PARTIAL ARC SHOCK RESPONSE

By William Sullivan, PE

In order to increase the part-load power output and efficiency from the first stage of blades in a steam turbine, the steam is often admitted in a “partial arc”. That is, steam flow through the nozzles is limited to an arc of less than 360 degrees. In this way, high steam velocities can be achieved under both full-load and part-load conditions, thus enabling the blades to operate at optimum or near-optimum aerodynamic conditions. Unfortunately, this is one case where what is good for aerodynamic efficiency is not good for blade reliability. This is because as the blades pass into and out of the arc of admission, they experience sudden and complete loading and unloading.

This sudden application and removal of load increases the dynamic load on the blades, which in most cases is limited to the nozzle wake perturbations, by a factor of about 10. Furthermore, depending on the natural frequencies of the packeted blade modes, the shock loads can be multiplied by the blade modes being in resonance with the blade-to-blade load applications. Of course, while all this is going on, the blades are also being subjected to the typical nozzle passing loads.

The effect of packeted blade frequencies and mode shapes on partial arc response can be demonstrated analytically using dynamic response modeling. In this case we will examine a packet of 5 blades. For simplicity, the blades and shroud will be built using “beam” elements. With beam elements, the blade and shroud cross-section properties (area and moments of inertia) are defined for specific intervals. The ends of the intervals are located and linked by nodes. The blade and shroud model can be seen in Figure 1.

In the analyses, the blades are loaded sequentially at intervals based on the assumed rotor speed. The blades remain loaded through the arc of admission. Finally, the blades are unloaded sequentially as they leave the arc of admission.

One of the key factors in determining the response of a group of blades to the sudden load application is how many blade vibration cycles occur as the blade progresses one blade pitch (cycled per blade pitch).

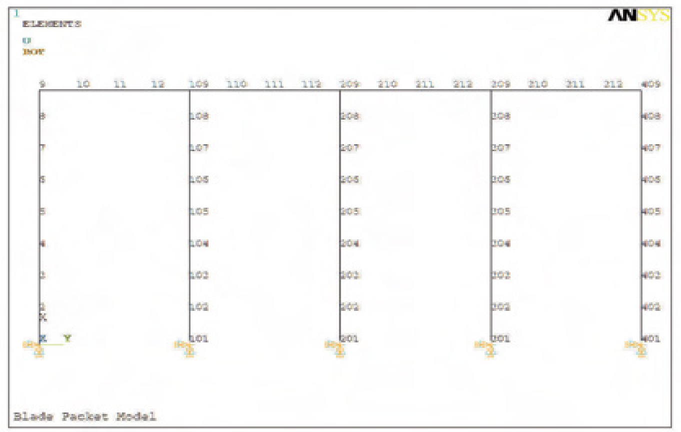

Figure 1: (Node Numbers Turned on for Visibility)

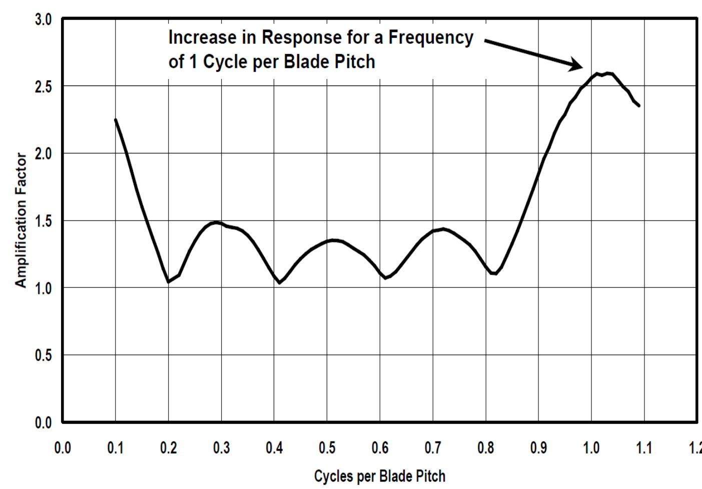

Figure 2: Shock Amplification for 5 Blades per Packet

This can best be visualized for the case of one cycle per blade pitch for the first tangential mode. As the first blade enters the arc of admission it is immediately deflected. The shroud passes the deflection to the remaining blades in the packet. At this point we should probably point out that any sudden application of load excites all of the blade modes of vibration to some extent (this is what happens during an impact vibration test). Therefore, if the first tangential mode is excited, and the frequency of excitation corresponds with the blades progressing one blade pitch, then as the second blade is loaded it already wants to move in the direction of the applied load. This can increase response significantly.

The effect of the above can be seen in Figure 2, which is a plot of the response of the 5-blade beam model in terms of cycles per blade pitch. (For this plot, only tangential loads were applied.)

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