MOVING YOUR WORLD

IDEAS IN MOTION CONTROL FROM MOOG INDUSTRIAL

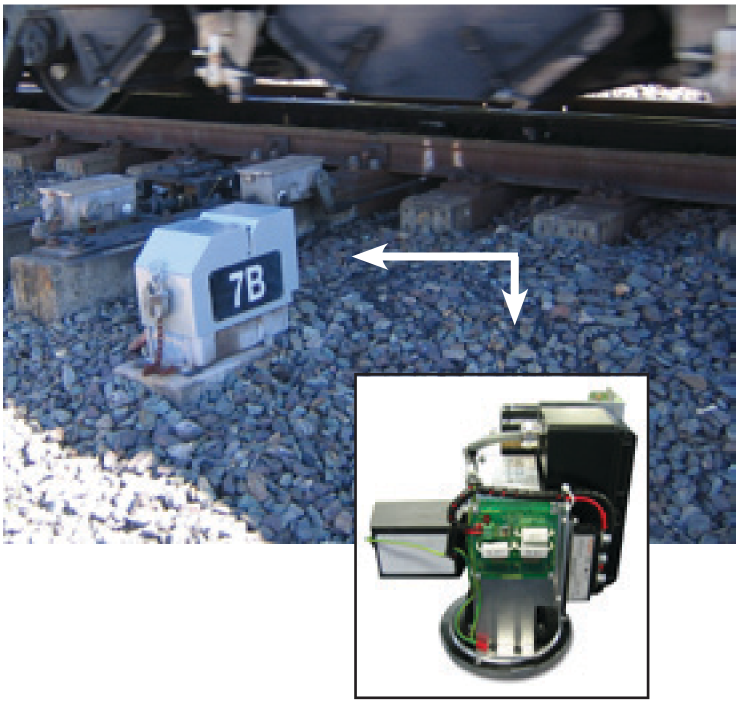
FEBRUARY 2010 | ISSUE 22

MOOG

IN THE AUSTRALIAN OUTBACK WITH THE WORLD'S TOUGHEST BRUSHLESS SERVOMOTORS AND DRIVES

By Peter Clements, Western Australia & Queensland State Manager, Moog in Australia

At the heart of the modern railway network is the "points operating equipment" (POE). These are devices that facilitate the seamless flow of both passenger and freight trains between interconnecting railway tracks. These systems spend their life exposed to the harshest of environments such as extremes of temperature, driving rain, high humidity, and lightning strikes, not to mention the constant exposure to electromagnetic interference (EMI) from high voltage overhead power supply lines.



Moog designed a special robust brushless servomotor and drive for the hydraulic power units placed alongside rail tracks in "Points Operating Equipment." After 2 years of in-field use it has proved to be 100% reliable with no failures.

By far the largest percentage of all POE are powered by small dedicated hydraulic power units (HPU) located directly alongside the track. In recent years there has been a move from within the rail industry to convert the electric motor used in these HPUs from a brushed motor to a brushless servomotor in an attempt to eliminate reliability issues from brush and commutator wear and the problems associated with carbon debris from the brushes falling through the motor windings into the bearings and resulting in catastrophic failure of the motor. Many brands of COTS (commercial off the shelf) brushless motors have been trialled in this demanding application but none have survived beyond a few months.

continued page 2

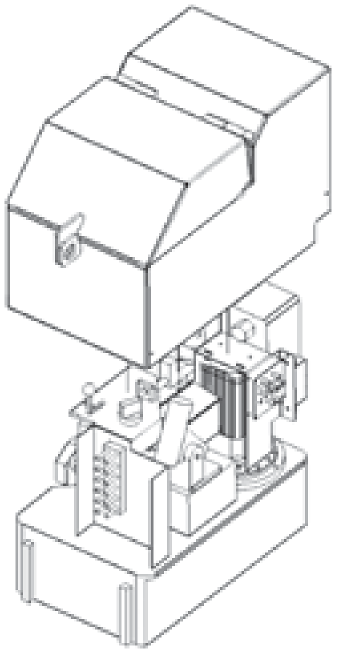
IN THIS ISSUE

Queensland Rail Partners with Moog

Queensland Rail Ltd is Australia's largest passenger, freight and coal rail transporter. They have over 60 million passenger movements per year with a rail network that spans more than 10,000 km's. After a long history of field failures with both the original brushed motors and also the new COTS brushless motors, Queensland Rail approached Moog in Australia to develop an alternative servomotor and drive that would withstand the rigors of this environment whilst providing a robust and field proven solution.

Our major challenge came in designing a solution that would survive two serious threats to the drive electronics:

- Lightning transients that induce thousands of amps into the drive
- Traction fault currents from the high voltage overhead power supply lines that induce many hundreds of volts into the drive.



The Moog brushless motor is designed for both use in new points changing HPU's and also as a 'drop-in' for retrofit into existing HPU's. It provides a fully integrated solution that can be fitted by field maintenance staff within minutes.

The engineering team at Moog in Australia accepted the challenge and built 10 prototype units that were field tested throughout the Queensland Rail network, located at both metropolitan and regional locations that experienced both the highest volumes of rail traffic and also the most extreme climatic conditions.

After 2 years of in-field use, all 10 prototype motors proved to be 100% reliable, with no failures experienced. Not only that, but in many cases the Moog servomotor was located directly alongside groups of POE where the COTS motors continued to fail. As a result of these exhaustive field tests Queensland Rail has endorsed the Moog servomotor and has subsequently issued a Full Signalling Type Certificate approving its use. This is a level of accreditation that is recognized within the international rail community.

Moog in Australia is now in the process of supplying servomotors in production quantities to Queensland Rail in support of an active retrofit program where existing motors are being replaced over a number of years with the Moog solution.

The Moog motor is designed as a 'drop-in' replacement for existing motors and can be fitted by field maintenance staff within a matter of minutes. It can also be supplied with a customized HPU top cover, designed to accommodate the slightly larger Moog motor assembly.

This program demonstrates two elements of what enables Moog to provide superior motion control solutions:

1. Moog's core skill is in designing and building robust motion solutions for the most extreme of conditions.

2. We have access to best-in-class components in house. In this case Moog in India manufactured the base Fastact G 400 Series Brushless Servomotor, Moog in Germany integrated the onboard electronics and Moog in Australia designed and added the customized protection circuitry.

Moog has already been approached by a number of local and international companies who specialize in rail trackside equipment and see the Moog motor as providing a robust solution to what is clearly a global problem.

Author

Peter Clements has been with Moog Australia for 8 years in the capacity of Queensland and Western Australia State Manager. Prior to joining Moog he worked extensively within the Hydraulics industry. Peter studied Mechanical Engineering at the Leicester Polytechnic, Leicester UK and also completed a technical apprenticeship within the UK machine tools industry.

THE FUTURE OF FLUID POWER: 6 CHALLENGES FACING HYDRAULIC ENGINEERS

By Dave Geiger, Hydraulic Systems Engineering Manager, Moog Industrial Group.

Why should a hard-working engineer worry about trends in hydraulic motion control, especially in challenging economic times? Smart engineers know that there is always more to learn from others who are facing similar challenges. Industry associations play an important role in bringing together people who are on the front lines of both issues and challenges facing machine builders. This article explores some trends identified by the National Fluid Power Association (NFPA), headquartered in the United States, that recently brought together a team to articulate a Technology Roadmap for the fluid power industry. Having the advantage of working with many companies in some of the world's most demanding industries, Moog has vast experience developing solutions that address these trends. Electro-hydrostatic systems are a technology area emerging in industrial applications and Moog is looking at it as a promising solution for addressing all of the tough issues identified by NFPA.

Six Challenges for the Fluid Power Industry

1. **Increasing energy efficiency**
2. **Improving reliability**
3. **Building smart components and systems**
4. **Reducing size and weight**
5. **Reducing environmental impact**
6. **Improving and applying energy storage and redeployment capabilities**

Source: NFPA Website Dec. 09.
Visit www.nfpa.com/ourindustry/technology_roadmap.asp

Figure 1: Six Challenges for the Fluid Power Industry

The NFPA in May of this year asked its members to develop a technology roadmap for the next decade addressing six challenges facing the industry. One motivation behind the NFPA technology roadmap is a realization that the industry has to change to face threats from electromechanical solutions that are increasingly encroaching on the fluid power industry's core business, such as power generation and sub-sea drilling applications. As the NFPA and its members see it, the six challenges for the fluid power industry are listed in Figure 1.

There are many implications for designing new hydraulic products and systems that can be considered from these challenges. For example, improving reliability can be accomplished by developing smaller, self-contained hydraulic systems with far fewer components. Size and weight can be reduced by designing a solution optimized for the application. Energy efficiency can be increased by designing a motor rotating only when movement is required and smart components allow greater customer interaction.

A Practical Look at Addressing the Big Six

As Moog is a leader in the design and manufacture of hydraulic solutions and products, we have been a member of the NFPA for many decades. I was selected to represent our company as Moog has an interesting perspective on the topic. We are known for being "technology-neutral" and are one of the few companies that design both hydraulic and electric solutions. Literally, our electro-mechanical and electro-hydraulic teams sit in adjacent cubicles. Every day, these teams see the advantages and disadvantages of hydraulic systems and their competing electro-mechanical solutions, across a wide range of applications as diverse as steel mills, aerospace testing and even wind turbine pitch control.

For each of these trends, our engineers have a fascinating story to tell. For example, as described in Challenge #1 plastic injection molding machine manufacturers have been enjoying greater energy efficiency using the Moog Digital RKP-II (Radial Piston Pump). One of the most high force hydraulic applications, needing extreme reliability for 24/7 operations are automotive test labs that perform structural testing of the latest auto component

continued page 4

prototypes. Moog recently introduced a rugged, compact servoactuator for this market that exactly meets the need identified in Challenge #2 with its compact, self contained piping and special seal-rod technology for a long service life. In this market, Moog also developed a simulation table for automotive R&D testing with a hexapod 6 Degree of Freedom design that has a much smaller footprint and reduced weight yet it can attain higher frequencies than traditional solutions (See Challenge #4).

Smart components, addressed in Challenge # 3, are the area where Moog has invested extensive R&D and application resources. Moog has a range of Digital Servovalves and Digital Radial Piston Pumps that offer the opportunity for customers to use our Advanced Configuration Software to optimize performance, perform diagnostics and provide easier set-up. In addition, there are many examples where Moog offers customers biodegradable fluids and closed-hydraulic systems that are even suitable for clean-room medical manufacturing (See Challenge # 5).

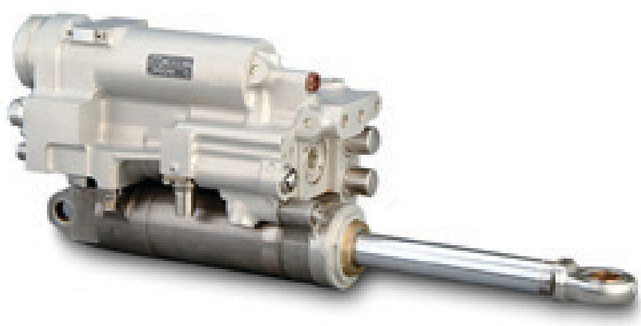
Moog D637 and D670 Servovalves, Digital Radial Piston Pump

Emerging Opportunities with Electrohydrostatic Actuation

For the hydraulics industry and, ultimately, customers who seek high-performance systems for some demanding applications Electrohydrostatic Actuation (EHA) addresses the six challenges listed above and so warrants a discussion. EHA is sometimes known as "powered by wire" as actuation can be provided in a self contained unit combining both electric (e.g. servomotors) and hydraulic (e.g. pumps and valves) with a common controller and software system. The self-contained package has the advantage of no hydraulic piping required. The term hybrid technology is sometimes used for this technology as well.

Moog has extensive experience since 1990 with the use of EHA in flight controls for the next generation of military and commercial aircraft such as Lockheed Martin's F-35 Lightning II and has been selected by Airbus for both the A400M and A350 XWB. Moog has spent the last two decades refining and maturing EHA technology for a variety of systems including simplex and dual redundant actuators, dual and triplex redundant actuator controllers and highly integrated designs with on-board power and control electronics.

While EHA is not typically used for industrial applications, Moog has begun working with OEMs with hydraulic applications that require high force requirements but also need for energy savings, environmental cleanliness or elimination of piping. EHA is also an option for electric applications that have high forces and require redundant or advanced fail-safe systems, such as wind turbine blade pitch control.



Moog EHA System for Aircraft

continued page 5

The Wind Turbine Pitch Control Example

An example of how EHA can be used in place of classic hydraulic systems is demonstrated below for a hypothetical wind turbine blade pitch control customer who wishes to change from a traditional hydraulic pitch control system to EHA. Each number corresponds to the list of 6 challenges identified in Figure 1.

1. Increased energy efficiency because the pitch control system's motor turns only when the inclination, or pitch, of the wind turbine blade needs to change its angle.

2. Improved reliability since EHA enables a wind turbine maker to replace a rotary fluid slip ring and accompanying hoses with an electro-optical slip ring assembly which ensures the transfer of electrical power and signals across a rotary interface.

3. A smart system, since the self-contained EHA actuator, which adjusts the angle of the wind turbine's blades, has motion controls and diagnostics integrated inside the device.

4. Reduced size and weight because EHA allows a wind turbine manufacturer to remove the large hydraulic power unit (HPU) normally found high off the ground in the turbine's nacelle, reducing the weight by up to 40%.

5. Reduced environmental impact because the removal of the rotary fluid slip ring located in the wind turbine's nacelle eliminates leak points found in the slip ring, hoses and fittings.

6. Improved energy storage and reuse via emergency pitch brake accumulators, which are located in the wind turbine's hub with the blade pitch control actuators. The accumulators provide emergency fail-safe pitch adjustment in case of power failure.

Conclusion

The NFPA's roadmap is designed to advance fluid power technology and spur discussion of new options that can help the hardworking engineer facing today's challenges. This article shared some ideas on practical ways these trends in hydraulics are being exhibited in high performance applications. As you can see there is an impressive range of hydraulic options including the emerging EHA option that can solve specific challenges in a variety of industries. Most importantly Moog offers the expertise to evaluate whether hydraulic or electric solutions are best suited to the needs of an application and then apply the best in class product or system to meet the needs of high performance machine applications.

The National Fluid Power Association (NFPA) is a 501(c)6 trade association founded in 1953. Its more than 300 members include manufacturers of fluid power systems and components, fluid power distributors, suppliers to the fluid power industry, educators and researchers. NFPA's mission is to serve as a forum where all fluid power channel partners work together to advance fluid power technology, strengthen the fluid power industry, and foster member's success. For more information visit www.nfpa.com/.

Author

Dave Geiger is Hydraulic Systems Engineering Manager, Moog Industrial Group. He sits on the Technology Roadmap Team for the NFPA. His experience includes the design of motion control systems for plastics, metal forming, power generation, oil and gas exploration and automation machinery. He holds four patents with an additional three pending. He can be reached at dgeiger@moog.com.

THE NEED FOR SPEED IN HELICOPTER TESTING

By Marie-Laure Gelin, Marketing Manager

Tom Pierce, Business Development Manager for Pacific Test & Simulation Markets

Stephen Ploegman, Project Manager for Aerospace Test Systems

Aerospace testing, whether military or commercial, is designed to validate the design and structural integrity of aircraft and it requires the highest accuracy and repeatability of test loads. When you consider the high value of the prototypes and the time sensitivity of new projects conducted by aircraft manufacturers, protecting the test specimen is absolutely paramount. Thus aerospace testing requires Moog to develop some of the most advanced testing and simulation solutions that push the absolute limits of technology allowing manufacturers to conduct rigorous and stringent test programs to ensure they meet a wide range of mission-specific performance, regulatory and commercial requirements.

This article discusses two recent projects where Moog worked closely with customers to create complex yet flexible test systems using state of the art hardware and software. The helicopter testing system that Moog developed with the Korean Aerospace Research Institute (KARI) runs full-scale structural tests and has potential for 12 independent helicopter tests. The helicopter rotor blade fatigue testing system developed for AgustaWestland pushes the limits of technology to provide complex data on loads during different maneuvers for ground and in-flight conditions. Both involved specialized testing servocontrollers with Real-Time Ethernet platforms capable of the accuracy and repeatability of up to 500 control channels yet with complete management of specific safety procedures.

What is Unique about Motion Control in Aerospace Testing?

In static and fatigue testing, commercial and military aircraft manufacturers place great emphasis on the accuracy of performance, repeatability of the test loads applied to their structures, and safety of the test specimen. The high value of the aero-structures and components requires advanced experience in a wide range of engineering disciplines and specialty areas.

Moog is the designer, manufacturer, and integrator of test and simulation systems and products for some of the most well-known aircraft manufacturers and test laboratories around the globe. Some of the trends that Moog is spearheading to meet the needs of this industry are incorporating advances in Real-Time Ethernet interfacing, data acquisition and control into advanced test systems as well as ways to provide faster testing. This allows aircraft manufacturers to undertake a growing range of test tasks more easily, reduce set-up time and optimize test running rates. Of course, accuracy and test specimen safety need to always be maintained even as these improvements in speed are made.

Faster testing is key to the success of aerospace manufacturers and this is where real operational improvements can be made in the lab. Test systems must be operational for long periods of time, anywhere from 2 to 6 years, to be able to run comprehensive and conclusive tests to verify aerodynamics and fatigue factors under a variety of conditions and loads. Moog has recently introduced a combination of communication interfaces based on Real-Time Ethernet that increases the functionality of servocontrollers and boosts bandwidth. Speed is improved by providing faster graphics, accurate synchronization of up to 500 control channels, reduced latency time and complete management of specific safety procedures to eliminate any risk on the test specimen. It also enables fast, easy to set up test systems that can be integrated with the users' existing test and laboratory infrastructure.

Another type of testing, known as Iron Bird solutions can be used to study and test flight controls, landing gears, and hydraulics of an aircraft system. Both the correct functioning of different aircraft systems, as well as endurance testing can be supported. Moog offers a hydraulically powered computer-controlled loading system to reproduce in-flight aerodynamic loads. During the test, the user can define virtually any real time relationship between any input and output including modifying mathematical functions, using measured values, and applying values of any channel or pseudo channels (e.g. real time updated calculations) as parameters. This allows for programming of different load versus angle curves for each flight phase to be automatically sequenced during the iron bird test. This requires a fully integrated multiple channel system with higher communications bandwidth that allows large scale multi-channel tests to be run faster with improved safety.

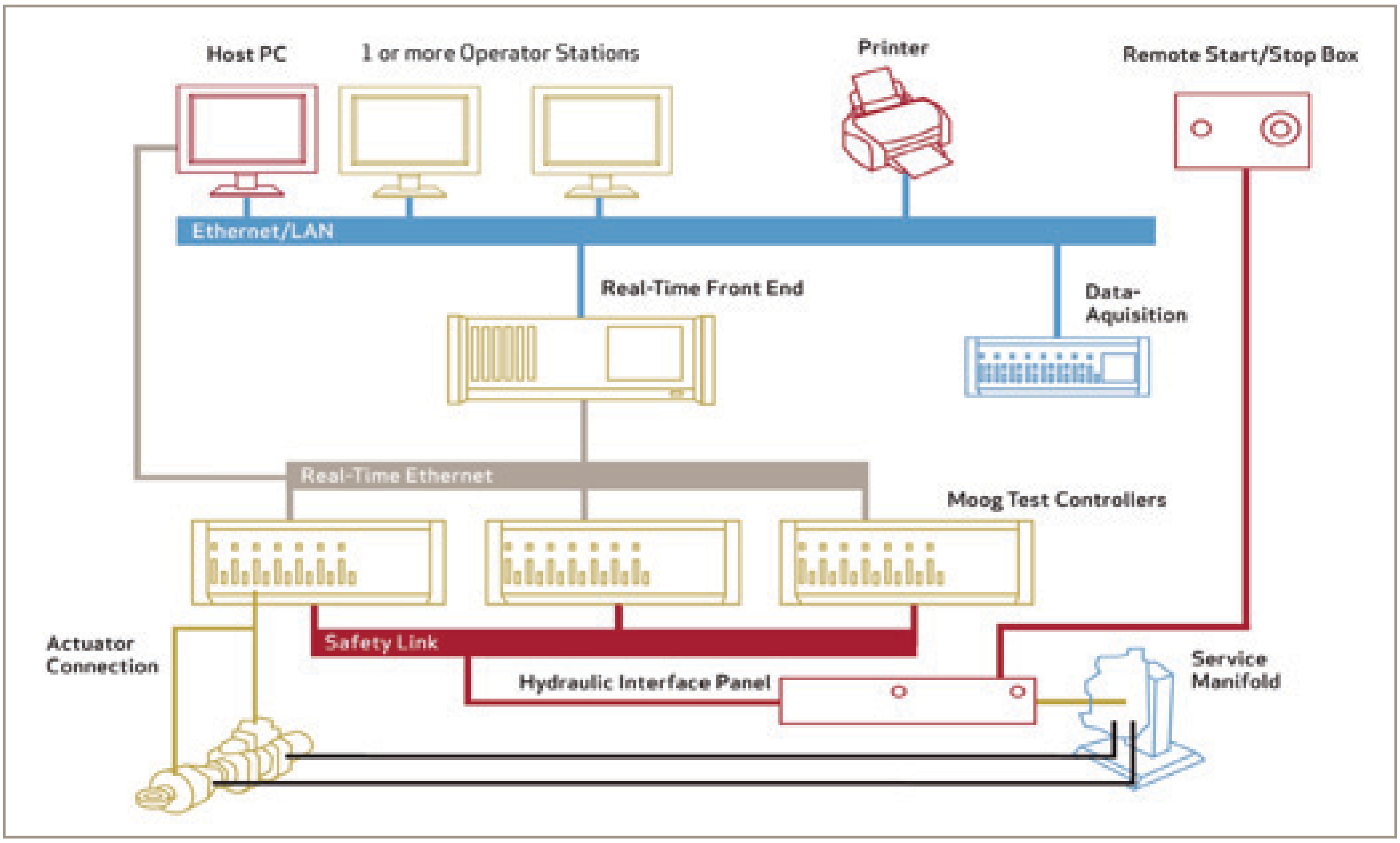
Helicopter Testing System for the Korean Aerospace Research Institute

Moog was awarded a project to help KARI develop leading-edge test capabilities for a wide range of structural and fatigue tests for helicopters' components. This system is part of a multi-billion dollar procurement project by the South Korean Ministry of National Defense that involves developing and building 245 utility helicopters over a 16-year period.

Moog's previous experience with similar test rig installations, knowledge of helicopter test techniques and on-the-ground technical support from its Korean engineering team were key reasons for KARI's selection of Moog for this project. That system, which was installed in just three days in 2008, now runs full-scale structural tests and has potential for 12 independent helicopter tests.

Key deliverables of this highly customized test rig installation include:

- Six cabinets with 16 control channels each
- A 256-channel HBM Catman Data Acquisition System
- New software functionality that allows Real-Time Ethernet-based data transfer between the command generator (Real-Time Front End) and the localized control loops
- A dedicated Ethernet interface for the transfer of the load cell, position and spectrum data from the Moog Test Controller to the CatMan data acquisition unit and activation of commands (e.g. Take Snapshot) from the Test Controller System to the CatMan System



Moog Test System Architecture

continued page 8

The system also delivers faster, more efficient analysis and comparison of tests. Because the two systems are connected via Ethernet, KARI can directly cross-check data from the Load Control System and Data Acquisition System through time stamps. This allows all data to be stored and archived on a hard disk for post-test analyses. Currently, KARI's test program runs eight distinct and independent component tests simultaneously. Moog's test rig also needed to allow for future upgrading in line with KARI's plans to develop new facilities to run more ambitious test plans as the helicopter build program expands.

Bank of Moog Aerospace Test Controllers

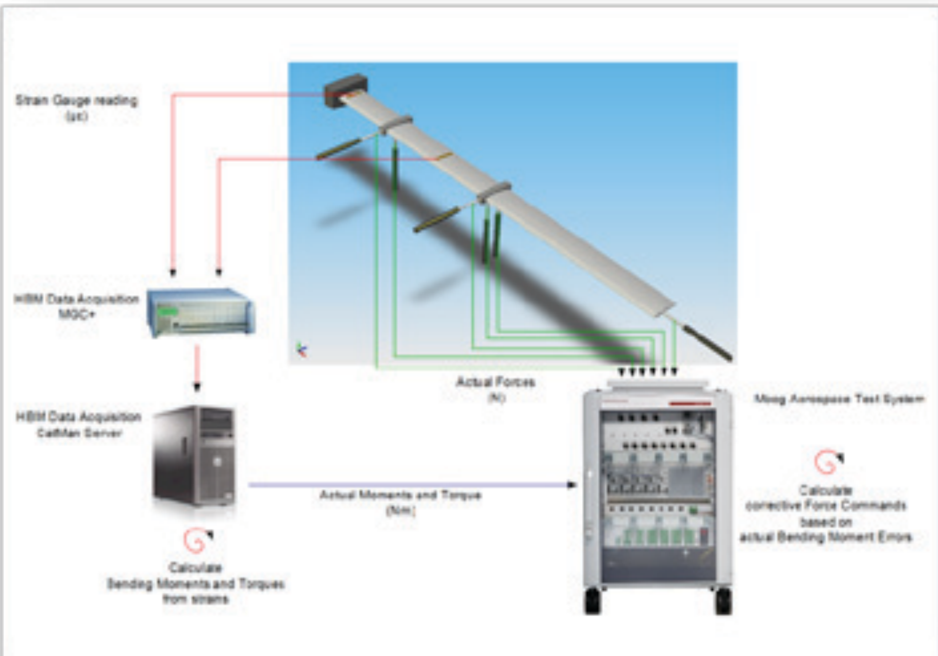
Moog's test controllers incorporate a unique control loop technology that can handle complex multi-channel tests of up to 500 servo channels. Their flexibility -and high performance handling of complex testing formulas utilizing proprietary software are particularly suited for advanced aerospace testing. Moog provides servocontrollers that run structural tests (static and dynamic) ranging from complete aircraft and sub-assemblies to components.

Helicopter Rotor Blade Fatigue Testing System for AgustaWestland

An important part of helicopter development is the fatigue testing of the rotor blades. During operation helicopter rotor blades are subject to substantial flap (vertical), lag (horizontal), torsion and centrifugal (CF) loads. Flap and lag occurs as bending of the blade as well as shear loading. The Moog Aerospace Test System, in conjunction with the HBM Data Acquisition System, has been designed to accommodate all of these elements and to ensure the required relationship between the flap, lag and torsion moments on the blade at all times.

At AgustaWestland all test conditions are defined in terms of CF load, flap, lag and torsion moments to be applied at a particular blade station (span-wise location). Moments and torsions are measured by strain gauges installed along the blade. As it is possible for strain gauges to be damaged during fatigue testing these must not be used to close the control loop. The controller must therefore control the loading actuators in force mode using 6 load cells to provide the individual loop feedback.

To meet the specifications Moog supplied the Aerospace Test Controller, with 6 servo control channels, incorporating the latest Quad Core IPC processor and real-time Ethernet platform to allow playback of the complex loading spectrum on the helicopter blade. Fatigue loads vary during different manoeuvres, both for ground and in-flight conditions. Moog's Aerospace Test Software accommodates this by the use of multi-level instruction blocks. A fatigue spectrum for rotor blades consists of up to 200 instruction blocks containing a total of 10 million fatigue cycles.



Moog's Aerospace Test System proved to be a perfect match for AgustaWestland's fatigue test application, offering all functionality needed by the test engineers in one, all-embracing, software suite.

continued page 9

Conclusion

These recent test system installations by Moog involved a fully integrated multiple channel system that combines Moog software and test controllers and including real-time Ethernet interfaces. The test systems feature a higher communications bandwidth that allows large scale multi-channel tests to be run faster with improved safety. By using advanced technology, world-class products and application know-how, Moog was able to deliver the complex requirements of faster testing, while ensuring the highest accuracy, repeatability and safety. Expertise gained by working in industries such as aerospace testing enables Moog to implement advanced solutions in other industries with similar complex requirements for multi-channel control and faster throughput.

Appendix A: Detailed Description of Helicopter Blade Fatigue Testing Control System

To apply the correct bending moments on the rotor blade cascaded closed-loop control is used, where an inner loop is controlling 6 servo-hydraulic loading actuators in force mode and an outer loop is adjusting the actuators' command set points based on current bending moment errors.

The strain gauges are measured and converted into bending moments by the HBM Data Acquisition System and then sent to the Moog controller via a bi-directional Ethernet communication interface. In the Aerospace Test Software these 'actual' bending moments are compared against 'desired' bending moments using a corrective PID loop in soft real-time. The output of the PID loop is translated into force commands, for the individual force loops, using a 6×6 Transfer Matrix. The Transfer Matrix is setup using the Aerospace Test Software's online calculation channels, called Shared Memory.

It is assumed that the transfer functions for the lag movements and the flap and torque movements are decoupled, then blade bending moments and blade forces are related as:

$$\begin{bmatrix} STA0\_FLAP\_BM \\ STA1\_FLAP\_BM \\ STA1\_TORQ \\ STA0\_LAG\_BM \\ STA1\_LAG\_BM \end{bmatrix} = \begin{bmatrix} k_1 & k_2 & k_3 & 0 & 0 \\ k_4 & k_5 & k_6 & 0 & 0 \\ k_7 & k_8 & k_9 & 0 & 0 \\ 0 & 0 & 0 & k_{10} & k_{11} \\ 0 & 0 & 0 & k_{12} & k_{13} \end{bmatrix} \cdot \begin{bmatrix} STA1\_FLAP\_F \\ STA2A\_FLAP\_F \\ STA2B\_FLAP\_F \\ STA1\_LAG\_F \\ STA2\_LAG\_F \end{bmatrix}$$

(vertical), lag (horizontal), torsion and centrifugal (CF) loads. Flap and lag occurs as bending of the blade as well as shear loading. The Moog Aerospace Test System, in conjunction with the HBM Data Acquisition System, has been designed to accommodate all of these elements and to ensure the required relationship between the flap, lag and torsion moments on the blade at all times.

At AgustaWestland all test conditions are defined in terms of CF load, flap, lag and torsion moments to be applied at a particular blade station (span-wise location). Moments and torsions are measured by strain gauges installed along the blade. As it is possible for strain gauges to be damaged during fatigue testing these must not be used to close the control loop. The controller must therefore control the loading actuators in force mode using 6 load cells to provide the individual loop feedback.

To meet the specifications Moog supplied the Aerospace Test Controller, with 6 servo control channels, incorporating the latest Quad Core IPC processor and real-time Ethernet platform to allow playback of the complex loading spectrum on the helicopter blade.

Fatigue loads vary during different maneuvers, both for ground and in-flight conditions. Moog's Aerospace Test Software accommodates this by the use of multi-level instruction blocks. A fatigue spectrum for rotor blades consists of up to 200 instruction blocks containing a total of 10 million fatigue cycles.

However, while running the test, the commanded forces are a matrix multiplication of the bending moments. As a result the relation becomes:

$$\begin{bmatrix} STA1\_FLAP\_F \\ STA2A\_FLAP\_F \\ STA2B\_FLAP\_F \\ STA1\_LAG\_F \\ STA2\_LAG\_F \end{bmatrix} = \begin{bmatrix} c_1 & c_2 & c_3 & 0 & 0 \\ c_4 & c_5 & c_6 & 0 & 0 \\ c_7 & c_8 & c_9 & 0 & 0 \\ 0 & 0 & 0 & c_{10} & c_{11} \\ 0 & 0 & 0 & c_{12} & c_{13} \end{bmatrix} \cdot \begin{bmatrix} STA0\_FLAP\_BM \\ STA1\_FLAP\_BM \\ STA1\_TORQ \\ STA0\_LAG\_BM \\ STA1\_LAG\_BM \end{bmatrix}$$

So, the constants c1…c9 are an inverse of constants k1…k9:

$$\begin{bmatrix} c_1 & c_2 & c_3 & 0 & 0 \\ c_4 & c_5 & c_6 & 0 & 0 \\ c_7 & c_8 & c_9 & 0 & 0 \\ 0 & 0 & 0 & c_{10} & c_{11} \\ 0 & 0 & 0 & c_{12} & c_{13} \end{bmatrix} = \begin{bmatrix} k_1 & k_2 & k_3 & 0 & 0 \\ k_4 & k_5 & k_6 & 0 & 0 \\ k_7 & k_8 & k_9 & 0 & 0 \\ 0 & 0 & 0 & k_{10} & k_{11} \\ 0 & 0 & 0 & k_{12} & k_{13} \end{bmatrix}^{-1}$$

The matrix constants c1…c9 are determined during a system identification process. During this process the individual actuators are controlled to several representative forces. For each load applied, the measured bending moment is registered. The constants of the Transfer Matrix are loaded into the controller during the test start-up procedure using the controller scripting functionality.

The corrections to the inner force loop commands are made at intervals, rather than instantaneously. This is because it is necessary to verify that the bending moment information can be relied upon to guard against damage of the strain gauges before the system responds to the outer loop. The control system brings the test to a controlled stop in the event of significant errors being detected, or an emergency stop switch being operated.

Authors and Contributors

Stuart Bibb, T Eng. Mechanical Engineering, Managing Director Test Systems, Moog in the UK has 20 years experience in the automotive industry in vehicle development and test laboratory management as well as 20 years as a company director responsible for general business administration, sales and applications engineering.

Marie-Laure Gelin, MBA degree, Marketing Manager for Moog, brings over 15 years of experience in Marketing including business integration, brand strategy, corporate communications, market research and public relations for multinational companies from different industries.

Karel van Gelder, M.Eng.Sc (control electronics) is Product Line Manager for Moog's Industrial Test Controllers. He brings 18 years of experience in engineering, project management and management of product development in the Aerospace and Automotive markets.

Hans Klaufus, MSc (Aerospace Dynamics), BSc (Aerospace Technology), Program Manager for Business Unit Test Systems. He brings 10 years of experience in project and program management for Moog Test Systems.

Thomas Pierce, BAEM (Aerospace Engineering) & MS (Aerospace Engineering) is the Business Development Manager for Pacific Test & Simulation Markets. He brings 28 years of experience in engineering, project management, product management, sales and market management, and general management during a career with several multinational companies. Tom has over 21 years of Asian experience and has lived in Asia for more than 12 years.

Stephan Ploegman, BSc. (Aerospace Technology), Project Manager for Aerospace Test Systems, brings 8 years of experience in project management and applications. His previous experience has been with project management for an international company specializing in aerospace equipment.

Paul Garner, B.A . (Computing & Electronics), HNC (Mechanical Engineering), is a Senior Sales & Application Engineer for Moog Test Systems in the UK. He brings over 30 years experience in test systems use, sales and support gained in various sectors in the Automotive and Aerospace Test industry.

For the location nearest you, visit:
www.moog.com/contact

MOOG

Moog Industrial Group
www.moog.com/industrial