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Monitoring Choke

This memo discusses the methods Flexware uses to determine choke margin, its advantages and limitations and means to confirm the choke margin. Also discussed is the definition of choke and the potential forces associated with operation in choke that may result in compressor damage.

Choke Margin

Choke margin describes the region the compressor is operating relative to the choke point. Mathematically this is (choke flow – operating point flow)/choke flow, where flow is expressed in volumetric units at the compressor inlet nozzle (impeller eye for mid section sidestream compressors). The measured nozzle flow is assumed accurate and adjusted as necessary for the pressure and temperature at the compressor inlet conditions to obtain actual volume flow. For sidestream compressors, the mid section inlet is a combination of the discharge from the first section and the sidestream nozzle. Flexware Live mixes these two streams and determines the actual volume flow at the impeller inlet based on the calculated mixed stream pressure and temperature.

The performance curve is adjusted for speed by using the fan laws (flow is proportional to speed).

Definition of Choke

As noted in Sorokes et al "The Consequences of Compressor Operation in Overload", there is no commonly agreed upon definition of choke (overload). OEMs truncate the performance curve short of Mach 1 for various reasons. One reason is that beyond a certain point the head has dropped so much it is not reasonable or economical to operate beyond this point as not only the head, but also the efficiency has dropped so low.

While not necessarily specified as such by an OEM, the performance curve suggests the compressor may be operated anywhere within its boundaries. Thus, Flexware defines the choke point as the high volume flow end of the performance curve for a given speed. It must be kept in mind though; the OEM may not have terminated the curve with this definition in mind. Some define the choke point as a volume flow percentage (120% to 140%) from the design point or drop in head (10 to 30% from the design point head or peak efficiency point). Others limit the overload capacity based on calculated values for the impeller inlet relative Mach number (0.96 or less). Thus the user should confer with the OEM in this matter.

Forces Associated with Operation in Choke

In an overload (choke) condition, flow separation occurs on the pressure side of the impeller blade. This flow separation reduces the effective throat area of the impeller and as a result significantly increases the velocity through this area. If the velocity gets high enough, a shock wave (Mach 1) will develop. The pressure field associated with shock waves is highly dynamic and cause excessive forces on the impeller. When other nonuniformities within the compressor flow path are involved such as blade interaction or discharge scrolls, conditions can become ripe for impeller failure especially if liquids are involved.

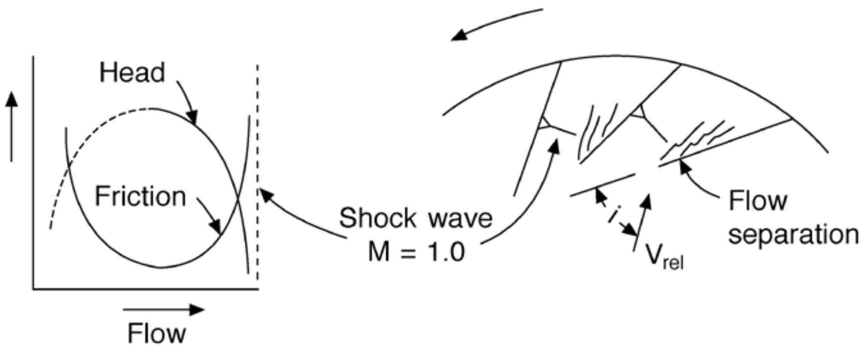

Figure #1. Choke Flow. High flow rates result in flow separation at the impeller blade leading edge reducing the effective impeller throat area and eventually a shock wave will develop (Mach 1) limiting flow through the impeller.

Limitations

There are limitations to the accuracy of any field monitoring system in determining the choke margin. Noted below are limitations of the Flexware Live software:

1. As noted above, the definition of Choke is not standardized, thus it is prudent to discuss this matter with the OEM.
2. For a variable speed machine, the choke point is constantly changing with speed. Flexware uses fan laws to compensate. While this is accurate for small speed changes, errors do build up when the speed changes more than 5% beyond the original speed line.
3. Performance curves change somewhat with pressure, temperature and gas analysis. So, the end of the curve may change some as inlet conditions change. This is another reason to get an agreement with the OEM as to their definition of choke and what they define as a safe operating region.
4. For sidestream compressors, the actual flow rate through each section is not an exact science unless internal pressures and temperatures are available, and in most cases they are not. The mixing conditions at the entrance to each section is an estimate based on external measurements and the estimated work input curves provided by the OEM.
5. The potential for real damage being done to the compressor is more a function of the velocity through the impeller throat, not the inlet flow rate. However, the performance curves are typically plotted vs. the compressor section inlet volume flow, not the impeller throat velocity. In the ideal world we would measure the throat velocity and base limitations in flow rate on this value.
6. If a compressor is not performing up to design values due to rubbed seals or fouling or other reasons, then the downstream stages see more than expected flow and thus higher throat velocities. Thus looking at discharge flow and the corresponding throat Mach #'s is essential in determining the true relationship to choke flow.

Liquid Ingestion

Most sidestream compressors are in refrigeration service and by nature are susceptible to liquid ingestion at high flow rates. Regardless of what dynamic forces are occurring in a compressor, adding liquid to the flow stream will only increase the intensity of these excitation forces. Also, the liquids tend to evaporate as they pass through the compressor and energy is added to the flow stream. This evaporation adds to the volume flow through the compressor, increasing the throat velocity through the last few stages of the compressor section, further increasing the intensity of these exciting forces.

Verification

Verification of the position of the operating point to the choke point for sidestream compressors can be accomplished by completing an in-depth field performance test utilizing internal temperature and pressure measurements to assure accurate volume flow rate calculations for each internal section. The results of this test must then be plotted on OEM corrected performance curves for the exact inlet conditions for each section.

Another very realistic and probably the most practical means of determining the relationship to choke flow is to model the compressor aerodynamically and enter these values into CompAero, a design and analysis computer program. Once the compressor is properly modeled, the performance curves can be predicted to match the performance curves from the OEM. With the operating data used as input, CompAero can predict the correct performance curves for the machine, show where the compressor is operating on those curves and calculate the Mach # for the operating point.

Further confirmation may be obtained through the compressor acoustic signature. While this method is still in its infancy, with work transitioning from the laboratory to industrial testing, this procedure may result in added confirmation to methods described above.

mtg 13-Apr-09

References:

1. The consequences of Compressor Operation in Overload, JM Strokes, HF Miller, JM Koch, Proceedings of the 35th Turbomachinery Symposium, 2006.
2. Compressor Performance Aerodynamics for the User, MT Gresh, Elsevier, 2000.