KNIGHTHAWK TECH NOTES

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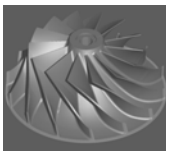
"Open Face Impellers – Failure Analysis and Design"

Open face impellers are used throughout the world in practically all turbomachinery related industries. The typical impeller is shown in the figure below. There are a number of reasons for using an open face impeller. The reasons include but are not limited to capacity, performance efficiency, and manufacturing cost depending on the details of the design. The typical components of the impeller are the hub, disk, and blades (sometimes referred to as vanes). For the most part the entire impeller is machined from a solid forging. With older impellers and in some rare cases, the blades are welded to the disk. Over the years the advancement of computers and technology has led to a better understanding of the performance of these impellers. Also, methodologies of analysis have been developed to reduce analysis cost.



Unfortunately, failures do occur for a variety of explanations. Many of the failures can be explained, but the so called "phenomena failures" are most often blamed on "corrosion fatigue" or "slug" or some other vague explanation. However, most failures can be explained with a proper root cause analysis. A typical failure analysis might include the following:

1. Metallurgical Analysis – Short of finding a foreign particle or object the following is also conducted.
2. Rotordynamics Analysis – Overall structural dynamics model of the rotor train.
3. Finite Element (FE) Analysis – Structural numerical model of the impeller
4. Campbell Diagram – Used to check for speed and vibration coincidence.
5. Interference Diagram – Used to compare a forcing function versus potential interference.
6. Computational Fluid Dynamics – This is done on occasion to evaluate the flow field.
7. Compressor Performance Study – Overall process analysis of the compressor to evaluate surge and stall.

Once all of these items are complete, an opinion about the cause of the failure can be presented. While the above list might seem to be complete there are weaknesses that may be present which could lead to faulty conclusions.

- The metallurgical analysis may conclude corrosion fatigue and everyone is happy "the cause is found", however there must be reverse loading for fatigue and some of the failed compressors may have run for years. While corrosion may have been a part of the cause, it could be that a vibration was induced that was sudden and high. The corrosion reduces the endurance limit so the impeller fails quickly.
- Usually any competent rotordynamist will produce a good analysis of the overall train and usually the frequency that fails the blades are high, so the generalized rotordynamics is not typically the problem, but should not be ignored.
- The results of FE analysis are dependent on the mesh design and boundary conditions. Here is where many errors are made. If the press fit is left off the hub, the results may be faulty as it will affect the natural frequency. The mesh design suitable for stress analysis may not be suitable for structural dynamics. Also stress stiffening due to the centrifugal load must be included in the analysis. Many false solutions are found without a properly designed and executed FE model. It is very user dependent and nothing beats experience.
- The Campbell diagram is the most conservative way to avoid interference. Many OEMs try to go to a higher level analysis because there are so many interferences.
- The interference diagram using nodal diameter methodology to predict whether a forcing function is present to excite the impeller, is widely used by OEMs and consultants but there are limitations that have led to faulty conclusions. First the methodology relies on the natural frequency analysis of the blades through experimentation or analytical means. Only the natural frequencies at running speed can be accurate and you can't measure them through traditional experimental methodology. Analytical is the best but the model must be nearly perfect. If the mode shapes are not correct the entire analysis is faulty. The other problem is the method does not consider secondary wake disturbances that can excite acoustical natural frequencies. The method, although widely used is simply not the SAFE way to determine the root cause.
- CFD is highly user dependent. While steady state solutions are helpful, only transient solutions can capture all possible load conditions, i.e. secondary wake disturbances.
- Generally a compressor performance study will be accurate, but oversights do occur.

In general, for an accurate result from impeller analysis the rubber meets the road with a proper understanding of the metallurgical results based on the actual load conditions and properly designed FEA and CFD models. The limitations of any interference diagram considered SAFE should be understood as results can be faulty.

As you can see open face impeller failure analyses are highly complex and should only be evaluated by personnel competent in machinery dynamics with direct in the field experience.

Cliff's Notes: KnightHawk is blessed to have personnel who have operated turbomachinery equipment in the field, worked as an OEM, worked in repair, and have designed this type equipment. KnightHawk is a world-class one stop shop for analysis of turbomachinery and is considered one of the best teams in analysis of open face impellers. Dr. Lee Hill is the head of our Specialty Engineering group and was the head of the computational fluid dynamics group at a major turbomachinery company. He has published many papers through the Turbo Symposium. Dr. Carlos Corleto who heads up our metallurgical lab and field services, worked in production for ten years prior to coming to KnightHawk. He is also known as a world class fracture mechanics expert. I have been involved my entire career in FEA and CFD of this type equipment. Chet Stroh has 40 years of experience and formally served on the Texas A&M Turbomachinery Advisory Committee. This is just part of our world-class team to serve you. Turbomachinery failures are a part of our everyday project load. KnightHawk had a great 2010 1st quarter. Much better than the start of the Astros who I am still rooting for. Enjoy the spring before the hot summer kicks in. God Bless you and we look forward to working with you to solve your toughest challenges.

Cliff Knight

KnightHawk Project Update

- Turboexpander Failure Analysis - Gas Plant
- Gear Drive Failure Analysis - Petrochemical
- Vessel Failure Analysis - Refinery
- Flare System Analysis - Petrochemical
- Reactor Failure Analysis - Petrochemical
- Laser Cutter Fire and Failure - Manufacturing
- Oxidizer Redesign - Petrochemical
- Oil Pump Failure Analysis – Petrochemical
- Piping System Thermal Analysis - Petrochemical
- Gasifier Equipment Design – Power
- Pump Vibration Analysis – Petrochemical
- Reverse Engineering – Manufacturing
- High Temperature Molten Salt Tank Design – Green Energy
- Tool Failure Analysis – Offshore
- CFD Ethylene Furnace - Petrochemical
- TLE Fit for Service Analysis - Petrochemical
- Oxidizer Failure & Redesign - Petrochemical
- Inlet Cone Design for TLE's – Petrochemical
- Bearing Design - Heavy Manufacturing
- Vaporizer Design - Petrochem
- Mechanical Equipment Design - Off Shore
- Transient Fluid Dynamics - Petrochemical
- Waste Heat Boiler Failure - Petrochemical
- Liquids & Solids Separation Technology
- Development - Coal
- Waste Heat Boiler FFS- Petrochemical
- Furnace Feed Header Analysis - Petrochemical