By: CLIFF KNIGHT
Owner/President
KnightHawk Engineering

Cavity acoustics

Once again you are in the conference room discussing the integrally geared compressor failure. This is the second failure of the system, and as a plant maintenance engineer, the pressure is on to find out what happened and fix it.

The compressor has been running for years with no problems. All the plant did was debottleneck and increase production well within the limits of the compressor, but now you are experiencing open-face impeller failures.

Both impeller failures experienced high-cycle fatigue. The metallurgist calls it corrosion fatigue. The OEM pointed out how the compressor was within its limits, and the SAFE diagram and the Campbell diagram showed no problems. It seemed there was a general consensus that the failure was due to a slug of liquid in combination with corrosion.

You are "bugged" by the situation because of three major points. The first is that the compressor failed at the same revolutions per minute (rpm) range, which is a higher rpm than the compressor ran before the plant was debottlenecked. The second point is that there is no evidence of a slug. The final point is that, for your entire career, you have observed pitting in these impellers.

After looking at the vibration data, everything was running smooth until the failure. As far as the corrosion is concerned, the pits still found a lot of "beef" in the impeller. The other point that really bugs you is the fact that the blade failures suggest it was the second mode and not the first, as one would expect with a slug of liquid.

This is a typical story regarding the so-called "phenomena failures" for open-face impellers. One of the biggest myths regarding the analysis of impellers is that if a SAFE diagram analysis is conducted and it passes, there will be no forcing function to excite anything.

It is an excellent tool for looking at internal guide vane (IGV) interference, but the fact is, the SAFE diagram does not include all the physics involved with impeller analysis. In particular, it does not include the "cavity acoustics."

Yes, this is the same issue that occurs in reciprocating compressors where pulsation bottles and all kinds of studies are done to prevent the problem. It is frequently and most often not considered in centrifugal compressor design and never considered in compressor up-rate design. Most likely because the acoustical natural frequencies rarely cause interference, but when it does, your impeller is history.

So when "cavity acoustics" is mentioned, what is that? Every contained volume has acoustical natural frequencies. For a centrifugal compressor, the diaphragm and volute comprise a contained volume at the impeller inlet. Where there is a forcing function present that can excite the acoustical natural frequency, then the fluid will pulsate. This will cause two things to happen with the compressor. A turbulent flow disturbance will be present that will affect performance or, in the worst case, the pulsation frequency can couple to a natural frequency of the impeller. The bandwidth of this is very low, meaning that it would couple in and out at only a small rpm variance.

The physics is an existing problem that can be captured with high-speed data acquisition equipment using dynamic pressure transducers. If it is a new design, a good finite element (FE) model of the cavity will capture the response. Note that most computational fluid dynamics (CFD) analysis work does not resolve the acoustic waves. It has to be addressed separately. The following methodology is recommended to troubleshoot and fix a problem.

1. Metallurgical analysis — The failure should be characterized. If it is fatigue, then it should be classified as low- or high-cycle, and striations should be counted. Crack propagation time should also be determined.
2. Process analysis — Process performance evaluation and simulation.
3. Controls and instrumentation review.
4. Field data acquisition — A field study should be conducted to capture the vibration and pressure pulsations.
5. A full CFD model should be conducted of the gas path.
6. An FE acoustical model should be developed of the cavity. A model analysis should be conducted on the impeller.
7. Root cause analysis.

A good approach and methodology can eliminate the failure so there can be a "walk-away" solution. Finally, make sure a professional engineer competent in turbomachinery reviews the work.

For more information, visit www.knighthawk.com or call (281) 282-9200. ❑