a 12.5mm overall stroke, the smallest Instron ElectroPuls Test instrument is rated at 1000N and has a 60mm stroke. While one might think that the MPLM approach would be superior to SPLM, there are relative advantages and disadvantages that the MPLM has with respect to the SPLM as follows.

MPLM Advantages over SPLM:

- More phases means the motor can generate more power. If the magnet assemblies are sized the same, a MPLM with three magnets (required for the multiphase motion) will generate twice as much force as an SPLM with a comparable-sized single magnet.
- The MPLM has longer stroke capability. This makes it easier to test longer specimens and to set up tests as the longer stroke provides more flexibility.

MPLM Disadvantages Compared to SPLM:

- Since the moving armature in an MPLM has more coil or magnet assemblies, the moving mass is greater. This means that at high test frequencies, the vibration induced into the test bench or floor can be substantial if care is not taken to isolate the frame from the bench.
- Due to the high moving mass, the ability to run the tester at accelerated frequencies is limited. Whereas the SPLM is quite comfortable running at 60Hz and up, MPLM systems generally have difficulty achieving frequencies higher than 30Hz.
- To provide a longer overall stroke, the MPLM system features a roller bearing support system. We are hopeful that this design will facilitate multi-hundred million cycle fatigue studies and are currently evaluating the durability of the bearing design.

Conclusion

MDT has a wide breadth of equipment including SH, SP, SPLM and MPLM test systems at its disposal. When setting up a test, we are able to choose the test system that is most appropriate for the desired test conditions. For example, if you want to test up to 15 specimens at high frequency (30Hz or greater) by applying a few millimeters of displacement, we would utilize a SPLM test system. If you want to test a single specimen at high loads and a lower test frequency we would look at using either an MPLM or SH based system. With our extensive equipment base and broad experience in the mechanical testing arena, MDT is able to provide the most reliable test conditions possible. Please contact us today with your testing requirements. We look forward to working with you.