BLADE RUNNERS

Rolls-Royce is using a new vibration controller for high-frequency, high cycle fatigue (HCF) tests of low damped engine components

BY SWEN RITZMANN & SCOTT COURTNEY

The Rolls-Royce Mechanical Test Operations Centre (MTOC) in Dahlewitz, Germany, is a new, innovative test center founded in 2010 for mechanical and structural evaluation of gas turbine components during development, production and service life. The role of the MTOC vibration test team is to conduct structural dynamic investigations of these components. The main tasks performed are fatigue testing (hot and cold), frequency checking, mode shape measurement, modal analysis and dynamic strain gauge measurement.

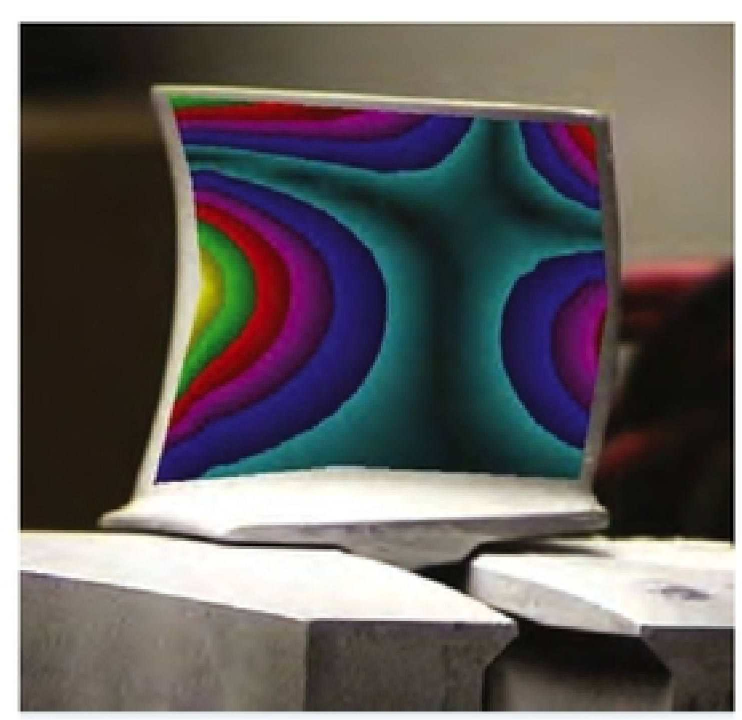
VIBRATION TESTING AT MTOC

Vibration testing is a major part of the Rolls-Royce strategy to ensure the reliability of the engine components over their lifetime, and high cycle fatigue (HCF) testing of engine components at their various mode frequencies is the primary test type within this role. The Finite Element (FE) models enable prediction of eigenfrequencies and mode shapes of engine components, and also calculate stress and expected fatigue levels for the required lifetime of each component. For the validation of FE models, the analyst has to compare experimentally measured mode frequencies, mode shapes and fatigue failure levels with the FE predicted frequency, mode shape and stress calculations. This is accomplished through component testing.

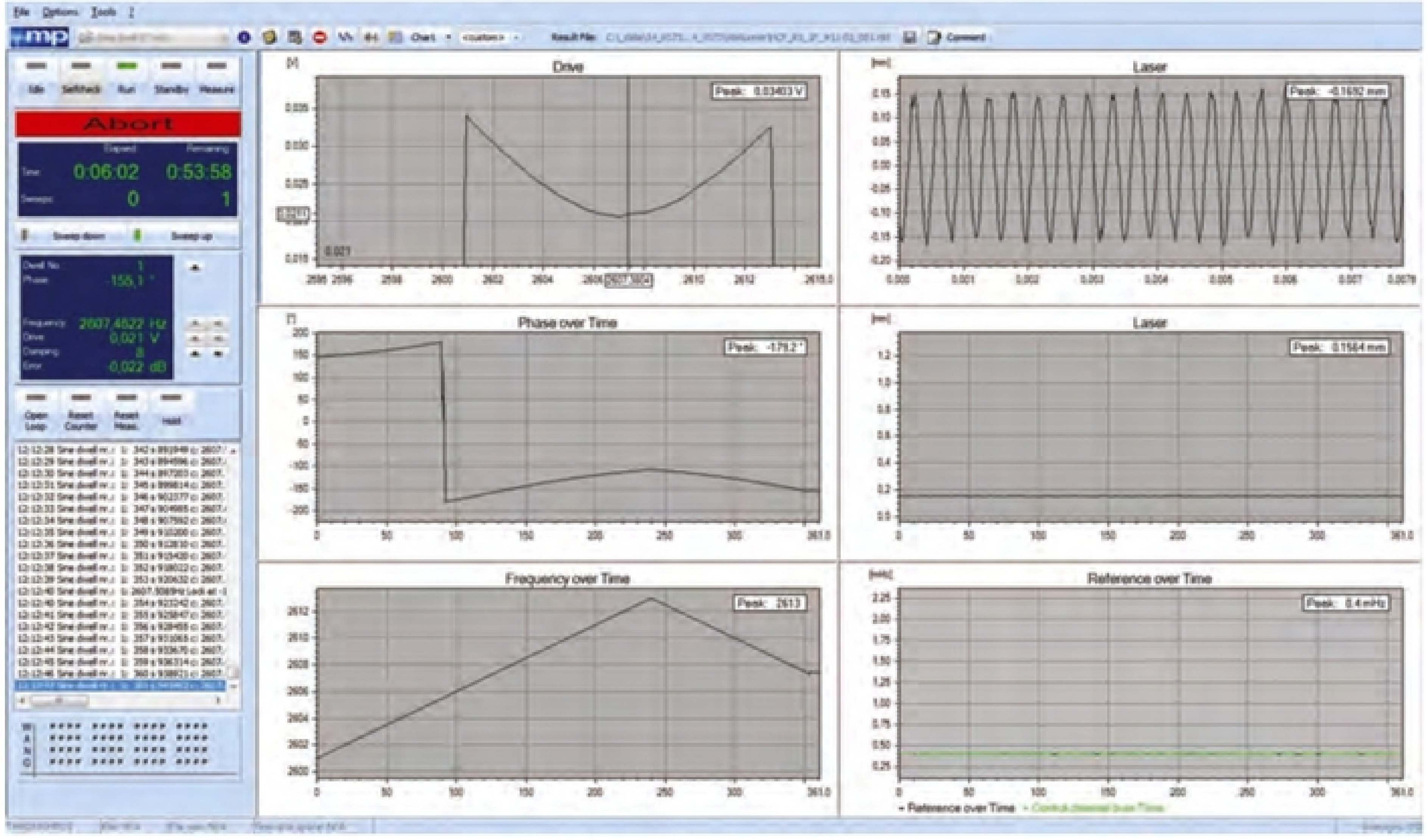
The MTOC vibration testing capabilities for HCF involve the following test rigs and equipment: fatigue testing of large fan blades; hot HCF testing of turbine blades; and HCF testing of compressor blades and vanes.

For HCF testing, several technologies can be used to excite the engine parts, including: a constant airjet (flutter); chopped airjet (pulsed air); electromagnetic shaker; and piezoelectric shaker.

These four technologies cover the resonance frequency range of engine components up to 40kHz. For the lower frequency range, both the constant and chopped airjet systems can be used. The chopped airjet system is able to excite fan blades in the low-frequency range, as well compressor blades and vanes up to 20kHz. The electromagnetic shaker has a frequency range from low frequency up to 5kHz with a special high-frequency shaker (Unholtz-Dickie Corporation). For high frequency modes (>5kHz), the piezoelectric shaker is the only available excitation source.

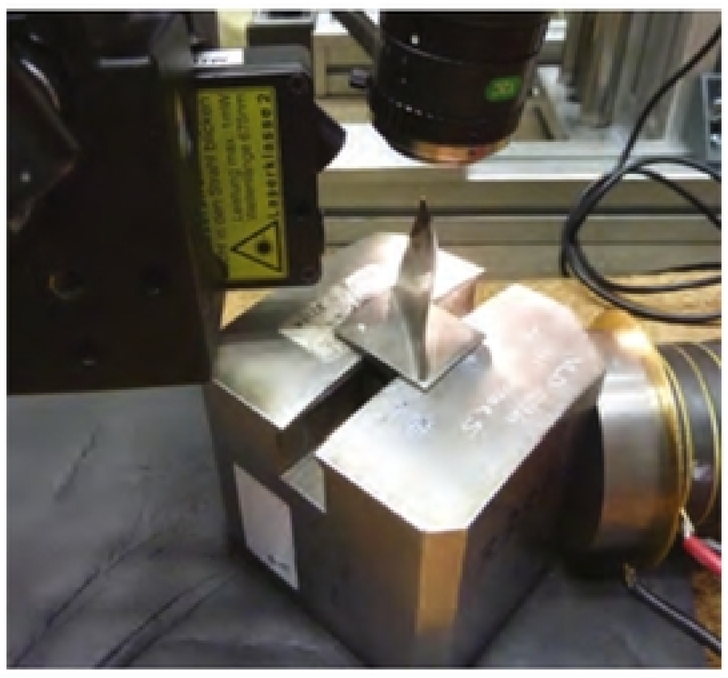


For testing with higher excitation levels, the MTOC piezoelectric shaker system works as a tuned resonance system. For HCF testing, the piezo shaker excitation system must be designed with a system resonance within the expected frequency range. The shaker system behavior can be calculated as a 2DOF system. This consists of: all hardware including the clamped engine component (mass 1); the piezo disks and connecting bolt



RIGHT: Time history graphs

BELOW: Standard HCF test setup



ABOVE: Piezoelectric shaker

CENTER LEFT: Scanning Laser Doppler Vibrometer (SLDV)

BOTTOM LEFT: Hot HCF testing of turbine blades

(spring system); and the specific mass necessary to meet the required system resonance (mass 2). The new MTOC's piezoelectric shaker design and tuning technology allow for the fast setup of HCF tests (including quick change-over to a different eigenfrequency on the same component) and is the most used vibration excitation technology within MTOC.

HCF TESTING PROCESS

The HCF testing of engine components can be performed as an incremental or constant sine dwell test. The dwell test can be run by manual or automatic control. However, for tests requiring large numbers of cycles and extended test times, an automatic control of the HCF test by a vibration controller is required. To control the HCF test, the displacement of the component response is measured by optical (video camera) or laser displacement sensors. The dwell test is controlled by the response displacement, and the vibration controller uses phase tracking to monitor the excitation frequency and to compensate for load-dependent frequency changes.

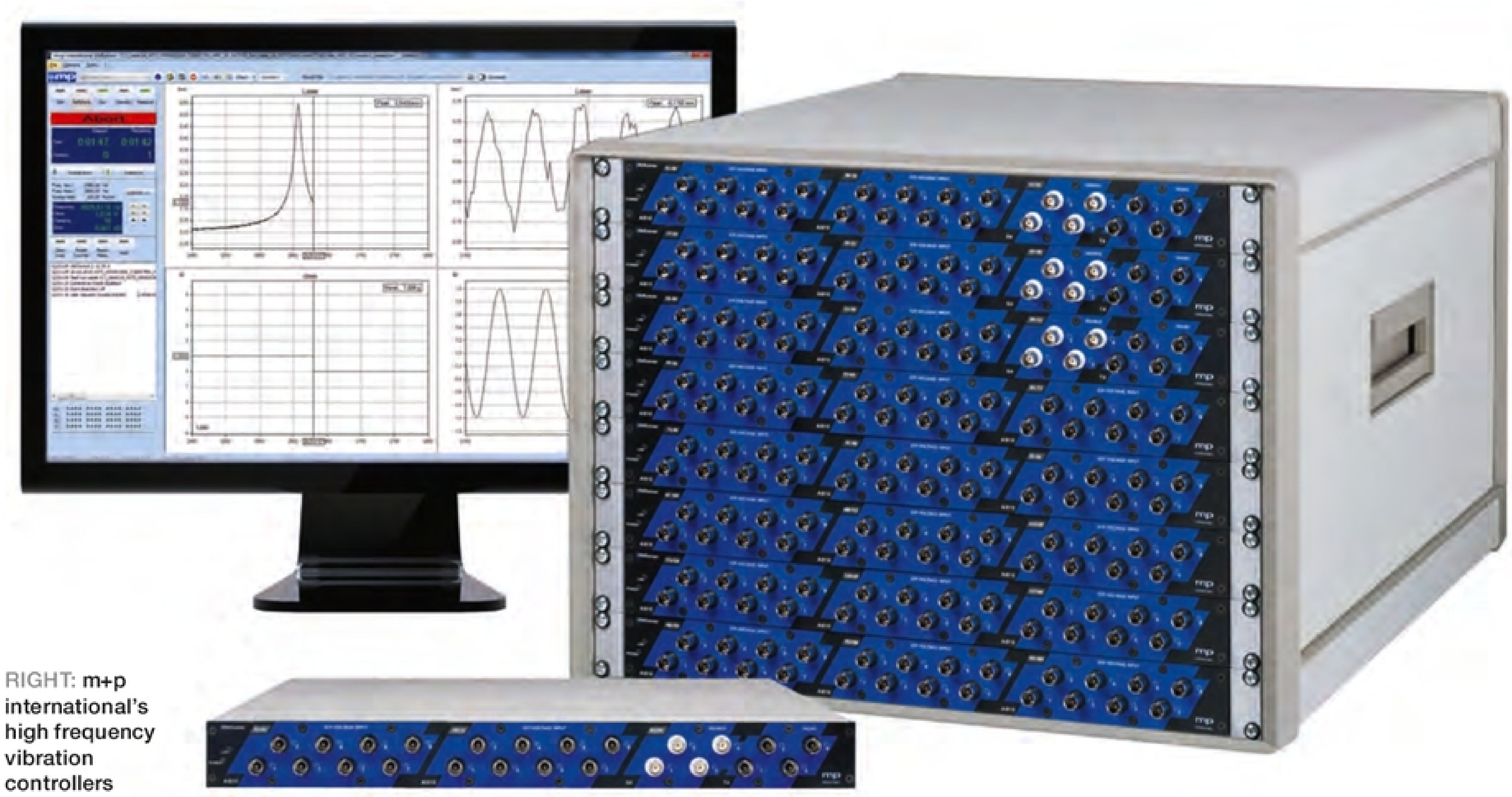
Within the Rolls-Royce group, the measure used for expressing vibration response is 'AF level' (Amplitude/Frequency), with the unit 'mHz' (meter * Hz). The AF level of a vibrating component is calculated by normalizing the response displacement by the test frequency. For example, the AF level of a compressor blade with 3mm displacement (measured at the maximum location) at 1.5kHz results in 4.5mHz. The objective of the HCF test is the validation of the predicted fatigue strength AF level versus the level at which failure occurs during vibration HCF testing.

> "TO PROVIDE A VIBRATION CONTROLLER THAT CAN HANDLE THE LOW DAMPING THAT EXISTS DURING CERTAIN ENGINE COMPONENT TESTING, M+P INTERNATIONAL DEVELOPED A SPECIAL AUTO PHASE TRACKING TECHNOLOGY"

TESTING ENGINE COMPONENTS WITH LOW STRUCTURAL DAMPING

For the low damped engine parts with quality factor between 500 and 1,000 or more, a standard dwell test is not possible. Since the high quality factor results in a very small frequency bandwidth, the load dependent resonance frequency can vary within the same excitation range. A standard dwell test with low structural damping requires a vibration engineer with a lot of experience, and in addition, more time is required to tune the test setup. In order to provide a vibration controller that can handle the low damping that exists during certain engine component testing, m+p international developed a special auto phase tracking technology. To adapt to Rolls-Royce MTOC test requirements, the m+p vibration controller software was upgraded with the 'HCF' option.

Since December 2011, MTOC has been using the standard m+p vibration controller for vibration testing. The 2012 upgraded controller is optimized for HCF dwell testing with phase tracking for components with low damping. As part of a typical HCF testing flow, first a sine sweep is used to find the resonant frequency range. The following dwell test starts with a sweep within the resonance bandwidth. Once the sweep through the bandwidth is finished, the controller sweeps back to the determined resonance frequency and locks the frequency and the phase between excitation and response. The locked phase angle will be used for the



RIGHT: m+p international's high frequency vibration controllers

> **"WITH THIS SYSTEM, THE PHASE LOCK-IN AND PHASE TRACKING WORKS THE SAME AT 30KHZ AS THE PREVIOUS SYSTEM WORKED AT 3KHZ"**

phase tracking during the remainder of the test.

MEASUREMENT AND TEST SETUP FOR HCF TESTING

The standard HCF test setup consists of: the excitation system with the clamped engine component in fixed free condition; a laser displacement sensor (LDS) for the frequency response measurement; and a video camera system to measure the maximum displacement. For the first flap or first torsion mode, the maximum displacement can't be measured by the LDS because this displacement is located at the component edge, and the sensor needs a stable measurement point that does not 'fall off' at higher amplitudes. Therefore, the measurement of the displacement sensor must be calibrated to the video camera measurement, and the sensor must be aligned to a lower but more stable measurement point.

If the frequency and phase is locked at the starting excitation level of the HCF test, the test flow follows the defined test parameters. For a constant AF level test, the test stops when defined test time or number of cycles has been reached. For an incremental HCF test, the excitation level is kept constant until the defined increment time or number of cycles is reached, and then increases to the next response AF level increment.

However, the reason for HCF testing is to measure the AF level when the component reaches failure. When the component structure loses integrity or starts to crack, the resonance frequency changes significantly. Therefore, the vibration controller's phase tracking feature must allow the excitation frequency to follow the actual resonance frequency of the component as it changes. When the defined abort level is reached (expressed as percentage of the start frequency), the vibration controller stops the excitation and aborts the testing. Typically, the abort level is defined as a 2% frequency drop, according to fatigue theory. With the saved protocol file, the test engineer can then trace the finished test according to the time history graphs shown on the previous page.

At MTOC, the m+p vibration controller VibPilot and VibRunner are in use. To achieve HCF tests for higher modes above 20kHz, the high-frequency option for the m+p VibRunner was installed. High-frequency laser measurement equipment is used as the control channel for the test. With this high-frequency setup, a resonance frequency with a small bandwidth (low damping level) is easily identified. With this system, the phase lock-in and phase tracking works the same at 30kHz as the previous system worked at 3kHz.

The installation of several high-frequency m+p international vibration controllers within the Rolls-Royce MTOC has not only helped improve the quality of HCF testing of engines blades and vanes, as well as improve overall test stability and quality, but also ensured the required setup time was considerably reduced. ∎

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