CONTROLLING KILN CONDITIONS

Palle Huus, FLSmidth, and Mike Hastings, Brüel & Kjær Vibro, outline the most common cement kiln maintenance issues and explain how they can be mitigated through comprehensive online condition monitoring solutions.

After a few years of joint research, FLSmidth and Brüel & Kjær Vibro (B&K Vibro) are now completing a comprehensive on-line condition monitoring solution for cement kilns. Today's high-performance kilns can now deliver optimal uptime to end-users by utilising a monitoring system with dedicated vibration condition monitoring techniques. Extensive research and development was conducted in collaboration with the project teams. FLSmidth provided expertise on equipment design, operation, failure modes, maintenance and cloud data sharing, together with their existing monitoring techniques. B&K Vibro provided technology and expertise on data acquisition and processing, together with optimising measurement techniques for early and reliable fault detection.

A B&K Vibro field monitor was selected for this purpose. It was subsequently customised to play a central role in a service strategy for delivering an advanced OEM installed healthcare package for cement kilns. This solution applies to both customers requesting comprehensive monitoring capabilities for their new kilns, as well as a retrofit on existing kilns. The solution can even be used on kilns of different manufacturers.

Why monitor a kiln?

The kiln is the heart of the cement plant, and its design capacity is what determines the total cement output of the plant. Traditionally, kilns have been stopped for inspections at frequent intervals, but nowadays this is considered too costly. For efficiency and profitable production, the kiln typically needs to operate continuously for a year between maintenance shutdowns.

Planned and unplanned shutdowns not only result in lost production, but the heating up and cooling down process is also long and thermally stressful, resulting in higher emissions, wasted energy, and a higher risk of maintenance issues with less sustainable operation. Kiln healthcare evaluation can now be carried out largely via continuous online condition monitoring solutions to minimise the frequency of planned shutdowns and avoid unplanned shutdowns. Condition monitoring of kilns becomes even more important when alternative fuels are used because wear and tear then becomes more difficult to predict with traditional maintenance and on-site inspections.

By avoiding a single shutdown, this can result in cost savings of €100 000 per day. This is based on a typical 5000 tpd size kiln, where production is valued at €20/t and there is 24 hour lost production downtime due to cooling down and heating up. This does not even take into account the additional cost for maintenance and spare parts.

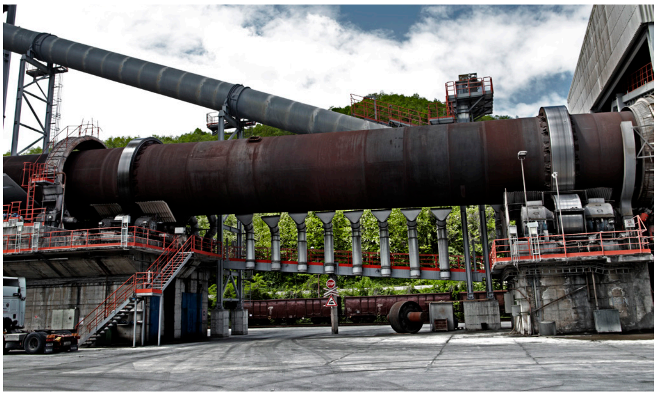


Figure 1. Typical rotary cement kiln.

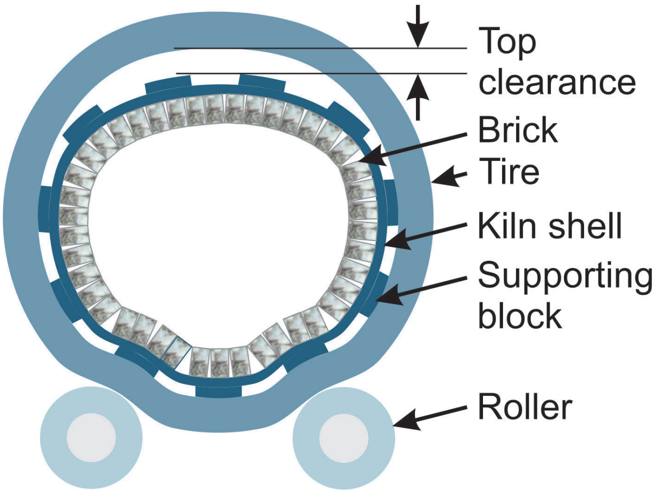


Figure 2. Cross section of kiln at the supports showing shell ovality and its effects on the refractory bricks.

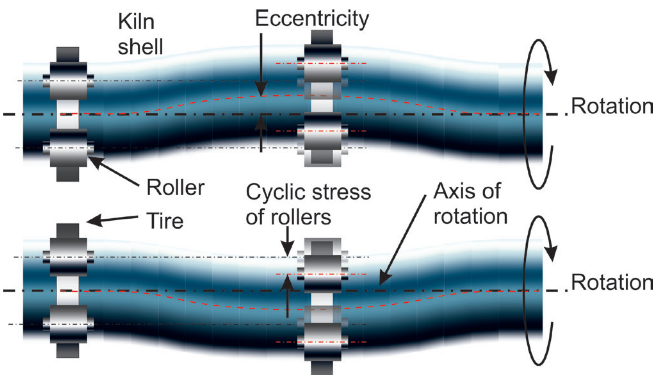


Figure 3. Bottom view of a section of the kiln showing kiln crank at two extremes of eccentric rotation. The bending stress on the rollers is shown in the middle.

What has to be monitored on the kiln?

The rotary cement kiln is generally a reliable asset of the cement plant, but there are maintenance issues that are inherent to the design, and others than can also occur if the system is not properly operated and maintained.

Kiln shell ovality

Kiln shell cross sectional ovality occurs primarily at the tyre positions because the shell is supported at these points. If the ovality shell deformation becomes excessive, it can lead to refractory brick damage and kiln shell cracks.

Kiln shell ovality occurs naturally because of its inherent thin-walled design, which is necessary to minimise the overall weight of the construction. This means that before start-up, the shell will deflect slightly within the larger diameter tyre. This extra space between the tyre supporting blocks and the inside bore of the tyre is called the 'top clearance' and is intended to allow for thermal expansion. When the shell and tyre have reached their equilibrium operating temperatures after start-up, there may still be a little top clearance left over as a safety margin. This is needed if, for example, there is a brief period of over-temperature.

If there is too much top clearance between the shell and tyre, for example, due to supporting block surface wear, this can result in too much ovality. This means there will be increased flexing of the refractory brick lining during rotation, which can result in damage to the lining. It can also cause longitudinal shell cracks in the vicinity of the tyre due to excessive stress and cyclic fatigue.

There are several reasons why excessive ovality might occur. If the kiln is heated too quickly, the shell will expand much faster than the tyre and it will quickly use up all available space between the shell and tyre. In case of further expansion, the shell will subsequently become permanently deformed within the confines of the tyre, creating a bottleneck shape. This will result in excessive running top clearance once the shell and tyre return to thermal equilibrium at normal temperatures. Again, this excessive top clearance will stress the brick lining and the shell itself as the shell rotates.

Kiln shell ovality can be indirectly monitored based on tyre migration. This is a measure of the relative circumferential movement between the tyre's inner bore and the top of the kiln shell's supporting blocks for each kiln revolution. Based on this measurement, the kiln shell ovality can be approximated, so any action needed to improve the shell ovality can be determined from the tyre migration.

Kiln crank

Kiln crank occurs when the centerline axis of a portion of the shell is eccentric to the axis of rotation. As shown in Figure 3, the curved section of the shell places extra cyclic load on the rollers, roller bearings, shaft and tyre during rotation and can result in cracks and failure. There are several causes for kiln crank, but these can be classified as being either thermal (temporary crank) or mechanical (permanent crank). If, for example, one side of a section of the shell becomes warmer than the other side (e.g. due to uneven thickness of the bricks or due to uneven coating build up), this can cause the shell section to longitudinally curve outwards. This condition could also be caused by the kiln suddenly stopping while operating. Kiln crank can additionally be caused by incorrect assembly of the shell sections.

Kiln crank, whether thermal or mechanical, causes cyclic deflection of the supporting roller shafts. This deflection can be measured during operation. As the measurement is made directly from the roller surface, surface irregularities and the roller shape must be filtered from the measurements to determine the actual deflection of the roller shafts.

Drive vibration

The drive system consists of the girth gear, pinion, gearbox and motor. The girth gear is tangentially fixed to the kiln shell to allow for circumferential thermal

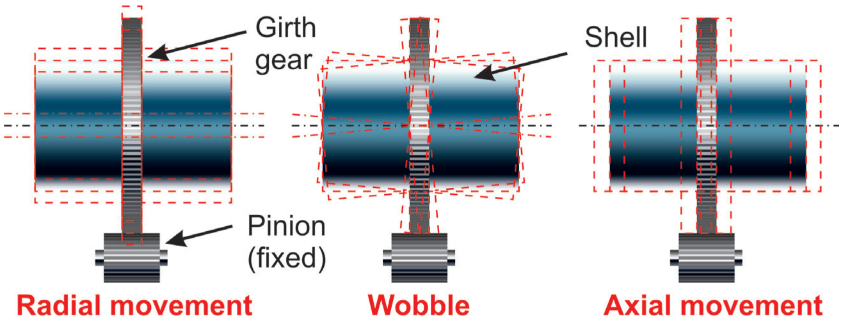


Figure 4. Left: Radial displacement (kiln crank). Middle: Wobble (shell deformation). Right: Axial displacement (axial kiln balance).

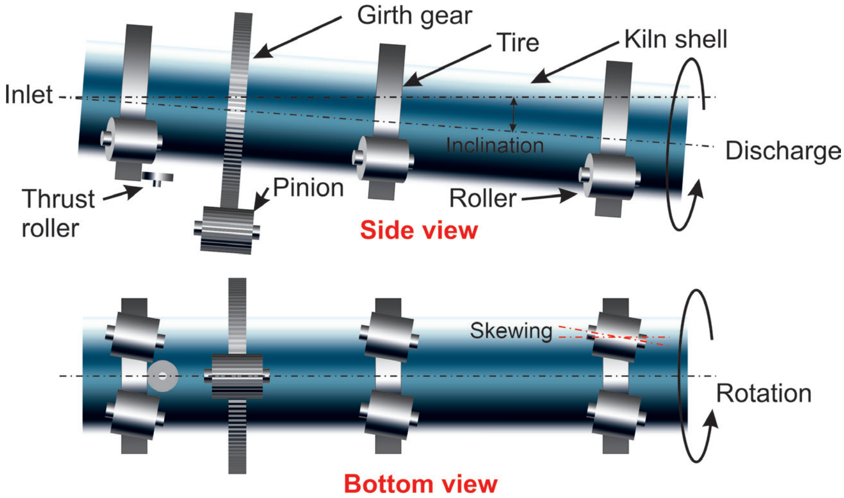


Figure 5. Top: Side view of inclined kiln. Bottom: Bottom view showing the skewed rollers.

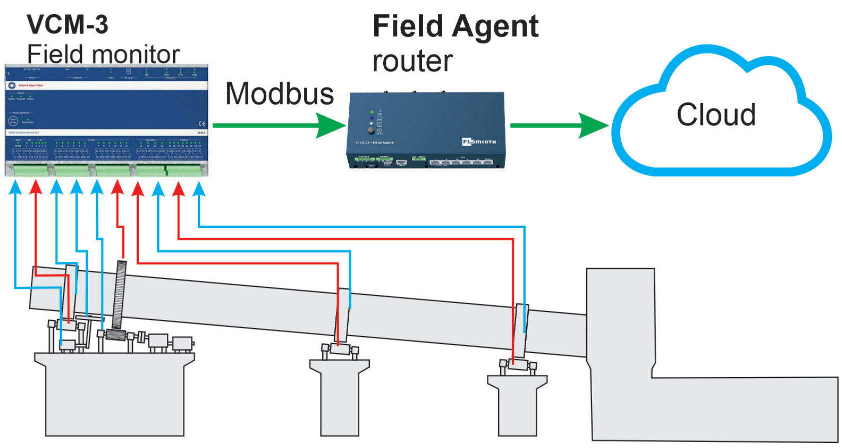


Figure 6. Advanced monitoring strategy of the cement kiln.

expansion of the shell, but it is influenced by both the kiln dynamics, girth gear connector looseness and any shell deformation that may be present. The pinion and its associated gearbox and motor, on the other hand, are fixed to the support foundation. Therefore, any relative motion between the girth gear and pinion can result in improper gear meshing, gear stress and eventually premature wear and failure. Moreover, as the gear teeth wear, this increases stress. Lubrication problems can also accelerate wear.

As shown in Figure 4, depending on the deformation shape of the shell, the girth gear can wobble in relation to the pinion (i.e. axial run-out), and/or there can be radial run-out which will affect the gear tooth root clearance and pitch circle alignment. There can also be axial movement.

The girth gear can be monitored by a combination of displacement and vibration acceleration measurements. The non-contact displacement measurements can determine girth gear radial, axial and wobble movement. The X-Y-Z directional accelerometers on the pinion housing can detect gear misalignment, balance, gear mesh anomalies and bearing faults. This is done by monitoring vibration measurements, such as running speed vibration and harmonics, tooth meshing frequency and harmonics, side band energy, bearing fault frequencies, high frequency crest factor, etc.

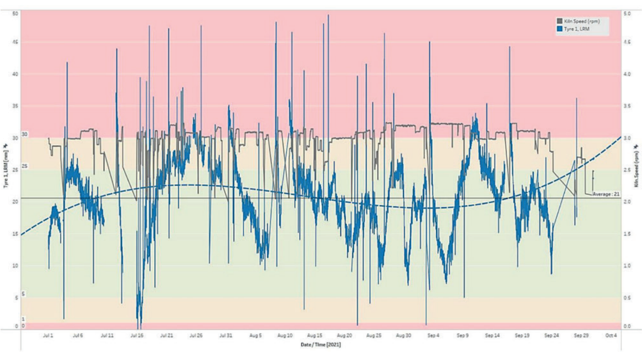
Axial kiln balance

Kilns are typically inclined vertically at 3 – 4° for proper operation. Since the kiln is not fixed to the supports, the kiln will have a tendency to slide downwards as a result of gravity, therefore this axial displacement has to be counteracted. This is done by ‘skewing’ the rollers in relation to the kiln centreline and its inclination, which will create an axial force between the tyre/roller surfaces. Any resulting forces not taken up by the rollers is consequently counteracted by the thrust roller. This is shown in Figure 5.

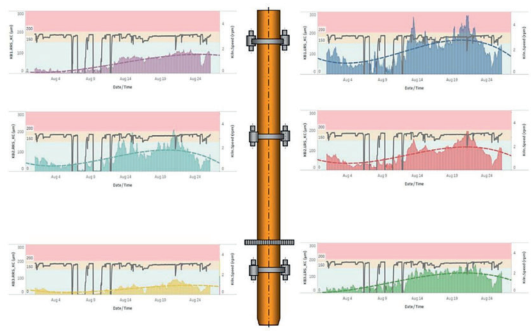
Any increased or incorrect axial forces between tyre and rollers can result in unstable operation and cause increased bearing temperatures, accelerated wear of rolling surfaces and thrust roller failure. It is, therefore, important to monitor any changes in the axial balance forces. To monitor and control axial balance, several inputs are needed, such as kiln axial position, hydraulic pressure on thrust roller, direction of the roller’s axial thrust and the magnitude of axial thrust.

Monitoring solution

The potential failure modes described earlier represent the majority of (but not all) faults that typically occur in a cement kiln. FLSmidth provides a comprehensive monitoring solution that detects and diagnoses a wider scope of faults. The overall kiln condition monitoring

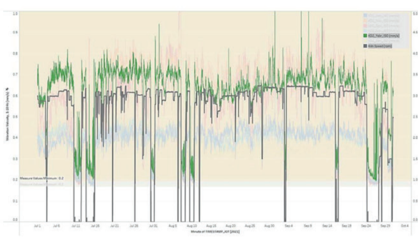


Tire migration trend for shell ovality at Support 1

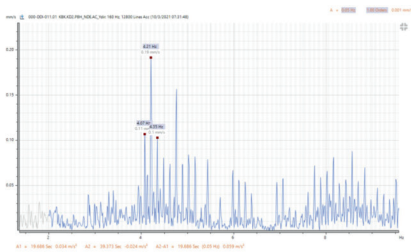


Kiln crank measurement trends on all rollers

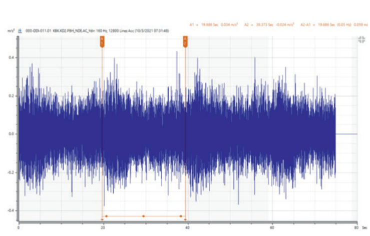
Figure 7. Left: Ovality trend plot. Right: Kiln crank plots.



Pinion 2 vibration trend, Y-direction



Pinion 2 FFT zoom, Y-direction



Pinion 2 Time waveform, Y-direction

Figure 8. Pinion gear plots. Left: Trend. Middle: Spectrum zoom. Right: Time waveform plot.

solution is based on various monitoring and control systems that are integrated together.

Monitoring packages

FLSmidth offers two monitoring packages. The basic package is based on existing instrumentation from the process control software platform, and offers good insights into wear life and for root cause analysis of many kiln problems. The monitoring functionality includes:

- Bearing monitoring.
- Hydraulic thrust device monitoring.
- Kiln drive monitoring (power consumption).
- Infrared thermal imaging of the kiln shell to detect refractory failure and early signs of hot spots.

The advanced monitoring package is based on the vibration measurements from the Brüel & Kjær Vibro VCM-3 field monitor, which are intended for monitoring the potential failure modes described earlier, such as kiln crank, ovality, drive vibration, and axial balance. Most of this type of monitoring was previously carried out only during on-site inspections, such as for a hot kiln alignment (HKA). With an online monitoring solution, the HKA can be scheduled more accurately ahead of time and based on the actual condition of the kiln. Moreover, plant operators have a better insight into what kinds of problems are developing long before a shutdown, so maintenance can be cost-effectively planned ahead of time and the interval in between shutdowns is extended. The advanced monitoring package provides the following benefits:

- Extending the life of rotating parts (kiln crank, drive vibration, axial balance).
- Improving the life of lining and kiln shell (ovality).
- Avoiding kiln shell constriction and reducing stress (ovality).
- Avoiding girth gear breakdown (drive vibration).
- Identifying alignment issues (axial balance, kiln crank).
- Stabilising bearing temperatures (axial balance, kiln crank).
- Reducing power consumption (drive vibration).

All inclusive service

The monitoring packages are part of FLSmidth's online condition monitoring service, where the customer is ensured full support 24/7. The kiln data is stored in the cloud and monitored to alarm limits. This data can be analysed by the plant operator or as a service, it can be accessed by the FLSmidth monitoring team. Experienced kiln specialists perform both failure mode analyses as well as predictive analysis for forecasting maintenance. Quarterly asset health reports are also issued to advise the customers and help them achieve highest equipment availability.

Monitoring system, strategy and configuration

The slow rotational speed of the kiln and its sheer size make monitoring no easy task. One key reason why the VCM-3 field monitor was selected for the task was because of its wide range of measurement techniques, which can be customised to the application using the Python calculation engine. The VCM-3 has been designed from scratch to monitor slow rotational machines and therefore is very relevant for monitoring kilns.

The vibration data is processed in the VCM-3 data acquisition unit and is exported as scalar and time waveform values to the FLSmidth cloud. End-users can also access data in the FLSmidth SiteConnect application. A smartphone application has been specially developed to provide live data and insights to plant and maintenance staff, no matter where they are.

Conclusion

A number of kilns equipped with the advanced monitoring solution have already been delivered, and the feedback on the monitoring results has been positive. Other projects are also in the pipeline.

In summary, this monitoring solution represents a breakthrough within kiln predictive healthcare. Most critical failure modes can now be monitored continuously and reliably, which was not feasible with standard off-the-shelf instrumentation or portable devices. Previously, fault detection was only conducted by on-site intervention inspections once a year, or even less.

This monitoring strategy success was fundamentally due to the close cooperative development efforts of FLSmidth and B&K Vibro working towards a common goal of delivering more value to the end-user. ■

About the authors

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Mike Hastings is a Sr. Application Engineer with Brüel & Kjær Vibro, where he has been working for the past 32 years. He is currently working with strategic market development, analysis and communications. He is also convenor for an ISO work group for creating standards for condition monitoring and diagnostics of machines.