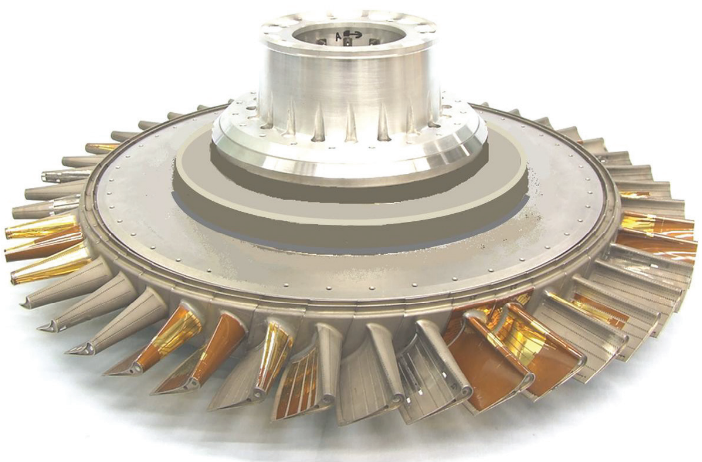
Advanced Turbine Research



Instrumented Turbine Rotor Assembly

Introduction

The Turbine Research Facility (TRF) at Wright Patterson Air Force Base in Dayton, Ohio is dedicated to the research and development of advanced turbine rotors for military and commercial jet engines. Testing at the TRF is used to evaluate new airfoil designs and ultimately to improve aircraft engine performance, reliability and durability.

The TRF's blow-down wind tunnel accommodates full-scale turbine assemblies and allows for high-frequency response heat transfer and aerodynamic measurements. The tunnel, heaters and two independent cryogenic cooling systems simulate non-dimensionally scaled in-flight conditions that the turbines will encounter, including complex unsteady rotating flowfields comparable to the engine environment.

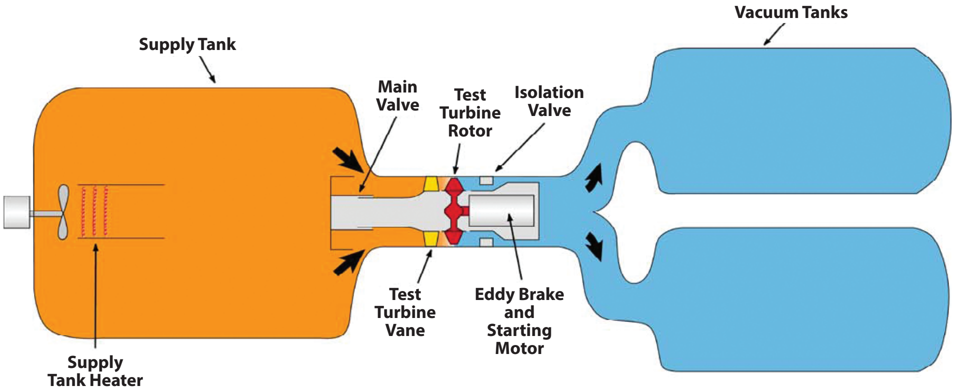


Diagram of TRF Wind Tunnel

More than 1,000 dynamic sensors are routinely installed on test rigs. These include custom thin film sensors, designed and fabricated by Wright-Patterson's Heat Flux Instrumentation Laboratory, that measure heat transfer through the turbine blades in the high-speed flow environment of the tunnel, and full bridge sensors that capture air pressure readings for flow analysis. As many as 200 additional sensors, installed upstream and downstream from the turbine, monitor temperature and pressure profiles.

Older signal conditioning for TRF could not efficiently support an order of magnitude increase in channel count needed for future test with desired measurement accuracy. Precise null of sensor and pre-test bias readings were critical to obtain usable data, but difficult and time consuming to achieve.

Hours of labor intensive manual readings, adjustments, and documentation were required to balance sensor bias voltages, confirm sensor and cable health (loop resistance, excitation current, and open/short tests), and verify signal conditioner settings. In addition, the equipment could only be calibrated off-site by the manufacturer.

To obtain the desired data quality and reduce labor cost associated with manual setup and documentation, the TRF required a signal conditioning upgrade. The new system needed to be able to support the TRF's magnitude and variety of instrumentation—including heat flux and pressure sensors, thermocouples, accelerometers, and proximity probes—and facilitate setup verification and calibration.

Solution Highlights

- **256-channel scalable, universal signal conditioning solution**
- **Support for a variety of transducers in one system**
- **Balanced constant voltage (zero common-mode) or Balanced Constant Current excitation**
- **Programmable constant current configuration – 2/4-wire (Kelvin) connection**
- **Real time display of sensor excitation, sensor resistance and leakage**
- **Latching overload detectors capture transient overload conditions**
- **Programmable Flat/Pulse low-pass filter for static or dynamic measurements**
- **High density, 42 inches of rack space for 256 channels**
- **Automated validation of sensor, cable, and signal conditioner**
- **Fully automated NIST traceable calibration tests performed in place**

Solution

The Precision Filters, Inc. (PFI) 28000 Signal Conditioning System with dual-mode 28114 conditioning cards was selected to provide the analog signal conditioning. The 28114 cards support both constant current and constant voltage excitation. Heat flux sensors are powered by PFI's proprietary Balanced Constant Current™ (BCC™) excitation technology and pressure sensors by bipolar constant voltage excitation. The balanced topologies result in substantial improvements in noise immunity, dropping the noise floor on average 50 dB, and reducing crosstalk to negligible levels.

The 28114 Zero Suppress function provides an automated voltage injection at the amplifier input to null sensor DC bias voltage created by the excitation current across the sensor. This function enables an entire 64-channel system to be bias compensated in seconds, a process that previously required hours of manual adjustments. By removing the DC gage bias from the amplifier input, both static and dynamic data can be measured.

Using the PFI 28114 Balanced Constant Current excitation with a 4-wire (or Kelvin) sensor connection provides balanced impedance between the sensor and instrumentation. This offers superior immunity to electrostatic noise pickup in the sensor cabling versus an imbalanced ¼-arm Wheatstone bridge circuit. In addition, the PFI Balanced Constant Current excitation used with the Kelvin connection is immune to zero shift and desensitization problems that arise when using ¼-arm bridge circuits.

Every sensor channel contains a low-noise differential amplifier with programmable gain to x1024. The gain is distributed before and after the filter, allowing attenuation of out-of-band energy from the highly resonant sensors to avoid signal clipping and distortion. Using the 28114 Reserve Feature, gain is apportioned before and after the filter, leaving headroom for the out-band signals before filtering. Post-filter gain is applied to achieve the desired full-scale output.

The 28114 programmable low-pass filters define the bandwidth and transfer function characteristics of the system. With Precision Filters' Flat/Pulse Filter technology, the user selects the filter for a linear phase characteristic (superior to a Bessel response) or a maximally flat/sharp roll off characteristic (superior to a Butterworth response with flat pass band). For transient tests or tests where time-domain wave shape preservation is important, the Pulse Mode characteristic is used. For frequency domain analysis, the Flat Filter characteristic results in excellent transfer function flatness and a sharp, selective filter response.

The 28114 card features real time readout of sensor resistance, excitation level and sensor open/short failure modes. In BCC Mode, the sensor leakage to ground is monitored and reported. For a system using hundreds of sensors, these features provide information to verify sensor and cable health during test setup and result in time savings.

The 28000 system allows for test and verification of the signal conditioner and hundreds of sensors. The 28000 system's Test and Monitor Busses allow signals to be injected and monitored at the push of a button. The 28114 card's AC Current mode creates sensor-based signals from the signal conditioner, verifying sensor and cabling setups and removing the need to access breakout panels or inaccessible sensors. By creating sensor-based signals, the transfer function from the sensor to the DAS is verified.

The 28000 Factory Acceptance Test makes automated, on-site, NIST-traceable calibration, eliminating the need for off-site calibration and the resulting downtime. In addition, the Go/No Go Test provides an automated functional test and verification of system settings and creates test reports.

For more information, please contact Doug Firth, Precision Filters, Inc. at 607-277-3550 or doug@pfinc.com.

References:

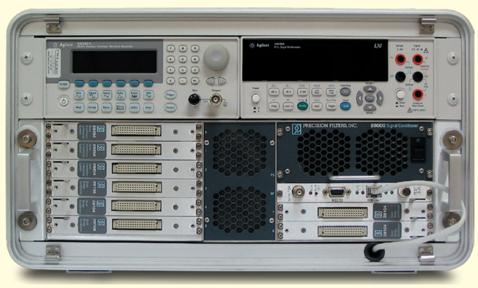
Anthony, R. J., Clark, J. P., Kennedy, S. W., Finnegan, J. M., Johnson, D., Hendershot, J., Downs, J.,2011, "Flexible Non-Intrusive Heat Flux Instrumentation for the AFRL Research Turbine," ASME Paper No. GT2011-46853

Anthony, R. J., Clark, J. P., Finnegan, J. M., and Johnson, P. D., 2012, "Modifications and Upgrades to the AFRL Turbine Research Facility," ASME Paper No. GT2012-70084.

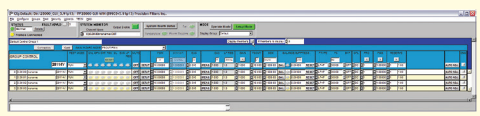
PFI Equipment Used in TRF Tests

28016 Mainframe

28114 Conditioning Card



Test System with 8-Slot 28000 System Mainframe Installed in Optional Transit Case



28000 Graphic User Interface (GUI)

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