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Bolts and impellers — Hanging by a thread

It is your first week on the job in a plant that is old but new to you. You find out that, once again, the plant is faced with another failure of an integrally geared compressor. To make matters worse it has failed five times in the past two years. This last failure occurred within just a few weeks of the previous failure. Now the plant manager has had enough and profits of the plant are suffering. One of the main functions of your new job is to perform a failure analysis of the latest failure and to assist with getting the compressor train operating reliably.

The failure has always been in a tie bolt that fastens the open face impeller to the shaft. This failure consisted of the third stage impeller separating from the shaft while running full speed during normal steady state conditions. The steady state failure is new for you because you have been told by the operators that the other failures have occurred during a start-up or shutdown.

To start the project you read all the previous work on the other five failures. You also see where the compressor manufacturer has been called in on every failure. Every failure has been attributed to corrosion fatigue. The words "corrosion fatigue" catch your eye and you recall that in your 20 years of experience, rotating equipment OEMs (original equipment manufacturer) have almost always attributed failures to corrosion fatigue, slugs or surge. You rarely if ever found an admission of a design error as a probable cause from an OEM. What really caught your interest on this project was that the corrosion seemed to always occur on the same impeller bolt.

Realizing that there must be something else going on, you have a contractor perform a root cause analysis of the failure and the findings are interesting. The contractor concluded that the cause of the failure was due to an inadequate design of the stage impeller bolt and fastener system. Finite element analysis (FEA) indicates high stress in the failed area. This provides no allowance for any normal dynamic stress that impeller components would experience. During the investigation a few other items came to the table. Contributing factors were excitation of the impeller from a process instability while running coincident with blade pass frequency. Also maintenance procedures for bolt-up regarding mount and dismount cycle life of the tie bolt were an issue.

In most cases the problem was easily fixed with a change of material for the tie bolt, illumination of the process instability and scalloping the impeller to change the natural frequency. The problem was addressed from all fronts to ensure that the unit would not fail again.

It just happens that on initial tightening most of the load of the tie bolt is carried with only the first few threads of the tie bolt. If tightening continues such that the first three threads yield, the next three threads start to pick up more load. If the bolt is over-torqued, it is possible to compromise the bolt preload if a significant number of threads have yielded. With a loss of preload the full dynamic load is transferred to the tie bolt and a fatigue failure of the tie bolt could occur.

In approaching open face impeller issues to avoid failures, consider the following:

1. Perform a CFD (computational fluid dynamics) analysis of the gas path to insure a sound aerodynamic design. Consider any secondary wake interaction or acoustic effects.

2. Perform a detailed structural dynamics analysis of the impeller and tie bolt assembly. FEA is a good tool to evaluate the design.

3. Look at natural frequency interferences with the Campbell and nodal diameter mode shape interference diagrams.

4. If necessary create a Goodman Diagram for any anticipated dynamic loads.

5. After the impellers are built, perform "ring checks" to evaluate the natural frequencies. The dynamic stresses can be checked with strain gauges mounted on the impeller. Mode shapes can also be determined and evaluated.

6. Compare the measured frequencies to the FEA results for the impeller.

7. When the impellers are installed, the impellers can be instrumented to look at vibration during the first runs.

Not all of these steps are required but the return on investment is quite high for most large machines. All work should be performed under the direction of a professional rotating equipment engineer competent to do this work.

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