MODAL IMPACT TESTING USES FOR TURBOMACHINERY ROTOR BLADES

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Today we will focus on the uses of the blade frequency data gathered from modal impact testing. Both the common "proper uses" and the sometimes requested "improper uses" of the data will be discussed. It is very important to understand the limitations of use so that the data is not misapplied for rotor blade design. Reminder: Since the "fixed state" of the rotor blade spinning in the disc is difficult to simulate, the blades are typically tested in the "free state" by testing the unrestrained blade resting on a soft cushion so that it will freely vibrate all over.

Starting with the proper uses, one typical application is in order to make an assessment of the frequency variation of actual blades due to manufacturing tolerances. For instance, an entire stage of rotor blades could be impact tested and the frequencies from each blade compared to each other to make sure one blade does not deviate too far from the rest of the population. If any of the blades deviate significantly from each other or if they all deviate from the original design predictions, then the mass and/or stiffness of the blades is not as predicted. This could be because manufacturing has exceeded the tolerances or the tolerances specified were not tight enough to control blade shape to achieve the design frequencies. If all of the manufactured blades are trending towards one direction (either all higher or all lower frequency than the design prediction), then a qualitative assessment can usually be made to see if this change will increase or decrease frequency separation margin. They might still be acceptable if margin has increased.

Another typical use is for validating the frequency results of a finite element analysis (FEA) model of the rotor blade. In order to properly make this comparison, the FEA model must also be run in the "free state". This is achieved by simply running the model without any boundary conditions at all. In this case, the first few frequency modes extracted from the analysis will be "rigid body" modes that have a frequency approximately equal to zero. These are ignored and the next set of FEA results with non-zero frequencies are then compared to the modal impact testing results. The "rigid body" modes actually exist in the experimental test as well, but since the frequency is approximately zero, the modal impact equipment does not record them. When comparing the frequency results from each technique, results that are within 1% of the first four modes are typically considered good validation agreement. Sometimes the modal impact results are used to calibrate the stiffness of the FEA model (by modifying the Young's modulus) in order to make the FEA model more closely match the "as-manufactured" blade materials. Before doing this calibration it is very important to make sure that the FEA model has as close to the same geometry as the impact test blade as possible.

Sometimes it is requested to modal impact test a rotor blade and to create a Campbell diagram directly from the impact test results. The Campbell diagram is used to understand the frequency separation margin between excitation force frequencies and rotor blade natural frequencies at operating speed. Unfortunately, building the Campbell diagram from impact test results is not possible with the commonly used "free state" impact testing. This is only possible if the "fixed state" boundary condition of the rotor blade held very tight in the disc due to the centrifugal force of spinning is replicated. Replicating these conditions is quite difficult because it requires special tooling to simulate the disc attachment slot for each blade and a large applied force to match the centrifugal force from spinning.

"Free state" impact testing results should also not be compared to "fixed state" FEA model results, since the results will be completely different. This is why the "free state" testing is instead used to validate an FEA model that was also placed into "free state". If the frequencies from the testing and the FEA model are a close match, then the boundary conditions of the computer simulation can be changed to simulate the blade in the disc rotating at speed.

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