Application Note

Case study – High technology in monitoring and detection of rolling-element bearings at low rotational speeds of 3.5 RPM

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ABSTRACT

The Companhia Vale do Rio Doce (CVRD) is one of the largest mining companies in the world and the main one for diversification of products. There was a profit of R$ 2,5 billion in 2001. CVRD has established itself in this segment for the last 59 years, extending its activities with new investments and diversification. CVRD has mines in several Brazilian states, including the Carajás mine of Pará, the largest open pit iron ore mine in the world.

Mina de Conceição is in the city of Itabira in the state of Minas Gerais (see Figure 1). This mining complex produces approximately 60 000 tons of iron ore each day (1.8m tons per month), with the flexibility to produce 16 types final products. Production is 24/365, and therefore requires high availability of machines. An example to demonstrate the importance of machine availability is that one hour of downtime represents a loss of R$ 20 000.

Figure 1. Aerial view of the Conceição mine.

Introduction

The mining process is as follows: The ore is taken out by excavators and transported by off-road trucks (with a capacity of 240 tons) to the primary crushers. The material (iron ore) goes through the secondary and tertiary processes, which use equipment such as crushers, vibrating screens, conveyors and vibrating feeders. After this process the ore is stockpiled by a stacker in a line of homogenization piles and is sent to the Treatment and Beneficiation Plant by the drum reclaimer. In this plant beneficiation is done by various types of rotating machines that require condition monitoring, such as the magnetic separators, vibrating screens, vacuum and slurry pumps, classifiers, conveyors and compressors, vertical and horizontal filters, among others. The final product of this diversified process is stockpiled in the loading area by stackers and loaded by bucket wheels loaders into railcars or ships.

Predictive maintenance at the Conceição mine

The predictive maintenance group is located in the Crushing Sector and is monitoring around 700 machines, such as crushers, vibrating screens, conveyors, vibrating feeders, magnetic separators, slurry and vacuum pumps, classifiers, agitators, compressors, drive trains for the horizontal and vertical filters. There is a total of 7000 predictive maintenance items (*). Vibration monitoring strategy for this wide range of machines and their faults was started in 1996, using the B&K Vibro philosophy. Our current team consists of the technical analysts Joel E. Nunes, Rodrigos dos Anjos, Ronildo Folgado, Gustavo Fonceca and Emilson Silva, supervised by Marcelo Menezes and managed by the Area Manager Nicolaas and his staff Arthur Valente. In 1995 detection monitoring was done with the Type 2513 handheld vibration monitor and analysis by the Type 2515 analyzer. In the middle of 1996 we

purchased the 2526 and the software Sentinel. As of 2002 we already have three off-line collectors with intentions to buy a COMPASS system.

Vibration monitoring strategy

The off-line monitoring was implemented according to an internal expansion project at CVRD. After selecting equipment by GUT(*) we went through a definition stage. What would be necessary to detect a fault? Now we spend more time making measurement setups and taking the actual measurements than in the past, but what we lose in speed we gain in more reliability and efficiency in evaluations. For example, the following measurements are made in a gearbox:

- **CPB6%** for detecting toothmesh frequencies and its harmonics
- A real **zoom** over the tooth mesh and natural frequencies. This procedure allows us to verify the lateral bands (FM and AM modulators, distributed or local faults)
- The **cepstrum** technique is used while making a zoom. This procedure conditions the trending of the frequency that appears modulating and causes an error in the transmission of force and movement between the teeth.

The monitoring philosophy adopted by the predictive maintenance group of CVRD in CM, is going through a process of modifications in order that it be optimized without losing the essence that the diagnostic tools can condition in detecting a fault.

Condition monitoring, a powerful tool for detecting and diagnosing excitations and faults for a diverse range of faults.

Case story 1 - diagnosis description of a defect in the outer ring of the rolling-element Timken bearing 93825 at low rotational speed, only 3 rpm

Nowadays there is a growing need and difficulty in all industries of detecting and diagnosing faults in rolling-element bearings at low rotational speeds. What can we call low rotational speed?

Predictive monitoring group have developed a method for monitoring rolling-element bearings at low speed, when the amplitude modulation at the structural resonance is excited by periodic, repetitive impacts. This method consists of the following steps:

- Selection of an accelerometer
- Techniques for detecting and diagnosing faults
- Setup configuration
- Data collection point
- Interpretation of the spectra
- Definition of the area of the structural resonances excited by repetitive, periodic impacts generated by the bearing

Figure 2. Classifier.

Description on the operational and technical processes of the machines

One of the monitored machines that was diagnosed is the classifier 6301, located in the treatment plant at the Conceição Mine. Its function in the system is quite important , since it classifies a product called hematite. If the classifier is stopped for repairs, this will stop 50% of the hematite production line, which is 1250 tonnes of iron ore per hour.

This machine is composed of an electric motor that turns at 1200 rpm (20 Hz) and is stepped down in speed through pulley wheels to 585 rpm (9.75 Hz). The input shaft of the gearbox turns the middle shaft at 96 rpm (1.6 Hz), which in return turns the output shaft of 17.4 rpm (0.29 Hz). The tooth meshing frequencies in the gearbox are 126.7 Hz at the input and 27.2 Hz at the output. On the output shaft there is a pinion gear that turns a crown that is coupled to the classifier’s spiral shaft. Afterwards the gearbox (which has an input of 17.4 rpm) is stepped down to 3.48 rpm (0.058 Hz), the

Figure 3. Drive train of the classifier.

rolling-element bearing on the spiral shaft is the Timken 93825, as seen in Figure 3.

Detection technique - CPB23% - acceleration

With the use of this technique it was possible to accommodate all frequencies in the range from 1.6 to 12.5 Hz; making it simple to find out which frequency is developing and what is its origin. Below are some frequencies that indicate increasing amplitudes and cause alarms:

- 10 Hz frequency corresponds to a 2x external toothmeshing frequency with an abnormal symptom in the toothmeshing caused by irregular contact of the teeth - as an ellipse.

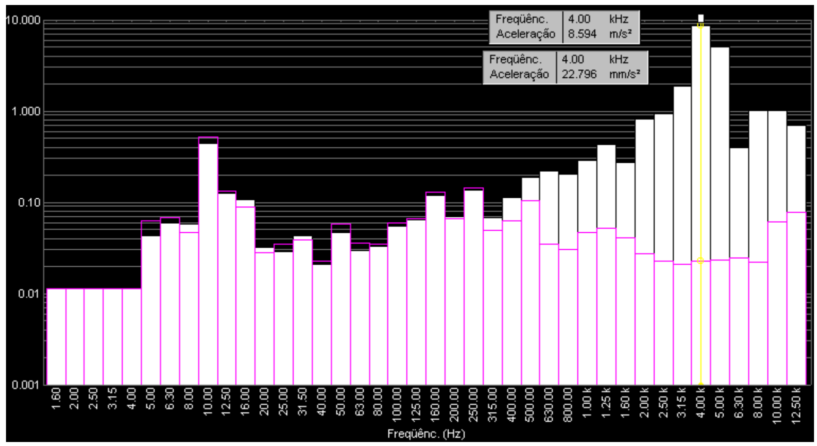

Figure 4. CPB23% of the spiral shaft bearing of the classifier.

- 4k Hz occurs in the region of structural resonance, which is excited by repetitive, periodic impacts, excited by the impacts originating from the contact of the rolling element with the defective external race.

Two points are observed:

- It is confirmed that the natural frequency of the bearing is independent of its rotation, but is dependent on the bearing assembly mass, spring and damping (rigidity) properties. The waves of impact between the rolling element and its external race creates harmonics, one of which coincides with the natural frequency of the bearing (high frequency). Therefore it is the amplitude (signal intensity) that is altered, which depends on the velocity of the element impact (kinetic energy impact), and this velocity depends on the rotational speed. These frequencies, which are the result of the impacts, are low frequency (which modulate at high frequency) and do not have enough energy to vibrate the bearing.

- Before repair the amplitude of the 4k Hz frequency (region of excited structural resonance) was 8.5 m/s2, and after replacing the bearing went down to 22 mm/s2 as shown by the pink bar in the CPB in Figure 4.

First step in diagnosis - envelope - in search of repetitive, periodic impacts

After confirming in the CPB 23% a region of structural resonance excited by periodic, repetitive

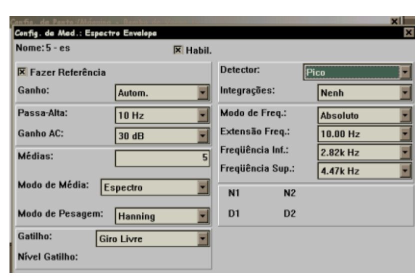

Figure 5. Envelope setup. Frequency 0.88 Hz. Toothmeshing frequency 5.5 Hz with pinion gear modulation of 0.22 Hz and smaller frequency amplitude bands of rotation of the crown gear of 0.058 Hz.

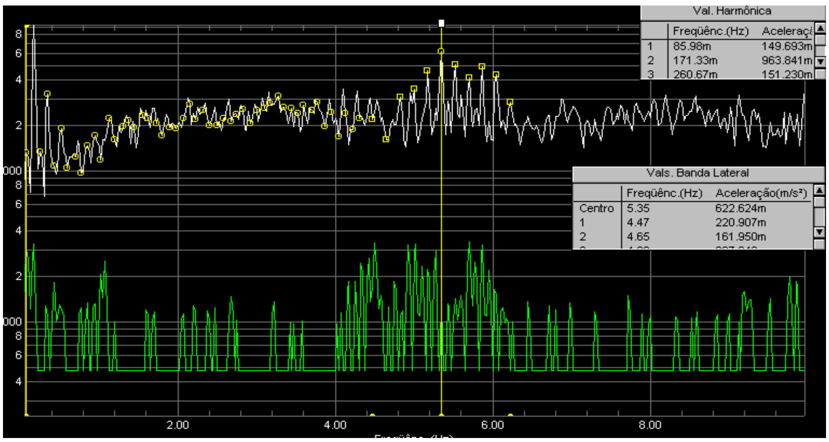

Figure 6. Envelope plot.

impacts of the rolling element, we make an envelope with a narrow filter that permits the resonance region to show itself at 10 dB. We demodulate at low frequency in a spectrum with a span of 10 hz at a resolution of 0.025 Hz.

Envelope setup configuration in Figure 5 shows the flexibility in making an envelope in 1/3 octave bands while selecting upper and lower limits of the frequency range taken from the CPB23%. One of the advantages of the SED (selective envelope detection) is that it allows the elimination of random noise (carpet noise) that could amplify some frequencies and attenuate others, making it possible to make an amplitude trend without outside contributing factors (amplifiers). The SED offers another advantage for trending a rolling element defect by the magnitude modulation method, which is the relation between the level of the major harmonic component of the defect in the spectrum and the level of the carpet noise.

While analyzing the envelope spectrum in Figure 6, we have proven the success of a group of factors that make up the procedure for diagnosing rolling element bearings that turn at low speed (3.5 rpm), in respect to the steps mentioned above. In this spectrum we verify the external race harmonics, especially the second harmonic of 0.88 Hz. After replacement (shown in green) the levels diminish to normal, including the external toothmeshing frequency that was excited by rotational frequency modulations of the pinion gear.

Once again we can confirm in practice, that the envelope technology - well used and understood - is a powerful tool for the trending and analysis of low speed rolling element bearings.

Second step in diagnosis and trending - crest factor - return to the beginning

In the search to increase the range of tools for detection of rolling-element bearing faults, we set up a technique called crest factor. But we do not want to observe only the division value, we want to also observe the trend behaviour of the peaks and the RMS values. The plot in Figure 7 shows the efficiency and the success of this technique for detection.

The peak (global value from 1 kHz to 10 kHz) after replacing the rolling element bearing, its trend, presented some alternations in the amplitude value, due to its sensitivity to the impacts of the external toothmeshing action. The RMS presents a linear behaviour after replacement.

Conclusion

This diagnosis permitted the maintenance sector of the Conceição Mine to change the bearing during a planned shutdown, avoiding corrective repairs. If this was not communicated in time the equipment would have been down for approximately 6 hours (7500 tons). This time could have been a major case if there was an unexpected breakdown, causing damage in the components. The satisfaction of the condition monitoring group was enormous, since we proved the efficiency in the junction between human resources and B&K Vibro technology (off-line system 2526 and software Sentinel 7107)

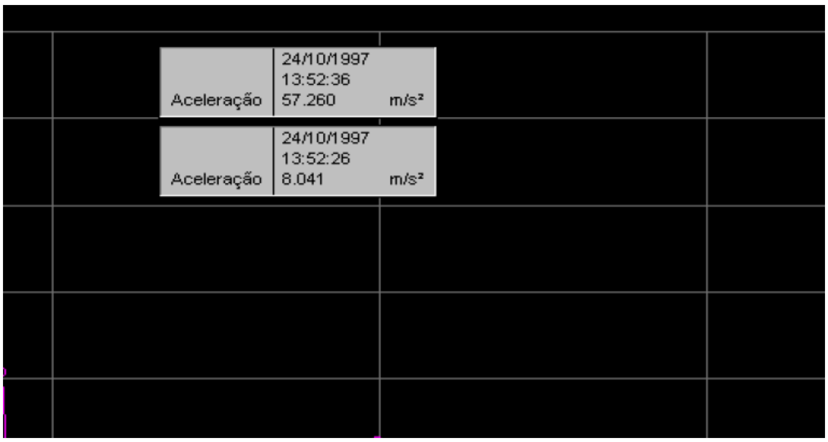

Figure 7. Crest factor.

detecting a defect in a rolling element bearing that rotates at only 3.5 rpm. This rotation represents one of the slowest rotations in the world, in which it was possible to diagnose a bearing fault using an off-line system. Needless to say, that besides the above mentioned diagnosis, we obtained a practical confirmation that the rolling element bearing natural frequency is independent of its rotation, only a function of the assembly mass, spring and damping (rigidity) properties.

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