Brüel & Kjær Vibro

A member of the NSK Group

Case study – Compressor rubbing and looseness diagnosed from protection system flight recorder

Chemical

Application Note

Innovative flight recorder condition monitoring architecture eliminates networks and servers yet allows detailed diagnosis of oxygen compressor rubbing and looseness from 8000 km away.

Abstract

Simple faults, such as mechanical looseness, can quickly progress to catastrophic failure of a critical machine if not detected in time. This case history examines how a compressor supplying oxygen to a steel mill in Germany employed a new approach to condition monitoring that gave the basic Machine Protection System (MPS) self-contained condition monitoring capabilities without need of networks or servers.

This "embedded" Condition Monitoring System (CMS) became useful within the first 6 months of system installation by detecting a serious machinery problem and then enabling remote machinery diagnostics expertise to be rapidly consulted without necessitating travel or even remote access to a CM server. The customer was thus able to rapidly isolate specific faulty components and likely causes, intervening before the situation progressed to a catastrophic failure with the associated costs of such an event.

Process

The Rhine-Ruhr area of Germany represents the largest steel production region in Europe, where much of the steel is used in the automotive industry.

Basic oxygen steelmaking is one of the most important manufacturing processes at the steel mill in this case study. High-carbon pig iron from the blast furnace is made into steel by injecting high-purity oxygen into the mixture of pig iron and scrap steel, burning off the excess carbon and other undesired chemical elements.

The high purity oxygen used for this process is produced by the cryogenic distillation method, where the liquefied air components are selectively removed during the distillation process, including oxygen. As with many customers requiring air or air constituents (such as oxygen) in their processes, they purchase this via an adjacent plant specializing in air separation. This case history thus entails a machine owned by the air separation provider. The steel mill is simply the consumer of the air separation plant's products.

Machine and monitoring strategy

The machine is an 8MW, 6-stage integrally geared centrifugal compressor that was manufactured in 2000. It is used in oxygen compression service where the discharge pressure exceeds 40 bar. The first two stages run at nearly 11,000 rpm, the final two stages at 22,000 rpm, and the total flow exceeds 350,000 m^3/hr.

The existing MPS for the oxygen compressor and main air blower was just replaced by the VC-8000 SETPOINT® system. At the time of the upgrade, embedded condition monitoring capabilities were added rather than just exchanging the old MPS with a newer one. While the intention was to eventually connect the new CMS capabilities to a network for remote access, the ability to capture CM data in the interim was desired.

Fault detection

During a startup, the new compressor tripped due to high vibrations at each end of the stage 1/2 rotor. There was also pressure loss detected at both stages.

Fortunately, because the new MPS now contained an integrated "flight recorder" for capturing condition monitoring data, a high-resolution record of the entire event (and several weeks prior to the event) was available.

However, because the trip occurred only 6 months after the VC-8000/SETPOINT® system was commissioned, the customer had not yet gained sufficient expertise in condition monitoring to analyze the data themselves.

They thus elected to use the services of a B&K Vibro machinery diagnostic engineer (located nearly 8,000 km away at the time) to look at the data.

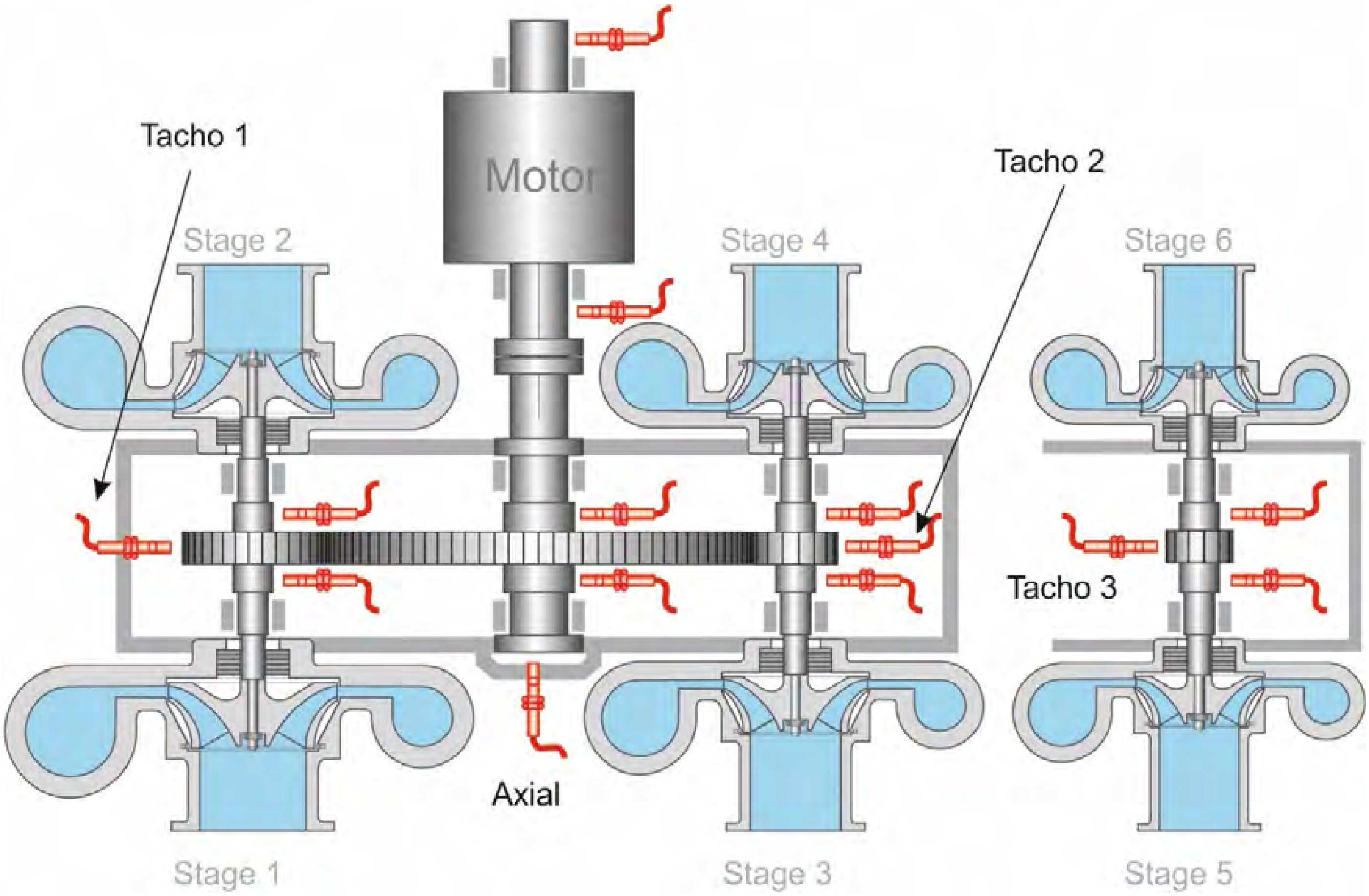

Figure 1. Sensors used for monitoring the compressor. An X-Y sensor configuration is used for all radial displacement sensors. Individual phase reference sensors are used at each of the three pinion shafts for making phase and speed measurements, as all turn at different speeds.

The data was provided by simply ejecting the SD memory card used in the VC-8000/SETPOINT® system flight recorder and transferring the card's contents to a cloud-based file sharing site.

The B&K Vibro machinery diagnostic services (MDS) engineer then downloaded the data and remotely reviewed it from his home office in Florida to render a diagnosis.

Diagnostics

Transient data obtained during the shutdown was first examined. The MDS engineer immediately observed that there was a marked change in the first resonance amplitude and phase (Figure 2) compared to a normal run-up (there was no normal shutdown for comparison).

This change in resonance could be caused by either a change in the system mass (e.g., a broken impeller blade) or a change in system stiffness.

Typically, it is a change of stiffness that occurs, and this is most often due to a seal rub. A decrease in the rotation speed at which the first resonance occurs is indicative of a decrease in the overall system stiffness.

This can be the result of seal clearances opening up, but can also be caused by other looseness in the rotor system.

The shaft centerline plots are not shown here, but were examined and indicated that there was no bearing clearance change when comparing the normal startup with the high vibration shutdown.

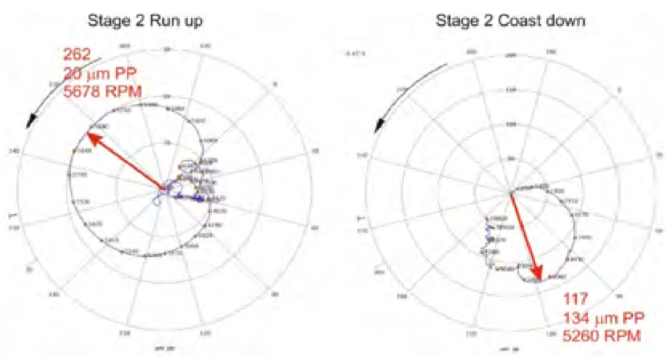

Figure 2. 1x polar plots from the stage 2 X-probe during a normal run-up (left) and during the ensuing coast down (right) after the compressor tripped due to high vibration amplitudes on the stage 1 and stage 2 probes.

This strongly suggested that the bearings were not the source of rubbing or increased clearances.

Although the bearings were an unlikely contributor to the suspected seal rub, there are various other causes such as piping strain on the compressor, seal failure, or debris.

In extreme cases of rubbing, localized rotor heating can actually result in a bowed rotor which manifests as unbalance with high vibrations.

Results

As a result of the diagnostic report and taking into account seal leakage and the possibility of rotor damage during the high vibration event, it was decided to inspect the compressor seals and rotor components. The compressor was disassembled and the stage 1 and 2 components were sent to the OEM to be examined.

During disassembly of the unit, the impeller bolting was found to be loose, consistent with the hypothesis that system stiffness had decreased, leading to a lower resonant frequency and higher vibration amplitude at resonance.

Upon examination of the rotor, impeller, and seals, it was also obvious that a seal rub had indeed occurred. Evidence of the rub was found on the impeller shroud face, axially and radially, for both stages 1 and 2 (Figure 3).

It was further hypothesized that this rub was most likely caused by a loose connection between the impeller and pinion shaft. This was corroborated by the observed condition of the serrated connection teeth on both the impeller and shaft (Figure 4).

There was also observed plastic deformation at the end of the labyrinth seal sleeve where the sleeve end circumference was enlarged (Figure 5). This enlargement almost certainly affected the seal seating, resulting in a seal leak. The plastic deformation was presumably caused by movement of the impeller on the shaft.

Looking at the connection serration teeth from the shaft and impeller, it can be assumed that the impeller bolt connection holding these components together was loose so the impeller was free to move both radially and axially on the shaft. This consequently resulted in high vibrations, seal leakage, and all of the damage observed on the stage 1 and 2 components.

The investigation was still ongoing at the time of this case study, and conclusive isolation of the root cause has not yet been found.

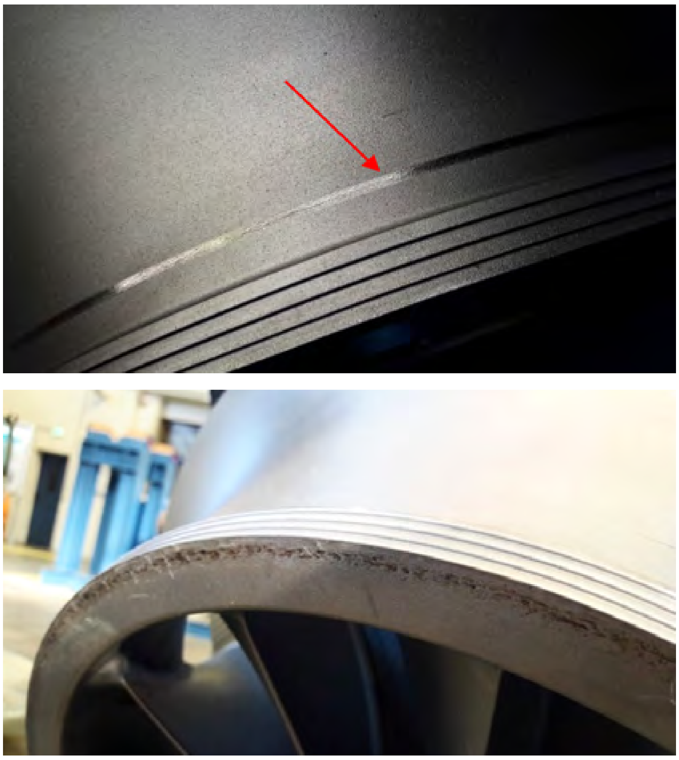

Figure 3. 1x polar plots from the stage 2 X-probe during a normal run-up (top) and during the ensuing coast down (bottom) after the compressor tripped due to high vibration amplitudes on the stage 1 and stage 2 probes.

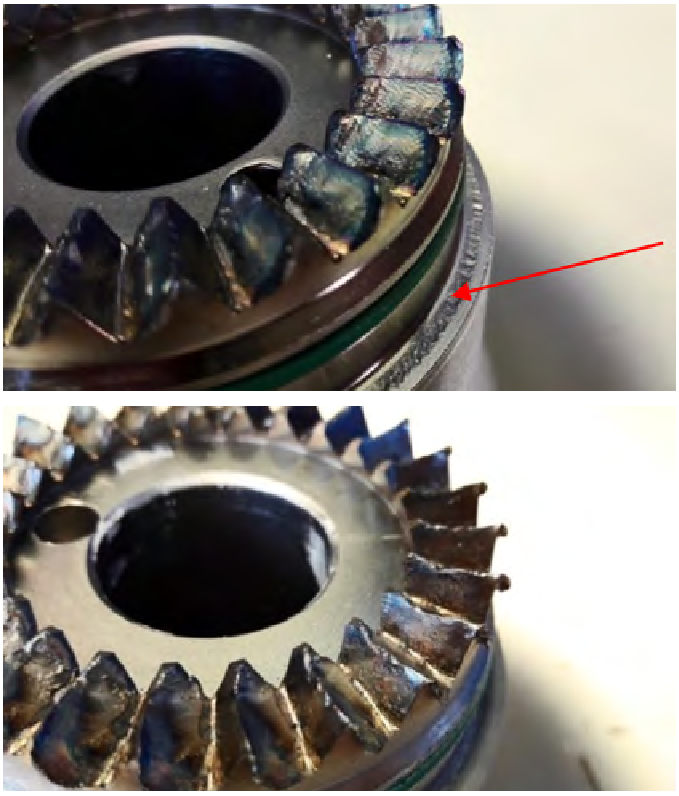

Figure 4. Serration teeth on the impeller for stage 1 (top) and stage 2 (bottom).

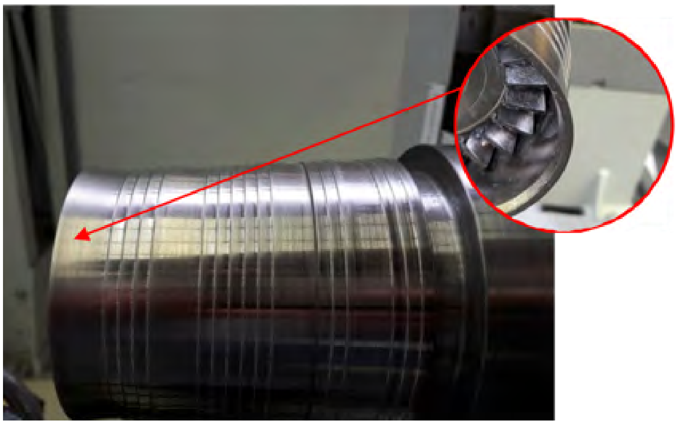

Figure 5. Widened circumference on the mouth of the labyrinth seal sleeve for stage 1 (similar for stage 2).

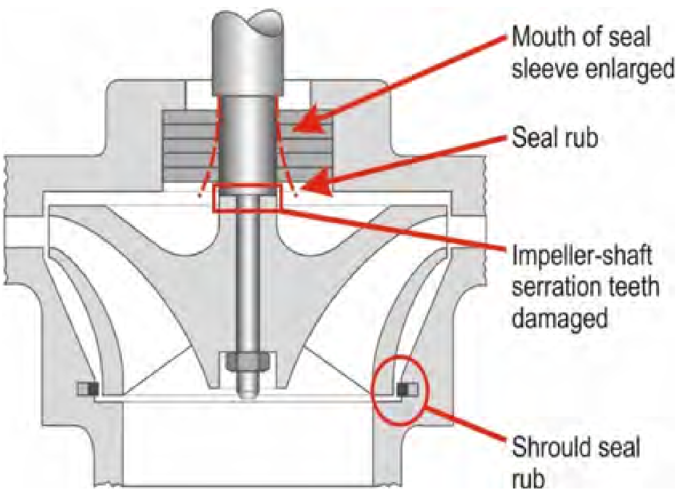

Figure 6. Graphical illustration showing the areas of damage to the stage 1 and 2 portions of the compressor.

Conclusion

Using condition monitoring data retrieved from an SD card used as the VC-8000/SETPOINT® system embedded flight recorder, B&K Vibro's machinery diagnostic engineer was able to quickly identify a lowering in the system's resonant frequency, usually associated with mechanical looseness or a change in clearances.

Symptoms of a rub were also present and a mechanical inspection was performed based on the quality of the data and the evidence it provided that serious problems would be found. The inspection corroborated the vibration data: Loose impeller bolting was found and a seal rub condition was confirmed on the oxygen compressor's stage 1/2 rotor.

The combination of a machinery protection system that tripped the compressor due to very high vibration and a flight recorder that captured high-resolution data in the weeks prior to the event and during the coast down allowed engineers to review the situation and render a diagnosis.

Had the customer been forced to wait for network connectivity to the MPS before implementing CMS capabilities, data would not have been available and the machine would likely have been restarted without knowing the extent or severity of damage. Or, engineers with portable data collection equipment would have been dispatched to site to witness a compressor re-start attempt and gather data, possibly further damaging the compressor in the process.

The ability to rapidly diagnosis the machine with high-quality data led to a high-confidence decision. The machine was opened for inspection with a clear understanding that the focus of the inspection could be on stages 1 and 2 of the machine, and that the seals rather than bearings were likely where damage had occurred. Looseness was also anticipated given the reduction in observed resonance speed, and the OEM was able to look for conditions that would result in a reduction in stiffness for the rotor system.

Combined, the data and a competent engineer to render the diagnosis allowed faster isolation of the problem areas, shorter downtime, and reduced costs. In contrast, if the customer had sent the entire unit back to the OEM for shop testing and balancing, the event would have incurred more than €2 million in outage costs.

In addition to the accurate transient data capture capability provided by the VC-8000/SETPOINT® system flight recorder, the ability to easily retrieve and transfer its data proved important in enabling a timely and reliable diagnosis.

Although all data from the VC-8000/SETPOINT® system will eventually be streamed into the customer's OSIsoft® PI System® (their process data historian), this will not be implemented until a later date, when the IT infrastructure and OSIsoft® PI System® enhancements are ready.

Had flight recorder capability not been available in the interim, the data would have been missed and a far more expensive and invasive outage would have ensued.

By storing detailed data on a removable SD memory card in the VC-8000/SETPOINT® system flight recorder, it was possible to quickly retrieve and transfer the data. Indeed, the software used to actually open and analyze the data is freely available for download on the internet, enabling the OEM, the customer, B&K Vibro engineers, and any other relevant parties to remotely view and analyze the data on a normal computer.

No onsite diagnostics service visit was required nor was there a need for a remote secure network connection to a firewalled monitoring system data server. The raw data on the SD card was simply uploaded to a cloud-based file server by the customer.

A noteworthy aspect of the VC-8000/SETPOINT® system flight recorder is that it employs patented data capture technology that ensures the SD card does not fill up too quickly with data, yet does not miss any important events or compromise the resolution necessary to perform accurate machinery diagnostics.

The technology relies on sophisticated change detection so that data is acquired only when it changes, thus preserving storage space without missing significant data. Customers such as the air separation plant and steel mill detailed in this case history now have more flexibility in implementing a condition monitoring environment.

They can stream the data into their existing process historian, they can forego streaming altogether and use a self-contained flight recorder, or they can use the two technologies in tandem to provide both local buffering of data for months at a time, and streaming to their centralized historian – ensuring important data is never lost.

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