Douglas Electrical Components

Meeting Feedthrough Challenges on the A-3 Test Stand

The purpose of this paper is to share the experience and knowledge that engineers at NASA and Douglas Electrical have gained regarding the specification of hermetic seals and feedthroughs used in engine test stand vacuum chamber applications. This paper looks specifically at the experience and solutions used in the new A-3 test stand that is being constructed at the NASA Stennis Space Center.

With hundreds and potentially thousands of control and sensor data channels entering and exiting the vacuum environment, it is essential for hermetically sealed conductor feedthroughs to solve cross-talk and leakage challenges as well as to provide flexibility to meet future custom data needs.

A ROCKET-POWERED ECONOMY

One of the bright spots in the U.S.'s post-recession economy is its technology innovation and leadership, including space vehicles, launches, and exploration. From civilian communication satellites to deep space exploration to military applications, the private and public space industry infrastructure forms a vital part of this country's ongoing economic engine. NASA continues to play a large role in this industry, operationally as well as in the development and testing of launch vehicles, propulsion systems and payloads – for both commercial and government projects. Current NASA plans include the Multi-Purpose Crew Vehicle, the Space Launch System (SLS) and continued participation in the International Space Station, just to name a few.

One of the key areas of U.S. engineering expertise is in the design and development of propulsion systems. Maintaining technology leadership while meeting budget constraints is an ongoing challenge, and has led to some innovative re-engineering of legacy propulsion systems, including the J-2 engine first used in the Apollo moon missions. The newest J-2 design was engineered to be more efficient and simpler to build than its Apollo predecessors. The engine called for the removal of beryllium, a redesign of all the electronics, and the use of the latest joining techniques and materials (see Photo One). The latest variant of this engine is the probable choice for the upper stage of the SLS, resulting in a need for true mission duration testing at atmosphere (vacuum) of these large propulsion systems.

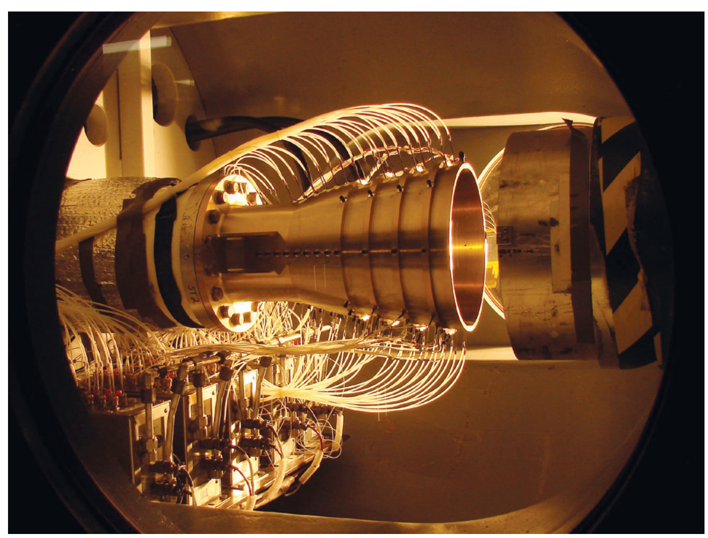

Photo 1: Powered by liquid oxygen and liquid hydrogen, the latest J-2 engine was engineered to be more efficient and simpler to build than its predecessors. (Photo courtesy of NASA.)

While upfit and expansion of several existing test facilities was studied, it was discovered that the ability to accommodate a 300,000-pound class engine with the steam generation capacity to create vacuum for a full ten-minute mission simulation, presented many retrofit hurdles. After several feasibility studies, the development of a new greenfield test platform, the A-3 test stand located at Stennis Space Center, was determined to be the most cost-effective solution.

THE A-3 TEST STAND

The new A-3 test stand was designed to simulate a 100,000-foot altitude at 0.16 psi pressure. The A-3 stand enables true vacuum testing of up to 300,000-pound class engines for a typical 550 second mission firing duration. With a vacuum base on a chemical steam generation process, which provides 650 seconds of steam, the A-3 test stand is the only test cell in North America that combines the ability to accommodate 300,000-pound class engines with vacuum capacity for a full mission profile from ignition at altitude. Allowing time for ramp up and ramp down, a 10 minute engine test can be conducted at altitude for simulation of full mission duration. The current construction schedule calls for completion of the facility during 2012, with staged activation occurring during 2013 (see Photo Two).

Photo 2: The A-3 Test Stand is the first large test structure to be built at Stennis Space Center since the 1960s.

According to Phillip W. Hebert, A-3 Lead Electrical Design Engineer, "For the test stand customer, data is our product. Therefore our biggest challenge during the design phase was ensuring clean data signals." That's a tall order, particularly considering the number of channels and the number of threats to data integrity. Eliminating cross talk and leakage across hundreds of sensors, controls, signal types, cables and connectors entering and exiting the test environment, as well as facing the challenges of vibration, long cable runs, vacuum penetrations and signal mix, presents a formidable engineering challenge.

The final feedthrough solution was based on using a number of port plates with pretested penetrations on each plate (see Photo Three). Designed and constructed by Douglas Electrical Components, each of these 12 port plates have pre-wired feedthroughs permitting pretesting of all connections, with verified sealing of the multiple penetrations. "Early in the design phase we made the decision to isolate each data channel to a single penetration. While this does increase the number of feedthrough penetrations, it greatly reduces the risk of crosstalk," said Hebert. Total penetrations number close to 1,500 to accommodate current and anticipated requirements. Spare cables and penetrations are in place for additional data and control channels as required, and to accommodate custom requirements of future projects.

Spare plugged penetrations allow for unanticipated variations in cabling requirements. "Troubleshooting a vacuum leak in a system with multiple feedthroughs and thousands of wire connections can be frustrating, time-consuming and expensive,"

Photo 3: This massive Douglas Electrical port plate, one of 12 used on the A-3 test stand, provides hermetically sealed feedthrough for the hundreds of sensor and control conductors running into and out of the vacuum engine test chamber. (Photo courtesy of Douglas Electrical Components.)

said Ed Douglas, president, Douglas Electrical Components. "That's where certain solutions such as port plates can really cut the risk of leakage, and provide great flexibility to handle future requirements."

On the A-3 test stand, the low voltage signals (30mV and lower) require continuous feedthrough to prevent signal attenuation, while the 28VDC control signals are routed using connectors. To prevent cross talk, each channel is routed through an individual penetration, rather than via multi-pin connectors. With atmospheric cable runs of several hundred feet, signal attenuation was a factor influencing the selection and testing of the controlled impedance conductors (see Photo Four).

Photo 4: With several hundred feet of cable run, each feedthrough is prewired and tested prior to installation.
(Photo courtesy of Douglas Electrical Components.)

Engine test programs can run for a year or longer, as in the case of the J-2X, to cycle through a complete evaluation of all engine components. The powerpack test alone demands the total range of test stand capabilities. "By varying the pressures, temperatures and flow rates, the powerpack test series will evaluate the full range of operating conditions of the engine components," said Tom Byrd, J-2X engine lead in the SLS Liquid Engines Office at NASA's Marshall Space Flight Center in Huntsville, Ala. "This will enable us to verify the components' design and validate our analytical models against performance data, as well as ensure structural stability and verify the combustion stability of the gas generator."

While the engineering challenges of designing, building, testing and operating a facility as complex and critical as the A-3 test stand is not an everyday occurrence, the advice from Jody Woods, the Chief Engineer for A-3, can be applied to any level of project complexity. "Quantify the requirements, and then design the solution based on consensus standards. Compliance with consensus standards across all the challenges of pressure vessels, vacuum, steam, electrical, plumbing and feedthoughs followed by conformance testing will lead to a robust solution that will provide reliable service for years to come."

With completion on schedule for 2012 and an in-service date in 2013, the A-3 test stand will be part of a new era in space exploration and commercialization. "It's exciting to play a role in the development of the new A-3 test stand. It is this type of project that positions the American economy for continued growth as well as spawning new technological developments that NASA continues to contribute to industry," said Ed Douglas.

SUMMARY

With the expansion and commercialization of the space industry, one of the greatest challenges faced by feedthroughs on the A-3 test stand is the ability to cater to custom requirements. Provisioning for the future takes care and planning, but building in flexibility is always less costly than retrofitting at a later date. The port plate solutions as designed for the A-3 project will provide years of service for all kinds of conductors and signal requirements. Please feel free to contact the author if you need any more details or additional information on solving your specific feedthrough challenges.

For additional information on DECo solutions, including product brochures and videos, please visit http://www.douglaselectrical.com.

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ABOUT STENNIS SPACE CENTER

Photo courtesy of NASA.

Located in Bay St. Louis, Miss., the Stennis Space Center (SSC) is a 13,500-acre facility developed in the 1960s. The center's primary mission at the onset was to flight certify all first and second stages of the Saturn V rocket for the Apollo program.

This program began with a static test firing on April 23, 1966, and continued into the early 1970s. Proof of the contributions made by SSC to the U.S. space program was that all the Apollo space vehicle boosters did their job without a single failure, including those for the Apollo 11 mission, landing the first men on the moon. A new chapter was added in June 1975 when the Space Shuttle Main Engine was tested at the facility for the first time. All the engines used to boost the Space Shuttle into low-Earth orbit are flight certified at SSC on the same stands used to test fire all first and second stages of the Saturn V in the Apollo and Skylab programs. Space Shuttle Main Engine testing is expected to proceed well into the 21st century.

Over the years, SSC has evolved into a multidisciplinary facility made up of NASA and 30 other resident agencies engaged in space and environmental programs and the national defense, including the U.S. Navy's world-class oceanographic research community. Offering engineers experienced in the J-2 testing, and the space to build, SSC became the location of choice for the new A-3 test platform.