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MOOG

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Feature Article
Aircraft Structural Testing

Aircraft Structural Testing

Using Motion Control Technology to Minimize Fatigue Related Accidents and Extend Operational Life

by Roy Park, Managing Director and Site Manager, Moog Australia


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Fatigue testing is a critical requirement for military aircraft to determine the life span of safe, economical service and extend the fleet beyond the specified flying hours. This testing can save governments many millions of dollars by delaying the purchase of replacement aircraft.

Let me provide some background on the challenges associated with this testing. You may think that one set of tests can be used for a particular aircraft around the world. Unfortunately, the mission profiles and usage varies significantly between countries such that individual testing is normally required to determine a safe life span and the extended operating hours.

Another challenge is simulating fatigue for a military aircraft. Load spectrums are gathered from instrumentation of actual flights over a period of about 12 months. From this flight data a compressed load profile is created using only the significant manoeuvre loads that cause fatigue. This loading is applied for the long term testing of an actual aircraft structure. For each hour of actual flying time the tests equate to approximately 10 minutes of testing.

This saving in test time is increased by the factors needed to validate appropriate life span providing for a margin of error on fatigue failures. Most new aircraft are provided with strain gauges for monitoring flight loading. Hence for a monitored aircraft the test must achieve 3 times and for a non-monitored aircraft 5 times the actual lifetime.

By operating the test continuously for 3-5 years or more, it is possible to complete the necessary full-scale testing hours ahead of the real flight time. It is interesting to note that more than half the test period is taken up with inspections to detect any cracking.

For more than 20 years Moog's facility in Australia has been designing and supplying custom low friction servoactuators for aircraft testing applications. We have partnered with many customers on important programs such as the FA18, Pilatus, F111 and more recently the P3 Orion test programme. The challenge Moog met was to create a specialized actuator design capable of achieving critical performance parameters required that are not possible to achieve with standard industrial cylinders. In addition, Moog developed a unique abort manifold for static and dynamic testing that is superior to that previously available.

BAE Hawk Mk127 Lead-in Fighter

Over the past 50 years, the Defence Science and Technology Organization [DSTO] in Melbourne has been widely recognized for its expertise as a world leader in the fatigue testing of defence platforms. When the Australian Government made the decision to purchase the BAE Hawk Mk 127 Lead-in fighter for the Royal Australian Air Force, DSTO was tasked with completing the programme in conjunction with BAE Systems. Hydraulic servoactuators and controlled abort manifolds for the project were designed and manufactured by Moog in Australia.

Test System Hardware

The main control system applies and monitors loads to the test structure from 83 hydraulic and 7 pneumatic channels simultaneously. Hydraulics is used to apply simulated flight loads across the complete airframe and pneumatics to pressurise the cockpit and fuel tanks. It also includes a 1,200 channel data acquisition system.

Servoactuators

With testing applications it is important to achieve critical performance parameters that are not possible with standard industrial cylinders. These include low friction, high duty cycles and structural rigidity.

For the multi-axis load test of an aircraft structure it is critical to predict and guarantee breakout and running friction for each servoactuator design. Essential factors for achieving these goals are:

- Realistic and repeatable test processes.
- An extensive database of measured values for a variety of solutions.
- Ability to design and produce small batches of custom servoactuators.
- Design and manufacture of customized sealing and bearing solutions including elastomer seals, laminar and hydrostatic.

Analysis of the Hawk test requirements indicated that most would require special design low profile elastomer seals and 15 would need "seal-less" hydrostatic bearings to achieve the extremely low friction levels specified.

Abort Manifold

About 3 years ago, Moog embarked on a development project for a new generation abort manifold to manage the controlled abort of the test should a fault condition occur.

Traditional abort manifolds use a conventional flow control valve to regulate the relaxation of the servoactuators. The new design has closed-loop pressure control using a Direct Drive Servo-Proportional Valve [DDV] so that the load is ramped at a controlled pressure using pressure transducers for feedback to the abort control system.

As part of the contract qualification, abort test rigs at DSTO were used for static and dynamic simulation of this critical aspect of the full-scale testing. Incorrect abort has the potential to corrupt test results, damage the full-scale test specimen and ground the fleet of aircraft.

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Key features of the Abort Manifold design are:

- Modular construction for "active" [closed-loop] abort or conventional "passive" fixed orifice abort.
- Optimized transition from normal control to abort to minimize structural disturbances.
- Developed under aircraft standard Failure Mode, Effects and Criticality Analysis for optimal reliability.
- Extensive static and dynamic performance testing.

The contract was recently completed and integration is well advanced at DSTO for full system start up during 2005.

Aircraft test systems demonstrate Moog capabilities for improving motion control and safety for material test applications. The requirements for high performance servoactuators, controlled abort and digital system control are also common for a variety of applications ranging from flight simulators to turbine controls to high speed injection moulding machines. Moog provides high performance hydraulic and electric motion control solutions for some of the world's most challenging machine designs.

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About the Author:

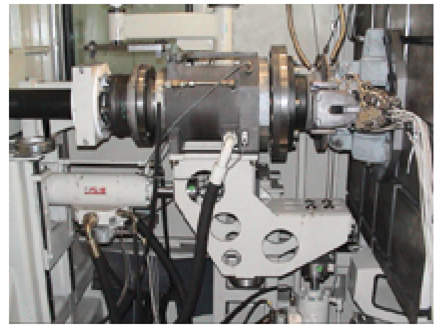
Roy Park has 32 years experience in engineering, marketing and management in the hydraulics industry including the past 21 years as Managing Director and Site Manager for Moog Australia. He has a B.E. honors degree in mechanical engineering from Monash University.

Did You Know?
Electro-Hydraulic Axes Control Solution for a Car Wheel Bearing Test Stand

Did You Know?

Electro-Hydraulic Axes Control Solution for a Car Wheel Bearing Test Stand

Bernhard Zervas, System Engineering Manager, Moog Germany



The development and production of wheel bearings requires comprehensive tests to achieve and maintain high quality standards. Bearings have to be tested for longevity of lifetime as well as suitability for different load conditions.

Testing of wheel bearings in a vehicle is time consuming and expensive. To automate testing of wheel bearings, a new test stand design was developed by Renk/FAG Kugelfischer AG. The challenge they faced was simulating the real load of a vehicle, which entailed designing the test stand with the capability to simulate all possible static and dynamic load conditions acting on a wheel bearing. For example this test stand must simulate the recorded load cycles measured in a specific vehicle driving on a racetrack.

Four electro-hydraulically controlled axes simulate the wheel bearing load conditions as follows:

- Brake system to control position, force, or torque.
- Horizontal load axis to control position or force.
- Vertical load axis to control position or force.
- Radial load axis to control position or force.

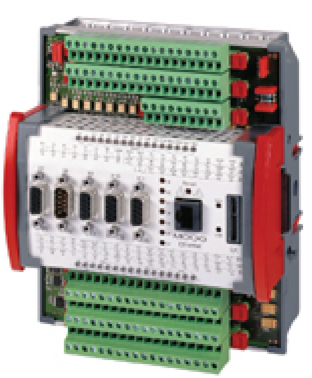
Technical Requirements

- Requested dynamics - 20 Hz sinus @ 50 % of maximum demand
- Requested accuracy - better than ± 2 % of full scale

D765 Servovalves

The horizontal, vertical and radial axes simulate the 3D bearing loads caused by the surface of the road, steering angle, acceleration, and speed of vehicle while the 4th brake axis also simulates the brake loads caused by the vehicle's inertia. The heart of the electro-hydraulic axes are Moog's D765 Servovalves with customized flow characteristic.

In close cooperation with the test stand user FAG Kugelfischer AG and the test stand builder Renk, Moog developed the closed-loop electro-hydraulic axes control algorithms for all four axes as well as the CANopen bus communication with the host controller and data acquisition system.



MSC (Moog Servo Controller) With CAN-Bus, Profibus and Ethernet Interface

The control hardware is the Moog Servo Controller (MSC), the programming software is the Moog Axis Control Systems (MACS) which is based on CoDeSys the IEC 61131-3 programming system. CoDeSys is one of the most powerful IEC 61131-3 programming tools for controllers applicable under Windows. All five programming languages of the standard are supported. CoDeSys produces native machine code for all common processors. CoDeSys combines the power of advanced programming languages such as C or Pascal with the easy handling and operational functions of PLC programming systems.

About the Author:

Bernhard Zervas is currently the Systems Engineering Manager for Moog's Industrial operations in Germany. He has over 30 years experience in the international hydraulic industry, with a focus on industrial electro-hydraulic closed-loop, electro mechanical and hybrid applications.

Hot Websites

Take a Look at These Various Testing Websites:

The American Society for Testing and Materials-ASTM (www.astm.org)
ASTM International, is an open forum of high-quality, market-relevant international standards used around the globe. This site has a vast source of material for you to use including a standards search function as well as books, journals, symposia, training, and much more.

Defense Science and Technical Organization-DSTO (www.dsto.defence.gov.au/research/air)
The DSTO is part of Australia's Department of Defence. DSTO's role is to ensure the expert, and impartial innovative application of science and technology to the defence of Australia and it national interests.

Aerospace Testing Expo 2006-Europe (www.aerospacetesting-expo.com/Europe)
Aerospace Testing Expo 2005-North America (www.aerospacetesting-expo.com/northamerica)
This is the site for the dedicated international trade fair for Aerospace Testing, Evaluation and Inspection that takes place in Europe and , now in North America. It tends to provide a showcase of the latest equipment, technology and specialist services meeting civil and military aerospace testing, evaluation and inspection program requirements.

European Federation for Non-Destructive Testing-EFNDT (www.efndt.org)
This helpful site is for the European Federation for Non-Destructive Testing (EFNDT). It was founded in 1998 by 27 national NDT societies who agreed to set up a powerful organization on a European level to develop powerful working groups that would provide answers to NDT problems of industrial and public organizations There is a full program of qualifications and certifications as well.

Product Spotlight - Electric Testing System

European Railway Train Monitoring System - Electric Test System for Simulating and Measuring Performance

by Bruno Fazzari, Sales Manager, Testing and Systems, Moog Italy

Moog has developed a complete electric test system named the European Railway Train Monitoring System (ERTMS) for the Italian Railway Company, Trenitalia. This system tests the speed of the train and simulates the behavior of the train equipment during normal use on the line. Data on behavior is based on over 300 conditions collected by Trenitalia using a special black box installed on the trains. This test system makes it possible to verify what might happen when a particular condition is encountered. This unique ability to test and measure simultaneously is one of the key benefits of the Moog Solution.

The Moog Solution involved the development of 2 different electric simulators and one pneumatic as follows:

- Ground Railway Simulator
- Wheel Simulator
- Brake Simulator

By replicating real conditions and certifying components using the same testing machinery it is possible to ensure safety and quality of the train under numerous possible conditions, while saving time and operating costs.

Ground Railway Simulator

This electric testing apparatus is able to simulate the movement of the train with the ground. It is based on 2 electric servomotors working on 2 parallel axes that move 13 belts. The rotation of the belts is able to simulate the velocity between the train and the ground. This test machine has 2 columns where it is possible to install the radar and the instrumentation.

This testing apparatus is enclosed in a sound-proof cabinet to ensure safety and noise protection, The maximum speed reached from the test bench is 180 km/h with an acceleration and deceleration of 3 m/sec. The velocity closed-loop system is made using the Moog DS2000 servodrive and brushless servomotors.

Wheel Simulator

The Wheel Simulator Testing apparatus simulates 2 wheels of the train and uses Moog's brushless servomotors and a T200 Moog Servodrive for motion control. Simulation of a complete train requires 4 test benches as 8 wheels correspond to the complete locomotive.

One advantage of this machine is the ability to measure the speed of the wheels by simulating the velocity of the train and verifying the measurement of the sensors used on the train. As the Ground Railway Simulator approaches the velocity set (which correspond to the velocity of the wheels) a mathematical model of the complete train is applied.

Brake Simulator

The Brake Simulator Testing apparatus uses 8 pneumatic actuators to simulate the actuation of the brakes. Specially developed mechanical springs are used to create the load on the actuators. When the train is braking the wheel simulator will reduce the speed. For example, when simulating the train stopping at the station, the Ground Railway Simulator will reduce the velocity of the belts (both the test systems are correlated by a mathematical model) and the hardware for the brake will make the train stop.

Conclusion

To complete this project, Moog in Italy collaborated with Trenitalia and the University of Firenze who prepared all the specifications. Moog designed and manufactured the complete test system in its facility in Italy. Moog was invited to participate in this project and has an agreement for further cooperation continuing in the future. This project was an ideal example of how collaboration results in the development of a superior solution. In this case the result is a test system capable of replicating.

About the Author:

Bruno Fazzari is currently the Sales Manager for Testing and Systems for Moog in Italy. He is an Electrical Engineer and has studied Physics at the University of Milan. In addition Bruno's background includes working as a System Engineer at Magnaghi Aerospace.

Ask the Expert

Safety Abort Manifolds for Aircraft Fatigue Testing

by Graeme Burnett, Aerospace and Commercial Consultant Engineer

How do you know if you need to use a safety abort manifold? What options do you have in its selection?

Hydraulic actuators provide a long life, economical, and low maintenance solution to applying load for the durability and ultimate strength testing of aircraft. However the high cost of test articles (in many cases a whole aircraft) and the long duration of fatigue tests, means that the probability of accidental damage to the test article due to equipment malfunction has to be minimized to (almost) zero. Consider that there is no possibility of carrying out a second test if an initial test is ruined. This means that systems designed need to tolerate component failures without compromising the safety of the structure under test. The problem is increased dramatically in situations where there can be more than one hundred actuators, mostly providing force control, simultaneously applying load to a complex structure that has a high level of cross coupling between channels.

A proven safety-by-design approach to this problem is to assume that every component (electrical and mechanical) can fail one at a time, possibly in multiple ways, and that there is hydraulics hardware, electronic controllers and control software capable of dealing safely with these failures. Examples of failures might include: solenoid valves failing to turn on as well as fail to turn off, servovalves failing in full-flow or a no-flow conditions, and relay contacts or semiconductor switches fused closed as well as open.

To provide an adequately safe system, a significant number of hydraulic components are required to supplement the primary servovalve, hence the need for a manifold as the smallest and most cost effective packaging solution for the hydraulics components. The following provides some of the reasoning for combining the main components within a safety abort manifold, and an insight into what influences the selection.

To achieve the desired control response, an optimally-sized actuator and servovalve will have full scale load pressure about two thirds of the supply pressure. This could mean an incorrectly configured controller could accidentally apply 50% overload, which could completely ruin the fatigue specimen. To avoid this, tension and compression cross-port relief valves are needed across each (equal area) actuator to limit the load independent of software settings. The limits are set typically 10% above the test full-scale load. In addition, to supplement this and cover several other possible single component failures, it is standard practice to have dual load cells on all loading channels to provide independent redundant load limit sensing and shutdown within the controller.

To accommodate a failure, the servovalve needs to be isolated from the actuator to either prevent further oil getting to the actuator or to prevent uncontrolled unpredictable leakage from the actuator through the servovalve spool. To provide this isolation, a pair of pilot-operated servo lock valves are needed between the servovalve and the actuator.

If some actuators have leakage, either by seal wear or deliberately to reduce friction, then having the system remain in a locked up state is undesirable. This is because it is possible because of structural interaction for the load in some locked up actuators to increase in load as the load is shed by other leaking actuators. For this reason it is desirable to quickly remove all load from the structure, typically over a period of five to ten seconds.
The unloading mechanism chosen for a system depends mainly on what the test structure can safely withstand under the test range of complex unloading conditions. In most cases, a Passive Abort is acceptable; however for this approach the time it takes to unload each actuator is dependent upon initial load in that actuator at the start of shut down. It is possible to adjust the needle valve for each actuator to have all actuators unload in the same time from one high-level complex load condition. However a shutdown from a different multi-channel load condition will result in some actuators unloading faster than others, which for some tests can cause undesirable reaction imbalances during the unload cycle. If however, balanced unloading under all possible initial conditions is required to maintain a reaction balance, then Controlled Abort is required. This can be Controlled Load Abort, Controlled Pressure Abort or even Controlled Displacement Abort depending on the feedback variable supplied. Any of these options have the advantage that they can be electrically set up. However it does add considerable cost because of the need for an additional unload control servovalve, transducers and an unload controller. It should be noted that the unload valve needs to be a Moog Direct Drive Valve as the pilot pressure will have been switched off or has failed during the unload cycle and this technology is ideal for this situation.

Although it is undesirable to have non-equal area actuators for control and cross-port relief reasons, it may be necessary. If there is no way of avoiding this type of actuator, then a more complex controlled unloading controller and unloading control valve configuration is required than is needed for equal area actuators. This is because to achieve the desired unload waveform, pressure has to be sometimes removed from the chamber with the lower pressure.

In conclusion, safety abort manifolds are essential on fatigue and ultimate strength tests where accidental damage to the structure under test cannot be tolerated. The decision to use a Passive Abort Manifold rather than Controlled Abort Manifold depends on the budget, set-up convenience, structural limitations and test requirements. The Moog Abort Manifolds do have a common base manifold for all configuration options.

The Hawk Lead-In-Fighter Full-Scale-Fatigue-Test uses a both Moog's Passive and Controlled Abort Manifolds under the control of an MTS Aero ST unload controller that is completely independent of the primary control system.

About the Author:

Graeme William Burnett is a guest contributor for the Moog newsletter sharing his expertise gained in over 35 years of work experience with the Defence Science and Technology Organisation (DSTO), Department of Defence, Melbourne, Australia as an engineer in support of aeronautical research. He is currently the Engineering Manager, Hawk Lead in Fighter, Full Scale Fatigue Test contracted to DSTO, Melbourne, Australia.

Upcoming Events

Exhibits and Trade Shows:

- IPF 2005, International Plastic Fair, Makuhari Messe, Chiba City, Japan (September 24-28, 2005)
- I/ITSEC Interservice/Industry Training, Simulation & Education Conference, Orange County Convention Center, Orlando, Florida, USA (November 28-December 1, 2005)
- Plast India, Pragati Maidan, New Delhi, Delhi, India (February 9-14, 2006)
- Plast 06, International Exhibition for Plastics and Rubber Industry, Milan Fairgrounds (Rho-Pero) Milano, Italy (February 14-18, 2006)

For more information, click on **Exhibits and Trade Shows**.

Moog Training Sessions:

Software training: Introduction to MACS / IEC 61131 Programming (2.5 days)

- 29 November - 1 December 2005: German Language Session
- 6 - 8 December 2005: English Language Session

MSC - Moog Servo Controller Hardware and Extension Modules Training (1.5 days)

- 1 - 2 December 2005: German Language Session
- 8 - 9 December 2005: English Language Session

Seminars are held at Moog GmbH in Boblingen, Germany (near Stuttgart).

For more information, click on **Training Opportunities**.

Published Articles:

- Read the article titled Simulation Technology: Feeling Fidelity-Developments in Control Loading in the May 2005 "Military Training and Simulation News" magazine

For more information click on **Published Articles and Newsletters**

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