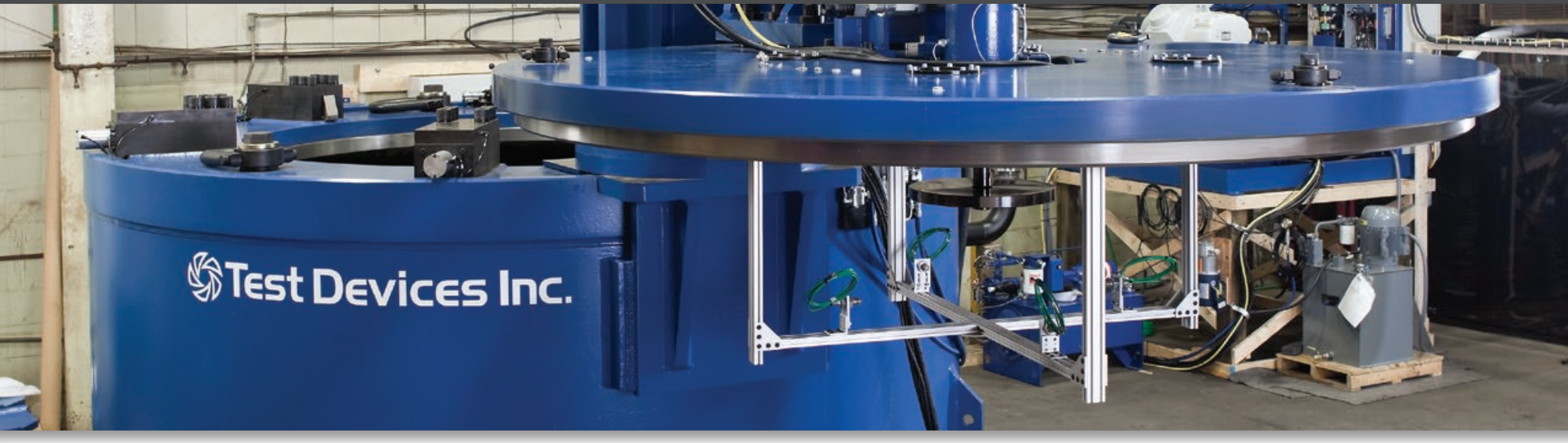
Test Devices Inc.



When the world's most advanced manufacturers of rotating equipment need the world's most accurate spin testing systems and services to evaluate the critical components they're designing and fabricating, they turn to Test Devices.

Test Devices provides rotational and other testing services and equipment to demanding markets with exacting applications and requirements. For aerospace, aviation and power generation clients, Test Devices offers rotational testing services and equipment that most closely represent operational engine environments. Test Devices has developed the world's most precise, accurate and efficient test equipment because we operate a contract test laboratory serving these demanding industries. For over 40 years Test Devices has developed and advanced the science of centrifugal, vibratory and thermal stress testing – critical solutions engineers need to evaluate the integrity and validate the life of component parts. We support our customers as they research and develop the safest, most reliable, best-performing products in the world.

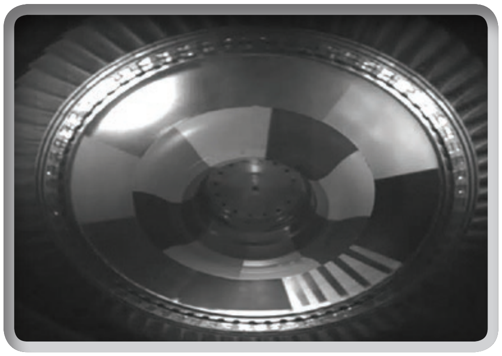


Figure 1 – Overspeed & Burst Testing

Spin Testing Capabilities

Test Devices Rigs

Spin Test Machines

- 54" (1372 mm) diameter x 48" (1219 mm) axial depth
- 42" (1067 mm) diameter x 36" (914 mm) axial depth
- 36" (914 mm) diameter x 36" (914 mm) axial depth
- 24" (610 mm) diameter x 24" (610 mm) axial depth
- 20" (508 mm) diameter x 20" (508 mm) axial depth

Drive Options

- Air Turbines & Electric Motors
- Speed accuracy:
  +/- .01% maximum speed for overspeed testing
  +/- 1 rpm for dynamic spin testing (HCF)

R&D Testing Offerings

Overspeed & Burst Testing

Overspeed centrifugal stress testing to the point of burst offers manufacturers valuable information about the ultimate strength of a part or material. Rigorous strain surveys and temperature control can provide critical data right up to the point of failure that helps improve the predictability of life and the modes of failure.

- Rotor burst tests (bladed & un-bladed)
- Blade liberation tests
- FAA certification tests
- Customized validation testing
- High-speed video recording
- Containment effectiveness testing
- High "G" field testing of electrical components
- Cryogenic tests of rocket motor fuel pumps

Low Cycle Fatigue (LCF) Testing

Establishing the fatigue life of a rotating component is critical to determining safe working life criteria. Test Devices offers LCF spin testing services with rapid cycling capability to accelerate fatigue testing programs, providing customers with life-assessment data earlier. Optional crack detection can monitor component integrity in real time, enabling a test to be stopped prior to catastrophic failure.

Spin Testing Capabilities *cont.*

- Lifing for new platforms or life-extension
- 24 hour unattended operation
- Component testing & material evaluation (mini-disk)
- Heated capability (isothermal & gradient)
- Monitoring with patented crack detection to prevent rotor failure

Blade Excitation (Dynamic Response)
Under certain conditions of operation, blades vibrate in response to pulsing flow from upstream stages. When the vibration matches the natural frequency of the component, the blades can resonate and fracture from High Cycle Fatigue (HCF). Repair of integrally bladed rotors (IBR's and Blisks) often results in changes to the tuning of these components. HCF testing offers a means of validating the repair as well as retuning the component for further service.

Test Devices has two different methods for exciting resonant frequencies of blades during rotation (Dynamic Spin Testing):

- Liquid Jet Excitation
- Aerodynamic Pulse Generation (APG)

These methods are used to excite blades under different conditions, evaluating their resonance response in a rotational frame. A benefit of APG is that it can be performed in high temperature environments.

Heated Dynamic Response Testing
Test Devices can employ its unique APG technique to perform HCF tests in elevated temperature conditions. This allows a more realistic way for OEMs to evaluate the durability and behavior of the rotating airfoils. The APG method:

- Uses the pumping action of the blades in partial atmosphere
- Can be employed with additional external heating to allow testing in an elevated temperature condition
- Provides a method for evaluating new high-temperature blade designs and coatings in complex engine-like conditions
- Evaluates damper effectiveness
- Characterizes the dynamic response of the assembled hardware and coatings

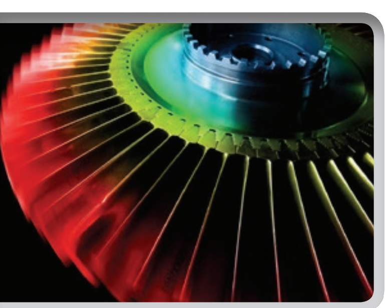


Figure 2 – Heated Testing

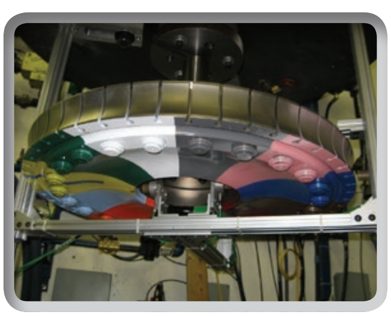


Figure 3 – In-Situ (Real Time) Radial Growth

In-Situ (Real Time) Radial Growth

Test Devices often measures elastic and plastic growth of a component using stationary probes. Most programs call for radial growth profiles as a function of speed, but axial growth can be logged as well.

- Eddy current and optical (laser) probes used
- Growth probes installed for measurement during spin testing
- Bore & rim most measured for validation of stress models
- Growth characteristics are measured in "real time" and can be recorded up until a burst event
- Measurements can be performed at representative engine temperatures using laser probes

Strain Survey Testing

Also an In-Situ instrumentation technique, information gathered in Test Devices' comprehensive strain surveys can be used to gain detailed understanding of local stresses and to validate stress models used for design under realistic loading conditions.

- Strain gauges are attached at specific points on rotating assembly
- Slip rings are used to transfer the signals with multiple channels
- Advanced data acquisition systems
- Actual measurements used to validate computer models
- Highly cost effective – typically costing substantially less than a complete FEA

High-Speed Video Testing

Test Devices can provide a high-speed video recording of the failure event in a burst test. These videos can provide visual data that is critically important to designers in determining what failed first in the rotating assembly. Often, during the first slow motion playback of the burst event, customers are able to determine if the rim or bore section of the test rotor triggered the burst event. Test Devices' high-speed video testing provides:

- Cutting-edge high-speed video technology to provide exceptional image clarity
- System captures and saves the trigger event as well as the visual history leading to the event
- Support for the failure analysis process that follows a burst test
- Ability for metallurgical engineers to quickly hone in on the critical pieces of the burst fragments to direct their examination

Unique Testing Techniques

Test Devices provides some of the most advanced testing services available in the world. Measurement of elastic/plastic growth, strain survey testing, high temperature (thermal gradient, extreme temperature and thermal mechanical fatigue testing), and HCF spin testing exemplify our highly sophisticated techniques. Following are several of our most important unique approaches.

Blade Excitation and Response

Excitation of blade resonant vibrations in fully assembled jet engine stages during rotational testing at operational speeds and/or temperatures.

- Excite and control the vibrations of rotating blades at desired modes
- Measure, capture and store blade strain test data
- Provide graphic display of vibration for individual blades
- Validate Campbell diagrams
- Assess the impact of strain amplitudes on the HCF life of the component
- Measure amplification factor (Q) at different modes

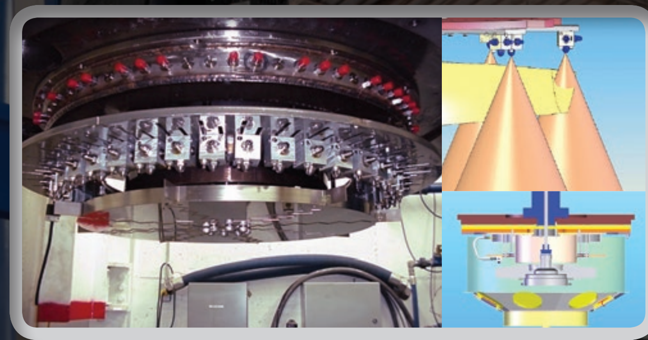


Figure 4 – Blade Excitation and Response

Thermal Mechanical Fatigue (TMF) Testing

TMF testing, which synchronizes the temperature gradient with engine speed in real time. Compared to constant gradient testing, TMF creates a more realistic test environment by simulating operating conditions to a much higher degree.

- Prototyped on DOD flight hardware
- High-response heating elements
- Active cooling
- Thermal gradient
- Program objective to demonstrate control

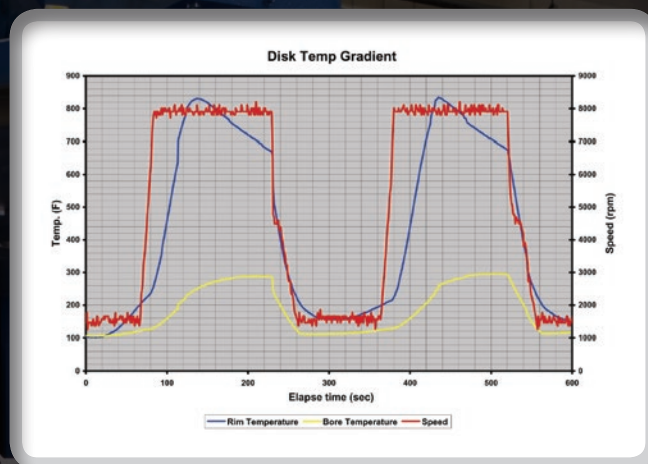


Figure 5 – Thermal Mechanical Fatigue (TMF) Testing

Aerodynamic Pulse Generation (APG)

The APG test method utilizes special hardware in a partial atmosphere test chamber to excite the rotating blades. The method is used to excite blades at different conditions, evaluating their resonance response in a rotational frame. One unique benefit of APG is that it can be performed in high-temperature environments.

- Partial atmospheric test
- Local Aero Impulse from static hardware
- Controlled rig pressure
- High engine order (54+)
- Aerodynamic heating; additional heating possible (1250F+)
- Blade response depends on multiple factors:
- Drive power
- Blade set/drag
- Heat limitations

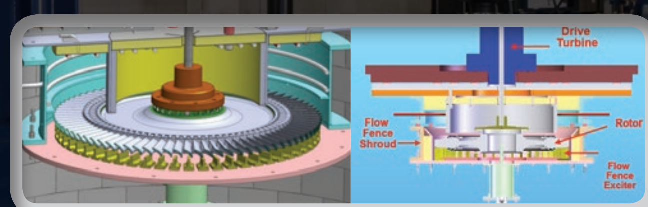


Figure 6 – Aerodynamic Pulse Generation (APG)

Specialty Equipment to Address Customer Challenges

Test Devices provides turnkey solutions for specialty testing needs including non-rotational. We leverage our unparalleled systems engineering capabilities to provide testing solutions that our customers need and cannot obtain anywhere else.

Test Devices' test equipment is ready to meet your most difficult testing challenges. We provide:

- Safest & most robust equipment in the industry
- Air turbine and electric drive systems
- Systems incorporate numerous innovations derived from Test Devices' testing experience
- Continual upgrades assure you get the best results
  - We adjust to evolving testing needs
  - Continually incorporating new technology

Test Devices can address customers' targeted applications, with:

- Industrial equipment design
- System integration
- Design for extreme thermal conditions
- Damping and stability
- Containment and safety
- Controls and user interface
- Structural analysis FEA
- Rotational drive systems
- High-speed bearing assemblies
- Vacuum systems
- Pressure vessels
- Precision components
- Tooling & fixtures
- Air flow delivery & control (e.g. heat exchangers)
- Blade erosion
- Aeromechanical

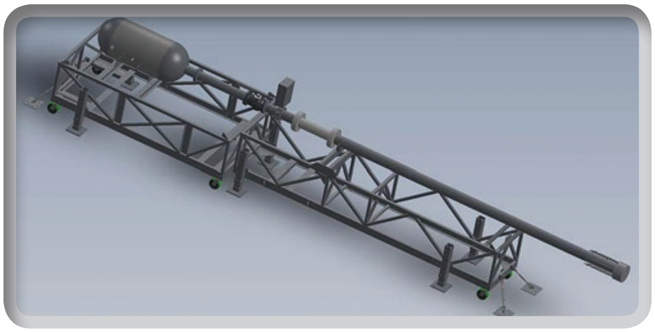


Figure 7 – Bird-Strike

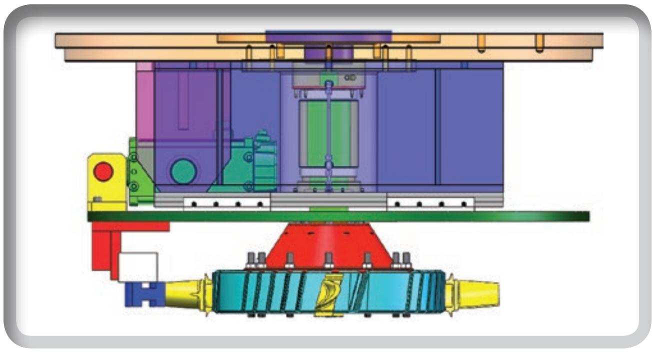


Figure 8 – Tip Rub Testing

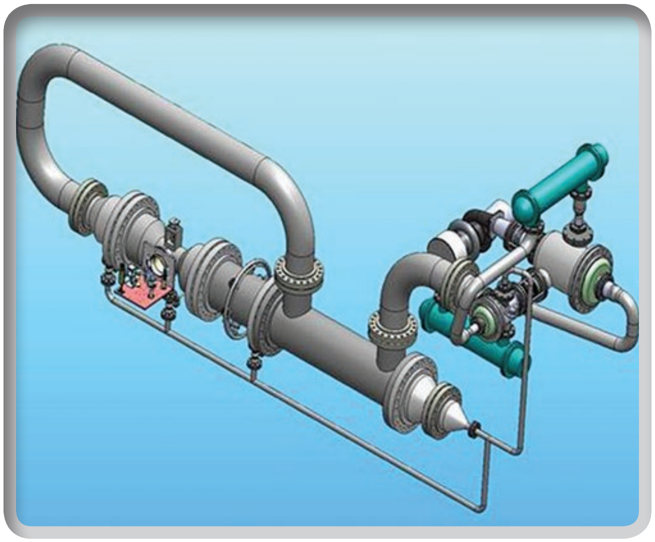


Figure 9 – High Temperature Thin Wall Test Rig

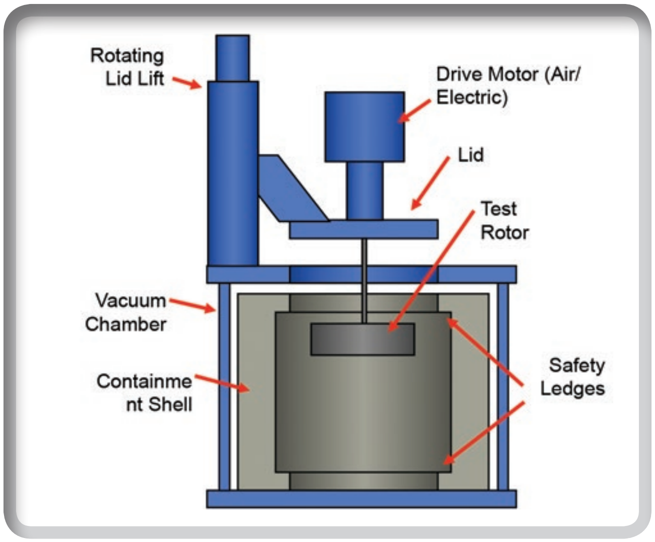


Figure 10 – Test Chamber

Test Devices Inc.
571 Main Street | Hudson MA, 01749-3035
Tel: 978-562-6017 | Fax: 978-562-7939 | www.testdevices.com