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NODAL DIAMETERS AND THE INTERFERENCE DIAGRAM

By William Sullivan

The interference diagram has become the preferred tool for displaying the interactions of rotor blade natural frequencies with periodic flowpath excitations for bladed disks with shrouds or tie-wires (typical of both compressor impellers and steam turbine stages). On the other hand, it also seems to be one of the least understood tools in the dynamic response arsenal. A typical interference diagram is shown on the right.

In our last newsletter, we discussed aliasing, which is the phenomenon that allows so much information to be displayed on one chart. In the next few newsletters, we will try to explain the diagram itself. That is, what it is and what it can tell us about the risk of exciting rotor blade natural frequencies. A good way to start would be to describe the X-axis (abscissa). To describe the X-axis, however, we first should describe what we mean by nodal diameters and nodal diameter families.
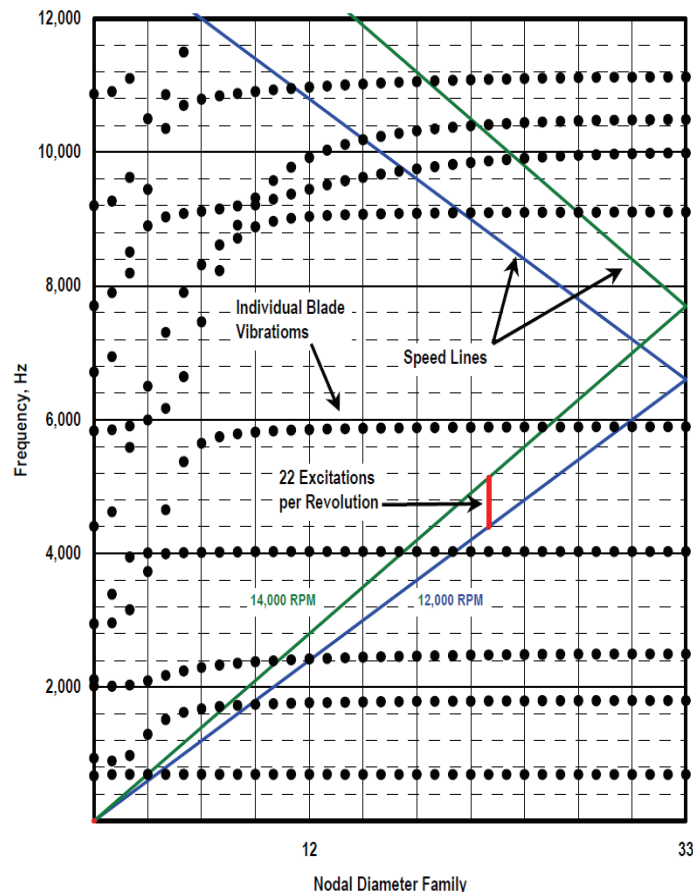

Figure 1: Bladed Disk Interference Diagram (66 Blades with Shrouds)

Nodal diameters can best be described by visualizing a flat round plate. If we were to suspend the plate in air, by a string, and tap it sharply with a hammer, we would excite all of modes of vibration. This can easily be simulated on a computer using the modal option in a finite element analysis (FEA) program. In this case, ANSYS was used to generate the following plots.

Plot A show a two-nodal diameter pattern on the circular plate. The upper view of Plot A shows a full view of the plate. In this, and all of the remaining full view plots, the red portions can be thought of as moving out of the paper (toward you) and the blue portions can be thought of as moving into the paper (away from you). Between the peaks, the plate displacement must pass zero. Zero displacement is marked by a line on all of the full view plots. For a continuous flat plate, these nodal lines will be diameters. Since places of zero displacement are called nodes, these diameters are called nodal diameters. Just below the full view plot is a side view plot. In this side view plot, one can see why the two-nodal diameter mode is often called the "potato chip" mode. The side view plots were added to aid in the visualization of the mode shapes. Plot B shows a full view and edge view of a three-nodal diameter mode.
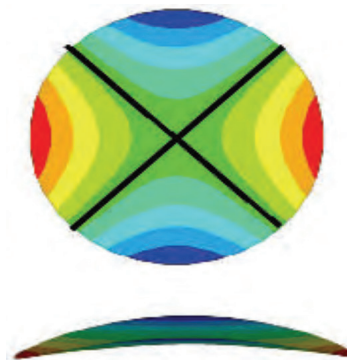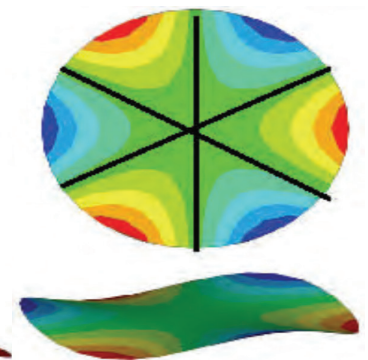

Figure 2: Plot A   *Figure 3: Plot B*

Plot C shows a full view of a six-nodal diameter mode. You should see a pattern emerging at this point. The number of red (or blue) portions, or peaks, around the edge of the plate indicates the number of nodal diameters in the mode shape. Counting the peaks around the edge makes identifying the number of nodal diameters much easier than trying to count the diameters directly, especially with many nodal diameters. In fact with the

complex geometry and modes encountered with actual bladed disks, counting diameters often is impossible.

Plot D shows a one-nodal diameter mode with one nodal circle. Note that there are two sets of peaks. One set of peaks is on the edge of the plate while the other set of peaks is inside the plate. As you move across the plate from the far left to the far right of the full view, you will encounter a peak moving out of the paper, then a peak into the paper, then a peak out of the paper and finally a peak moving into the paper. As explained above, between each peak the plate displacement must pass through zero. If we mark the zero displacement with lines, we will see that now, along with nodal diameters, we have nodal circles. Therefore, this pair of plots represents a one-nodal diameter, one-nodal circle mode.

Plot E shows a two-nodal diameter, one-nodal circle flat plate mode. This is the potato chip mode shown in Plot A with a nodal circle.

Generally, as the number of nodal diameters increases on a flat plate the natural frequency increases as well. Furthermore, the natural frequency of a mode containing a given number of nodal diameters will increase as the number of nodal circles increases. A fully bladed disk with shrouds or tie-wires will have much more complicated mode shapes than a flat circular plate. However, the same basic principles regarding the frequencies and the number of nodal diameters and the complexity of the modes apply.
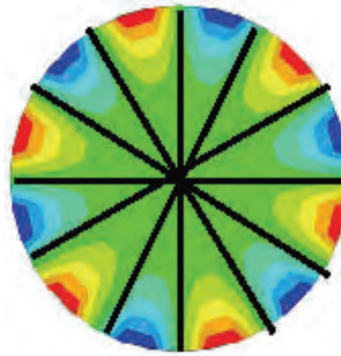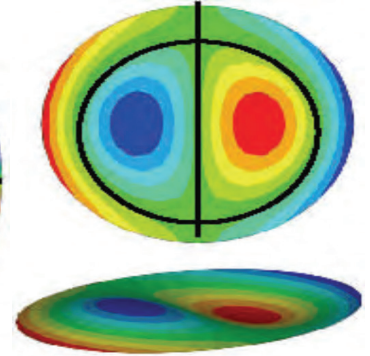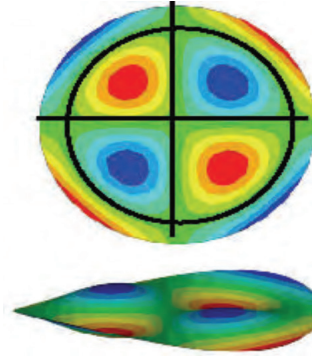

Figure 4: Plot C

Figure 5: Plot D

Figure 6: Plot E

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