RMS Rotating Machinery Services, Inc.

HARMONIC RESPONSE STRESS ANALYSIS OF BLADES IN RESONANCE

By Christopher Sykora

Encountering resonant vibration of turbomachinery blades can be very damaging since small forces are amplified by vibrational energy, resulting in rapid high stress oscillations. Resonant vibrations can potentially occur with many of the different natural frequencies of a system. How can we tell if the stress levels from a particular resonance are high enough to cause fatigue failures? Often if a potential resonance is identified on a Campbell or Interference diagram it will be ignored if it is a very high order mode shape that requires a lot of energy to excite. But how can we prove that this will not be an issue? A harmonic response stress analysis can begin to answer these questions if the right information is available.

Harmonic response (or frequency response) is a specific type of forced response analysis. It is a technique used to determine the steady-state stress response of a structure to loads that vary sinusoidally (harmonically) with time. The loading is defined as a sine wave having amplitude at a specific frequency. Harmonic response provides the capability to predict the stress & deformation experienced during an oscillating vibration, thus enabling the verification of whether or not a structure can overcome resonance. However, it does not predict stress during transient vibration events or vibration from random acoustic noise. It can be specifically applied to the case of rotor blade vibration excited by vane wakes since they generate sinusoidally time-varying forces on the blades.

In order to perform a harmonic response analysis, only a few more things are required beyond what has usually already been created for a static stress & modal analysis of the blade. A finite element model of the blade is used to find the blade natural frequencies. Then the frequency range of interest around a potential resonance point is used to pinpoint the analysis. Although the harmonic response can be generated at any frequency, it makes sense to run the calculations in a small range around the frequency of the resonance point of interest to save time. The maximum stress response is typically found at the resonant frequency. Therefore it is still important to identify resonance points with a modal analysis & Campbell diagram.

The two unique things needed for harmonic response analysis are the excitation force & an estimate of the material damping. The excitation force from vane wakes can be approximated as a small percentage of the aerodynamic bending load on the blade estimated earlier for the static stress analysis. Excitation forces from sources other than vane wakes may be harder to estimate. The material damping ratio (or log dec) is an estimate of the inherent damping inside the metals crystal structure. This damping ratio does not generally include the effects of frictional damping from features like interlocking shrouds, lacing tubes, riveted joints, etc. Most rotor blade metals (Fe & Ni alloys) have approximately the same material damping value, although some like 17-4PH are slightly less damped. These damping values are available in published sources. The resulting stress response of the blade will be inversely proportional to the amount of damping included in the analysis. More damping = less stress.

The results of a harmonic response analysis have two steps. The first is to create an XY plot (Figure 1) of deformation output (typically at the blade tip) vs. input frequency in order to confirm the location of the peak response. Second, the harmonic response stresses

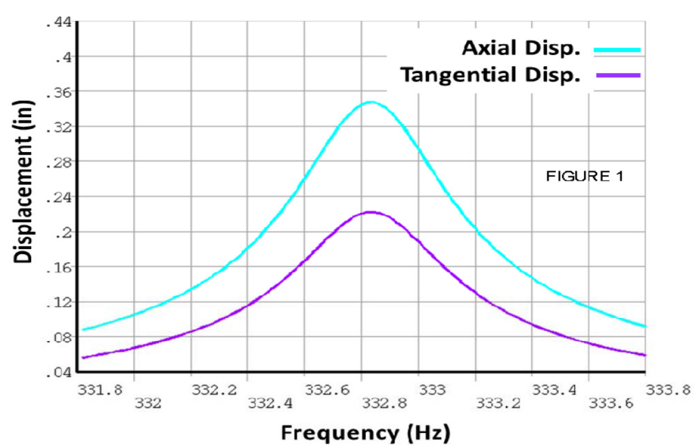

Figure 1: Blade Tip Displacement vs. Frequency

(Figure 2) can be extracted at the peak response frequency just like in a static stress analysis. The stress values extracted can be used as the alternating stress component of a Goodman diagram to check whether or not the part will be resistant to fatigue at that particular resonance point. This type of analysis can be used during the design phase to verify that resonance at a higher order mode can be ignored. Or it can be used during a root cause failure investigation to confirm that resonance of a particular mode shape was the cause of fatigue failure. It can be used on any of the bladed turbomachinery components (plus impellers) as long as the excitation force & direction can be confidently estimated & applied to the finite element model.

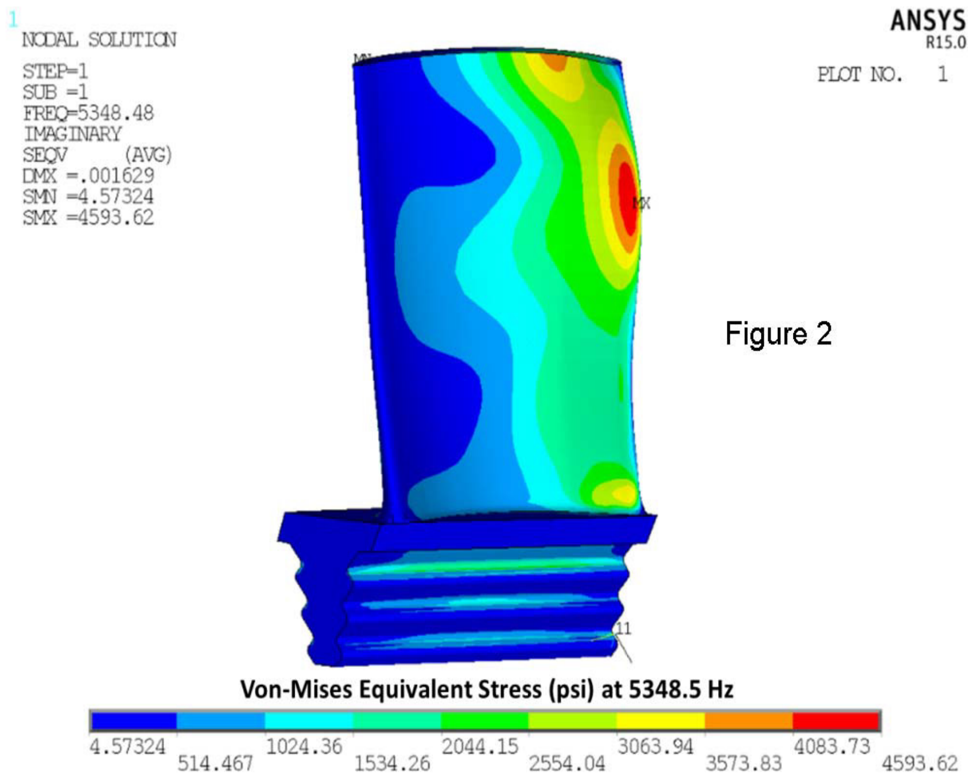

Figure 2: Harmonic Response Stress

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