Cash in on condition monitoring

Michael Hastings, Brüel & Kjær Vibro GmbH, Denmark, examines how today's condition monitoring technology has evolved to contribute significant value to LNG production assets.

Billions of dollars will be invested in LNG infrastructure to meet growth requirements within the next few years. Even now, where there is excess LNG installed capacity, the current expansion underway will pay itself off quickly, as the consumer's market for clean-burning energy increases and even outpaces all other fossil fuel sources. This growth is not only driven by a surging consumer market, but also by technical and commercial factors that ultimately result in lower CAPEX and/or OPEX for producing LNG.

One of these cost-reducing factors is improved technology. For example, great effort is currently being expended to make production assets more

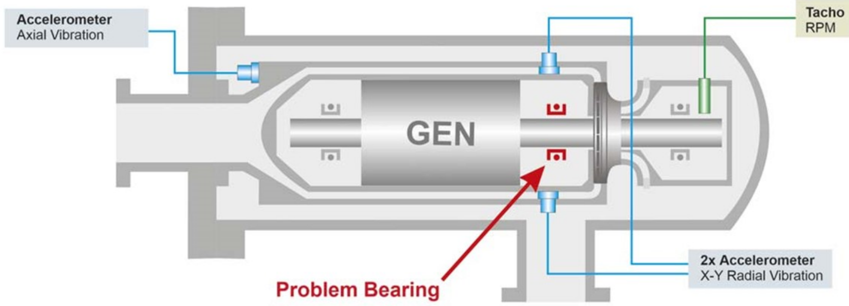

Figure 1. Vibration sensor configuration of the liquid expander. The bearing where high vibration was detected is shown in red.

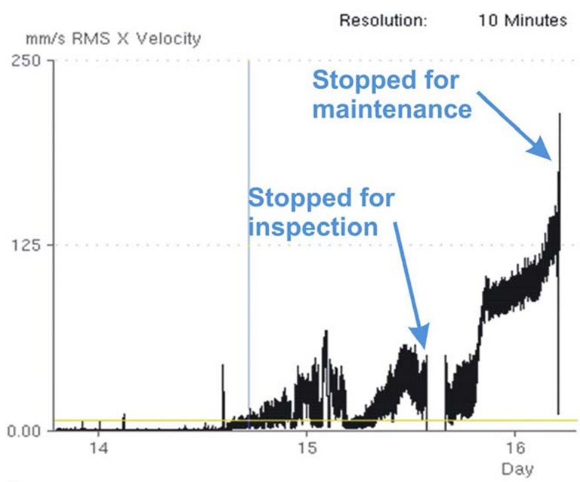

Figure 2. The vibration trend progressively increased after two startups, so the liquid expander was shutdown for inspection. No damage was found so it was started up again, but the vibration continued to increase. Finally, it was shutdown for maintenance and this time it was observed that the bearings showed signs of damage.

thermodynamically efficient, which will result in lower operating costs. The downside to this, however, is that actions such as this can sometimes be undertaken at the expense of adding additional equipment and complexity to production. This will also have to be monitored. In other areas, the production trains are becoming larger, which results in lower production cost. Nevertheless, in this case the cost of downtime becomes more expensive if the train is unexpectedly down. Ultimately, the benefits of developing technology in either case become much more significant if the risks can be mitigated.

Regardless of the chosen course of development, machine condition monitoring will play an even more important role in ensuring uninterrupted reliable production in future scenarios. Performance monitoring of machines is already standard practice for many existing machines and larger machine sizes present no monitoring obstacles. Condition monitoring is already geared for these and other future development requirements, based on past experience of successfully dealing with existing operation and maintenance challenges.

Asset healthcare challenges today

Machines in an LNG plant, especially those involved in the liquefaction process, are subject to extreme operating conditions. The thermal expansion of a refrigerant compressor, pump or liquid expander between startup and full production at cryogenic temperatures is intense, thereby subjecting the bearings and other machine components to severe loads during startup and shutdown. Even small variations in the process can have significant effects on the overall loading of the machines. As many machines are operated at variable speeds and loads, this basically renders calculated mean-time-before-failure values for the machine components to spread out and be unpredictable.

As in many other sectors of the petrochemical industry, ensuring the reliable operation of these machines is not a trivial task – especially when considering the reduced numbers of maintenance staff and specialists onsite at plants, and the increasingly competitive nature of the industry.

Condition monitoring solutions are evolving

Very few people in the LNG industry dispute the merits of effective condition monitoring, but there is a wide disparity on what constitutes an effective monitoring solution. Some simply continue to use their legacy system without being aware that condition monitoring technology itself has evolved over the years.

However, it is now possible to detect developing symptoms from a wider range of potential failure modes earlier and more reliably than 10 years previously. In a similar fashion, diagnostics have become more accurate in assessing fault severity and establishing the need for maintenance action within an accurate timeframe. Advancing data science technology enables process data to be more readily correlated with fault monitoring data, so that diagnostics and root cause analysis can be performed faster and more accurately. Automatic fault prognostics and decision support become a reality after many years of monitoring data has been accumulated and can now be analysed by artificial intelligence (AI) and machine learning (ML).

Case studies

Current condition monitoring technology provides early healthcare awareness for all the critical machines and much of the balance-of-plant to reduce downtime and maintenance costs, while at the same time avoiding catastrophic failures. Three case study examples highlight this.

A closer look at liquid expanders

The liquid expander plays a major role in the propane precooled mixed refrigerant process (C3MR) to make LNG. For the mixed refrigerant (MR) expander (there is also an LNG expander downstream), a pressurised MR stream from the heat exchanger is isentropically expanded with a pressure drop in the MR expander down to -130°C, so that it can be put back into the heat exchanger for further cooling. The liquid gas expansion is performed by the turbine portion of the liquid expander, where work is extracted from the gas/liquid mixture to turn the rotor, which in turn drives the generator. As the liquid expander is a cryogenic machine, the thermal loading on the components, and especially on rolling element bearings, can lead to component failure if not properly brought to load and controlled during startup.

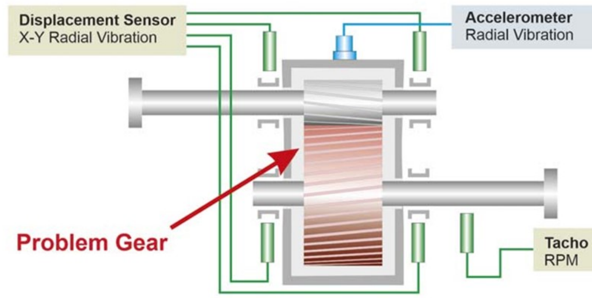

Figure 3. Vibration sensor configuration of the propane compressor gearbox. The gear where high vibration was detected is shown in red.

Different plant, same fault

At one particular LNG plant, the liquid expanders had been operating without mishap for several years, until a bearing fault was suddenly detected in one of the expanders during a routine startup (Figures 1 and 2). Shortly afterwards, the monitoring system detected a bearing fault on the same middle bearing of another liquid expander on a different train. In fact, the same fault was then also detected by the monitoring system within the same time period at an entirely different LNG plant. A diagnostic specialist was called in from the monitoring system provider to do a root cause analysis with the customer. After looking at the data, it was determined that the premature failure of the bearings was caused by a recent change in the startup sequence of the machines.

The importance of startup

Startup is critical for a liquid expander, since the bearings have to be precooled prior to operation. At ambient

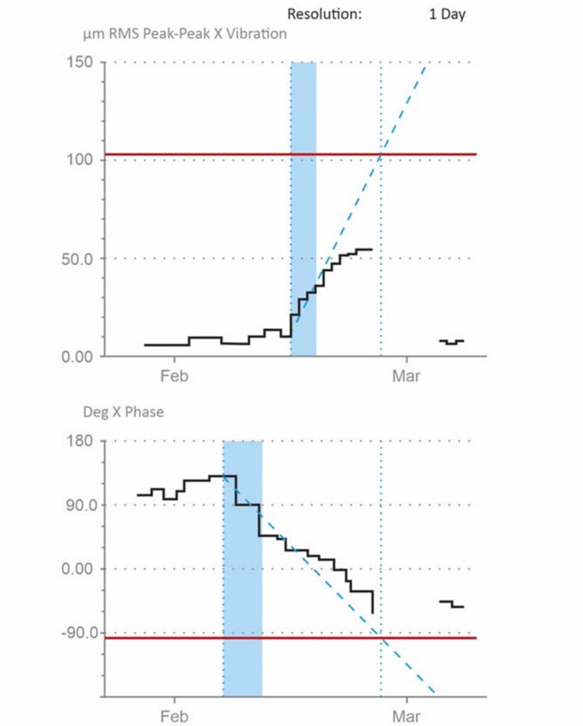

Figure 4. Automatic trend alarms for the first order magnitude (top) and phase (bottom) measurements from the middle bearing accelerometer. The phase trend alarm occurred four days before the magnitude alarm.

temperature, there is insufficient bearing clearance for operation. Cooldown MR gases pass over the bearings through channels to 'shrink' the bearings and open up bearing clearances to enable operation. Even during operation, the bearings on each side of the 1 MW generator require cooldown gases because of the nearby heat energy coming from the generator. This is especially true for the middle bearing.

The liquid expander cools down approximately 300 tpd of MR, but, during the startup sequence, the entire production is delayed because the bearings have to be precooled before operation. The plant manager and the expander OEM decided to shorten the startup time by allowing cooldown gases to flow through the expander and bearing channels at the same time in order to speed up the cooling process. This recommendation was also given to another plant.

After the new startup sequence was implemented, there were problems. Although there was no load on the compressor, the rotor started to spin due to the cooldown gas flow through the impeller, thereby putting stress on the bearings before they were at operational temperature. This is what caused the bearings to begin to prematurely fail.

Benefits

After this discovery, the new startup sequence was discontinued and the original one was re-implemented. Fortunately, while the new startup sequence was in use, there was no catastrophic failure of the liquid expanders because the monitoring system was capable of detecting and diagnosing the rapidly progressing fault in the liquid expanders at both LNG plants, before the protection system tripped. This lead-time allowed for a proper shutdown sequence.

Early detection of a propane compressor gearbox fault using diagnostic measurements with trend alarms

The propane compressor train gearbox in this case study connects the axial compressor to the 75 MW Frame 7 gas turbine. There is also a variable speed starter motor/generator at the other end that is used to help start the gas turbine, and afterwards the unused power from the gas turbine turns a generator which supplies power to the grid. The four-stage single casing centrifugal compressor uses propane at four different pressure levels to supply refrigeration to the incoming natural gas and precooling of the MR (C3MR process).

Trend alarm warning

Not long after service, one of the propane compressor trains at a major LNG plant gave signs of trouble at startup (Figure 3). The overall vibration amplitude was within limits, but the specialised fault detection measurements of the monitoring system told another story (Figure 4). An alarm trend warning for the first order phase measurement indicated that the detected fault trend in the propane compressor gearbox would reach a danger alarm limit within 14 days. As the fault severity was determined to be low, operations continued, but maintenance preparations were already being made. Four days later, the first order magnitude measurement gave an alarm trend warning of 10 days, but still no alarms related to the overall vibration (Figure 4). Eight days after this, there was an exceeded alarm limit for the overall vibration signal. Thankfully a decision had already been made to perform a machine shutdown to investigate, therefore preparations were already underway.

Not a defect or wear issue

Machine condition monitoring is not limited to detecting component damage or wear. In this particular case, it was the spur gear on the output side of the gearbox that was found to be improperly mounted.

Benefits

The specialised measurement techniques with a trend alarm proved to give much earlier and more reliable fault detection than the overall vibration measurements. This extra lead time can be very important when dealing with fast deteriorating gear faults, such as this one, in order to cost-effectively prepare for maintenance.

Defect bearings installed on the instrument air compressor

The instrument air compressor serves a critical role in an LNG plant, as well as in other industries. It provides clean, dry air that is used in a range of control and shutdown valves. There are three oil-free centrifugal compressors per train at the LNG plant. The three-stage instrument air compressor is driven by a motor though a gearbox

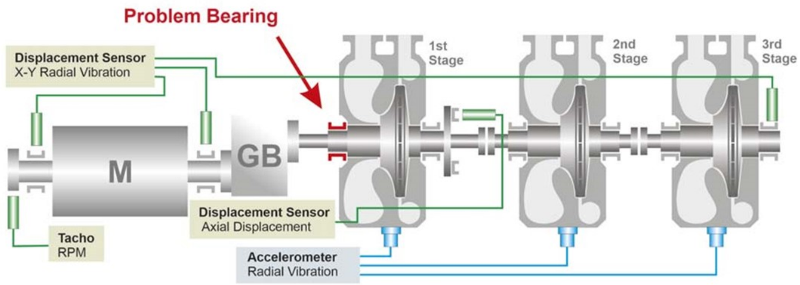

Figure 5. Vibration sensor configuration of the liquid expander. The bearing where high vibration was detected is shown in red.

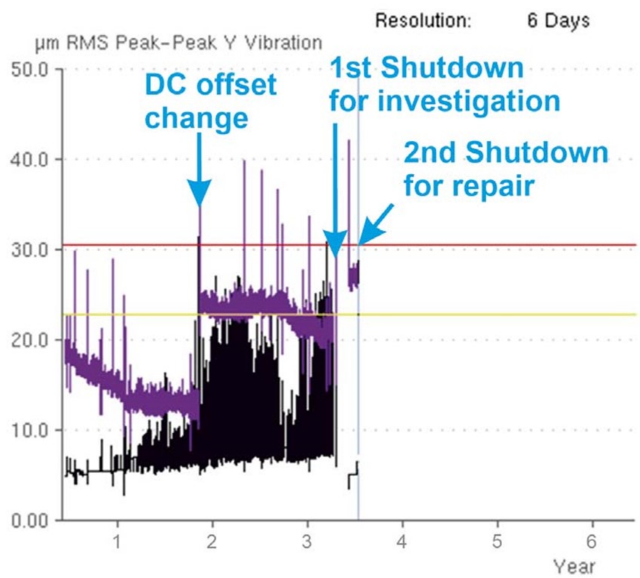

Figure 6. The third order bandpass vibration trend (black) from the inboard bearing of the first stage impeller over a period of several years. The DC vibration displacement (purple) shows shaft position. (Note: an offset change was made at the end of year 1, as can be seen in the figure.)

using tilting pad journal bearings (Figure 5). The units were relatively new and still under warranty at the time of this case study.

Observations

The third order bandpass vibration level on the inboard bearing of the first stage impeller had steadily increased for one year since startup (Figure 6). It subsided for a few months, but then began to increase again, and, after two years, it exceeded the alert alarm limits. Nothing was found after a quick investigation so the compressor was put back into service.

The vibration levels remained above the alert alarm limits after startup, which led to a series of tests being performed to try and identify the problem (e.g. changing the lubrication). The customer was not able to reduce the vibration levels, so the monitoring system supplier was asked to look into it and evaluate the problem. As the vibration levels began increasing towards danger alarm limits, the machine was shut down. Due to the compressor still being under warranty, the manufacturer was contacted to investigate the bearing.

Diagnostic analysis

It was surmised that vibration level increased for a while, decreased, and then increased again as a result of a bearing fault that initially sorted itself out for a while and then redeveloped again (Figure 6). The DC vibration displacement shown in the same figure shows a more or less linear change in shaft position over a period of more than three years. This indicates gradual wear of the bearing.

Root cause analysis

The manufacturer has determined that the fretting on the first stage bearing was due to poor bonding of the bearing surface, as a result of a manufacturing defect. This evaluation is based on the fact that the high vibration levels had already started an upward trend not long after commissioning. All bearings were subsequently replaced.

Benefits

The monitoring system successfully detected a fault at an early stage of development while the compressor was still under warranty. The monitoring system played a vital role here since four harmonics of the vibration signal were individually monitored. The vibration response of different machine faults manifests itself with different harmonics, and in this case it was the third harmonic that gave the earliest indication of a bearing fault. The fault was slow to develop, so long-term trend capability was necessary.

Conclusion

The operation and maintenance of LNG assets is extremely demanding, due to the inherent nature of LNG processes and production. For this reason, machine condition monitoring plays a critical role in ensuring maximum uptime and reduced lifecycle costs.

Component degradation due to fatigue and wear covers the majority of faults that are typically detected, but, as seen in the case studies, some faults can also be caused by assembly and manufacturing errors. An effective condition monitoring solution is critical to the detection of these kinds of faults early and reliably, and especially before a machine's warranty runs out.

More importantly, legacy condition monitoring systems that are 10 – 15 years old may no longer be able to provide the potential value that modern solutions offer today. Indeed, technology has changed, fault detection has become more refined, diagnostics are becoming more automated, data science has advanced and statistical analysis and prognostic capability is becoming more reliable and accurate with the vast quantities of data that are now available. **LNG**