ACOUSTIC EXCITATION OF TURBOMACHINERY BLISKS

Specialized software can be used in the design of turbine blisks by replicating and capturing the crucial excitation patterns set up during testing of the rotor blades

// **SEBASTIAN SCHWARZENDAHL**

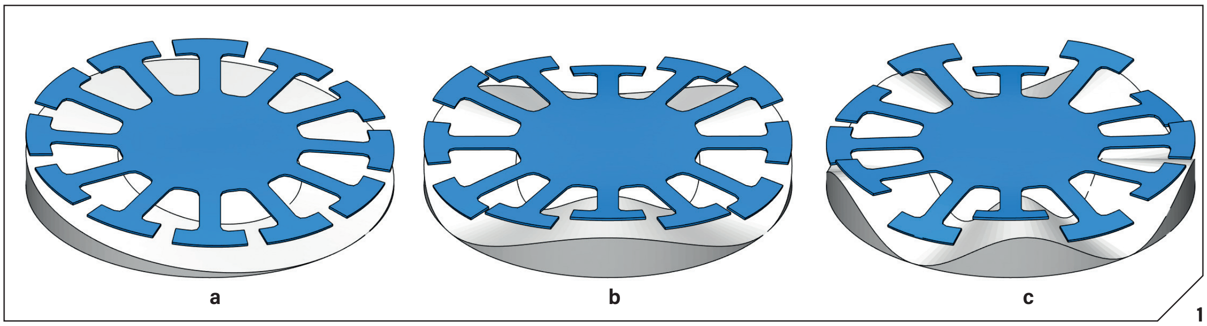
During operation, rotor blades of aircraft turbines are subject to high dynamic forces introduced by the working fluid. To assess the structural health of the blades, dynamic analyses are carried out in laboratory tests. Highly specialized test rigs are designed for analyses of blades in rotating and stationary operating conditions. Especially for stationary tests, it is crucial to artificially replicate the typical excitations acting on the rotor blades during operation, known as engine order excitation. A software package designed by m+p international enables engineers to generate an engine order excitation and analyze the dynamic responses of the turbomachinery blisks in the safety of the laboratory.

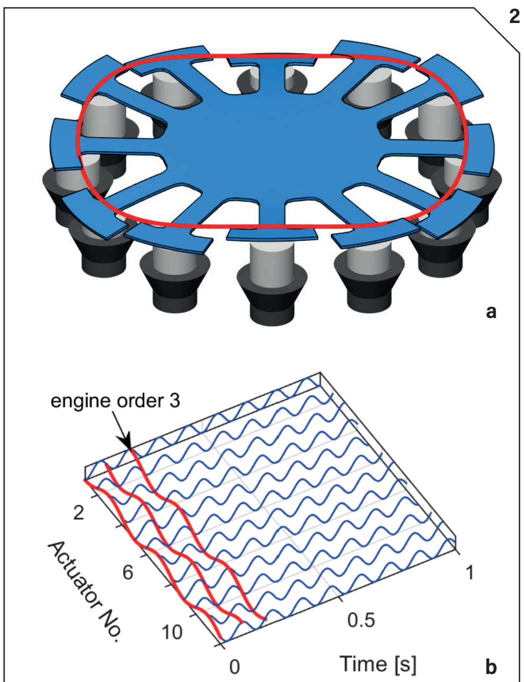
BACKGROUND

During operation, the working fluid acts on the rotating turbine blades, creating a pulsating pressure field. Circumferentially expanding this pressure field yields a harmonic series whose coefficients are called engine orders (EO). Basically, an EO describes the number of sine waves traveling along the circumference of the rotor (Figure 1). The corresponding excitation frequency is the product of the rotational speed and the specific EO.

$$f_e = \mathrm{EO} f_{\mathrm{rot}}, \quad \mathrm{EO} = 0, 1, 2, \dots$$

Only a few EOs will be encountered during operation. Thus, it is often possible to reduce the whole pressure field to a single EO. m+p international's excitation generation and analysis software replicates





1 // Simplified bladed disks (blue) with pressure fields (gray) representing three engine order excitations: a) engine order 1; b) engine order 3; c) engine order 5

2a // The stationary blisk in blue is equipped with 12 speakers (black). Sound pressure (gray) of each speaker adjusted to fit an engine order excitation

2b // Harmonic excitation signal (blue) for each speaker with relative phase lags adjusted to create an engine order 3 excitation (red)

3 // m+p VibRunner system used for sensor input and excitation signal output

4 // Experimental setup consisting of 10 rigidly clamped loudspeakers and a simplified blisk

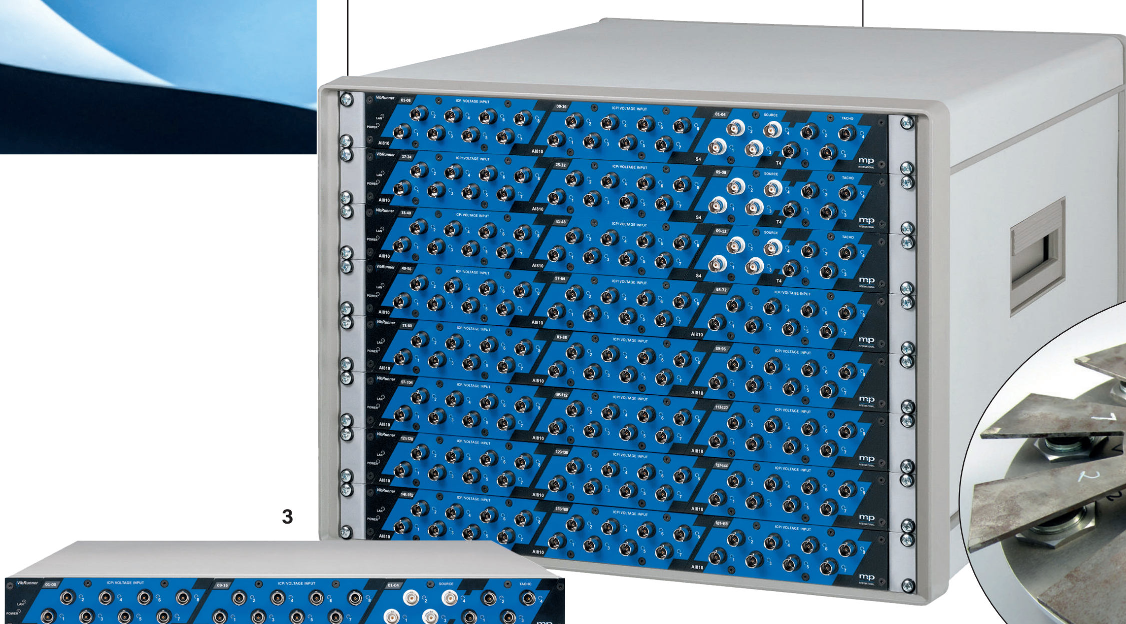
this engine order excitation by controlling the given actuators accordingly. Magnetic, acoustic, or electrodynamic actuators are just some examples of the excitation sources that can be chosen according to the applications needs based on the required excitation forces, excitation frequency range, etc.

A common experimental setup is shown in Figure 2a in which one actuator is placed beneath each blade. Thus, the continuous circumferential pressure field (engine order) is replicated at discrete points (the actuators). For example, in a setup with 10 actuators, an engine order EO=3 is generated by replaying a sine wave of a given frequency on each loudspeaker and introducing a constant phase lag between neighboring loudspeakers of:

$$\triangle\varphi = 360^\circ \cdot \mathrm{EO}/N_{\mathrm{blades}} = 360^\circ \cdot 3/10 = 108^\circ$$

Figure 2b demonstrates how this excitation replicates a steady-state operation of the machine at constant rotational speed. Run-up or run-down can be simulated by sweeping the excitation signal while keeping the required constant phase lag between the loudspeakers.

This article describes acoustic excitation using loudspeakers, which is well suited for excitation frequencies above 1,000Hz. The experimental setup was developed together with the Institute of Dynamics



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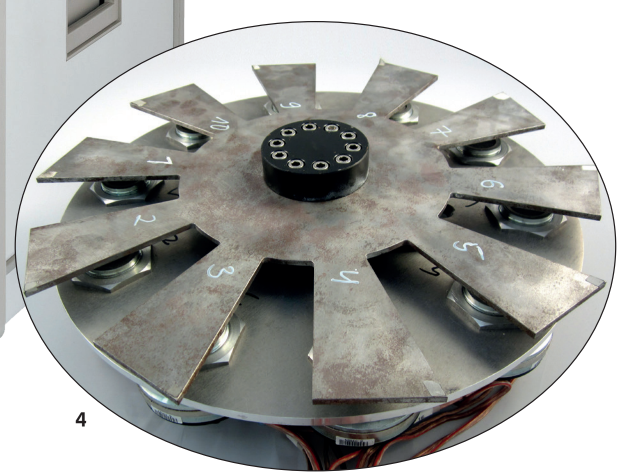

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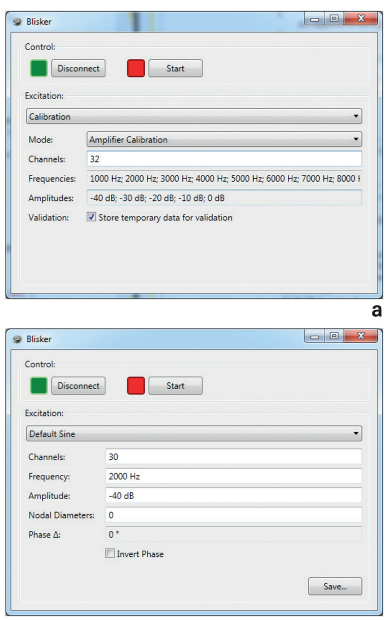
"IT IS CRUCIAL TO ARTIFICIALLY REPLICATE THE TYPICAL EXCITATIONS ACTING ON THE ROTOR BLADES DURING OPERATION"



5 // GUI for amplifier calibration (a). GUI for sine excitation (b)

and Vibration Research (IDS) at Leibniz Universität Hannover, Germany, and is used in several scientific research projects.

EXPERIMENTAL SETUP

The experimental setup designed at IDS consists of a simplified bladed disk with 10 blades. In the center, the blisk is clamped on a vibration isolation table. Loudspeakers (type BMS 4540) are mounted on a rigid plate and placed beneath each blade. Acoustic amplifiers (type IMG Stageline STA 1508) are used to drive the loudspeakers. The input signals (excitation) are generated using m+p VibRunner hardware. Multiple m+p VibRunner chassis may be combined into a single multichannel system, providing high output and input channel counts. Simultaneous sampling of all output channels ensures minimal phase error and high excitation signal quality, which is crucial in this type of application. The vibration response of the blisk is measured with accelerometers or a laser vibrometer.

Although the geometry of the IDS experimental blisk is very simple, it exhibits the main features of real-world blisks, such as traveling waveforms with different nodal diameters and mis-tuning effects. The m+p software provides a way to excite these traveling waveforms and measure the operational deflection shapes.

TYPICAL TEST PROCEDURE

Setting up the excitation system is a two-step process. The first step is to calibrate the system and the second step is to parameterize and configure the excitation. To calibrate the excitation system, the software offers a calibration routine (Figure 5a). All amplifiers and loudspeakers can be calibrated at distinct frequencies and amplitude levels. The results are saved to a database for future use and validation purposes. The system configuration (Figure 5b) is quick and straightforward.

The user inputs the channel count, test frequency, engine order (nodal diameter) and amplitude level. Everything else is automatically generated by the software. The excitation types are available in four different modes:

Sine is the most basic excitation. Users select a frequency, amplitude and nodal diameter; the software calculates the correct phase lag and generates the engine order excitation.

Custom sine is a mode where the user can introduce arbitrary phase lags between output channels at given frequency and amplitude levels. This can be useful if the number of loudspeakers is not equal to the number of blades.

Periodic chirp adds a periodic chirp using the engine order excitation. This replicates the run up/down of a rotating machine.

Custom periodic chirp, like custom sine, the user introduces arbitrary phase lags.

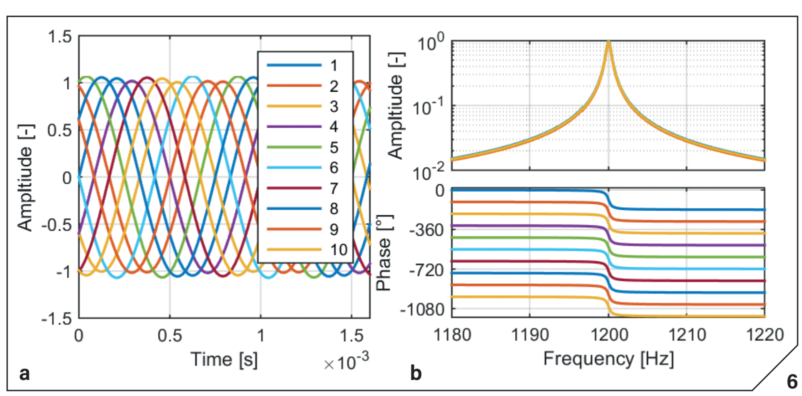
Standing wave excitation is also supported for all excitation types.

TEST RESULTS

Typical test results are depicted in Figure 6. A laser vibrometer was used to measure the tip amplitude of each blade in the frequency range from 1,180Hz to 1,220Hz. All data was acquired using m+p Analyzer, a multipurpose measurement software capable of acquiring and post-processing huge amounts of data. m+p's excitation generation and analysis software was configured to harmonically excite the engine order three (EO=3). The loudspeakers produced a rotating pressure-field with three circumferential waves. As can be seen in Figure 6a, the response of the individual blades is harmonic but phase-shifted. Just like the phase lag of the excitation between two adjacent loudspeakers was 108° (EO=3), the phase lag between the responses of two adjacent blades was also 108° (Figure 6b). Note that the maximum amplitude of all blades is nearly identical because of the rotating nature of the mode shape. Small differences in amplitudes of the individual blades are expected due to mis-tuning effects resulting from material and manufacturing imperfections.

m+p international's software package enables engineers to perform dynamic testing of aircraft turbine blisks. Replicating the engine order excitation on a stationary test stand rather than in a rotating regime saves test costs and time during turbine development. \\

Dr Sebastian Schwarzendahl is product manager with m+p international



6 // Measured time history (a) at each blade tip under excitation with engine order 3 at 1,200Hz. Phase-referenced spectra (b) of the blade responses in the frequency range from 1,180-1,220Hz (phase ref. at 1,180Hz blade 1)