

characteristics, this type of film would be ideal; however, at the time of this reporting, no such film has been known. Machined components (with known fractional thicknesses) of a like material (similar density) to that of the material to be measured are necessary.

The machined components should have machined through-holes. For ease of use and better accuracy, the through-holes should be a size larger than 0.125 in. ( $\approx 3$  mm). Standard components for this use are known as penetrameters or image quality indicators. Also needed is standard x-ray equipment, if film is used in place of digital equipment, or x-ray digitization equipment with proven conversion properties. Typical x-ray digitiza-

tion equipment is commonly used in the medical industry, and creates digital images of x-rays in DICOM format. It is recommended to scan the image in a 16-bit format. However, 12-bit and 8-bit resolutions are acceptable. Finally, x-ray analysis software that allows accurate digital image density calculations, such as Image-J freeware, is needed.

The actual procedure requires the test article to be placed on the raw x-ray, ensuring the region of interest is aligned for perpendicular x-ray exposure capture. One or multiple machined components of like material/density with known thicknesses are placed atop the part (preferably in a region of nominal and non-varying thick-

ness) such that exposure of the combined part and machined component lay-up is captured on the x-ray. Depending on the accuracy required, the machined component's thickness must be carefully chosen. Similarly, depending on the accuracy required, the lay-up must be exposed such that the regions of the x-ray to be analyzed have a density range between 1 and 4.5. After the exposure, the image is digitized, and the digital image can then be analyzed using the image analysis software.

*This work was done by David Grau of Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13206*

## Fuel Cell/Electrochemical Cell Voltage Monitor

*Lyndon B. Johnson Space Center, Houston, Texas*

A concept has been developed for a new fuel cell individual-cell-voltage monitor that can be directly connected to a multi-cell fuel cell stack for direct sub-stack power provisioning. It can also provide voltage isolation for applications in high-voltage fuel cell stacks. The technology consists of basic modules, each with an 8- to 16-cell input electrical measurement connection port. For each basic module, a power input connection would be provided for direct connection to a sub-stack of fuel cells in series within the larger stack. This power connection would allow for module power to be available in the range of 9-15 volts DC.

The relatively low voltage differences that the module would encounter from the input electrical measurement connection port, coupled with the fact that the module's operating power is supplied by the same substack voltage input (and so will be at similar voltage), provides for elimination of high-common-mode voltage issues within each module. Within each module, there would be options for analog-to-digital conversion and data transfer schemes.

Each module would also include a data-output/communication port. Each of these ports would be required to be either non-electrical (e.g., optically iso-

lated) or electrically isolated. This is necessary to account for the fact that the plurality of modules attached to the stack will normally be at a range of voltages approaching the full range of the fuel cell stack operating voltages. A communications/data bus could interface with the several basic modules. Options have been identified for command inputs from the spacecraft vehicle controller, and for output-status/data feeds to the vehicle.

*This work was done by Arturo Vasquez of Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-24592-1*

## Anomaly Detection Techniques With Real Test Data From a Spinning Turbine Engine-Like Rotor

**These techniques are suitable for engine manufacturers and industries in aerospace and aviation.**

*John H. Glenn Research Center, Cleveland, Ohio*

Online detection techniques to monitor the health of rotating engine components are becoming increasingly attractive to aircraft engine manufacturers in order to increase safety of operation and lower maintenance costs. Health monitoring remains a challenge to easily implement, especially in the presence of scattered loading conditions, crack size, component

geometry, and materials properties. The current trend, however, is to utilize non-invasive types of health monitoring or nondestructive techniques to detect hidden flaws and mini-cracks before any catastrophic event occurs. These techniques go further to evaluate material discontinuities and other anomalies that have grown to the level of critical defects that can lead to failure. Gener-

ally, health monitoring is highly dependent on sensor systems capable of performing in various engine environmental conditions and able to transmit a signal upon a predetermined crack length, while acting in a neutral form upon the overall performance of the engine system.

Spin simulation tests were conducted on a turbine engine-like rotor with and

without an artificially induced notch at different rotational loading speed levels. Health monitoring verification was performed by integrating three different advanced machine-learning algorithms for anomaly detection in continuous data streams from spinning tests of a subscale turbine engine-like rotor disk up to a speed of 10,000 rpm.

This study compares an outlier detection algorithm (Orca), one-class support vector machines (OCSVM), and the Inductive Monitoring System (IMS) for anomaly detection on the data streams. These techniques were used to inspect the experimental data under the same operating conditions employed in the tests, and using the measured vibration response (blade tip clearance) as a key input to check the viability of these techniques on detecting the disk anomalies and to evaluate the performance of each methodology. The performance of the algorithm is measured with respect to the detection

horizon for situations where fault information is available. Further, this work presents a select evaluation of an online health monitoring scheme of a rotating disk using a combination of high-caliber sensor technology, high-precision in-house spin test system facilities, and unprecedented data-driven fault detection methodologies.

The methodologies applied in this study can be considered as a model-based reasoning approach to engine health monitoring. Typical model-based reasoning techniques compare a system model or simulation with system sensor data to detect deviations between values predicted by the model and those produced by the actual system. In fact, a model-based reasoner uses the collected system parameter values as input to a simulation and determines if a particular set of input values is consistent with the simulation model. When the values are not consistent with the model, a “conflict” occurs, indicating that the sys-

tem operation is off nominal. The results obtained showed that the detection algorithms are capable of predicting anomalies in the rotor disk with very good accuracy. Each detection scheme performed differently under the same experimental conditions, and each delivered a different level of precision in terms of detecting a fault in the rotor. Overall rating showed that both the Orca and OCVSM performed better than the IMS technique.

*This work was done by Ali Abdul-Aziz, Mark R. Woike, Nikunj C. Oza, and Bryan L. Matthews of Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18758-1.*

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## Measuring Air Leaks Into the Vacuum Space of Large Liquid Hydrogen Tanks

*John F. Kennedy Space Center, Florida*

Large cryogenic liquid hydrogen tanks are composed of inner and outer shells. The outer shell is exposed to the ambient environment while the inner shell holds the liquid hydrogen. The region between these two shells is evacuated and typically filled with a powder-like insulation to minimize radiative coupling between the two shells. A technique was developed for detecting the presence of an air leak from the outside environment into this evacuated region.

These tanks are roughly 70 ft ( $\approx 21$  m) in diameter (outer shell) and the inner shell is roughly 62 ft ( $\approx 19$  m) in diameter, so the evacuated region is about 4 ft ( $\approx 1$  m) wide.

A small leak’s primary effect is to increase the boil-off of the tank. It was preferable to install a more accurate fill level sensor than to implement a boil-off meter. The fill level sensor would be composed of an accurate pair of pressure transducers that would essentially

weigh the remaining liquid hydrogen. This upgrade, allowing boil-off data to be obtained weekly instead of over several months, is ongoing, and will then provide a relatively rapid indication of the presence of a leak.

*This work was done by Robert Youngquist, Stanley Starr, and Mark Nurge of Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13211*

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## Antenna Calibration and Measurement Equipment

*NASA’s Jet Propulsion Laboratory, Pasadena, California*

A document describes the Antenna Calibration & Measurement Equipment (ACME) system that will provide the Deep Space Network (DSN) with instrumentation enabling a trained RF engineer at each complex to perform antenna calibration measurements and to generate antenna calibration data. This data includes continuous-scan auto-bore-based data acquisition with all-sky data gathering in support of 4th order

pointing model generation requirements. Other data includes antenna subreflector focus, system noise temperature and tipping curves, antenna efficiency, reports system linearity, and instrument calibration.

The ACME system design is based on the on-the-fly (OTF) mapping technique and architecture. ACME has contributed to the improved RF performance of the DSN by approximately a

factor of two. It improved the pointing performances of the DSN antennas and productivity of its personnel and calibration engineers.

*This work was done by David J. Rochblatt and Manuel Vazquez Cortes of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47599*