A Hoist Application in the Mining Industry

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1 Introduction

A hoist or winder is a mission critical application found in underground mines. The hoist is used either to transport ore to the surface or personnel to or from the mine shaft.

Basically, there are three types of hoists:

- **Friction hoist** typically used in Europe, Asia, and Australia
- **Drum hoist** typically used in North America, South Africa, and South America
- **Multi-rope hoist** for very deep mine shafts

![Fig 1. Drum hoist](image1)

![Fig 2. Friction hoist](image2)

![Fig 3. A multi-rope hoist of drum type.](image3)

![Fig 4. A multi-rope friction hoist.](image4)

In the **drum hoist** (see Fig 1), the hoisting cable is wound around the drum when the hoist is lifting. In smaller applications, a single drum can be used. In a double drum solution, two skips can be used in balance.

In the **friction hoist** (see Fig 2), the cable passes the drum and the tail end of the cable is counter-balanced; the friction between the drum and the cable enable the lifting action. The drum occupies less space compared to a drum hoist and is economically more suitable for more shallow shafts.

The **multi-rope hoist** (see Fig 3) is used for very deep mine shafts such as in many South African mines.

This case study describes a **multi-rope friction type of hoist** (see Fig 4).
A common working principle for all hoist types is the cycle time. The hoist is in operation for a limited time, followed by a stop time for loading and unloading. From a condition monitoring viewpoint, the measurement ‘window’ is limited by this cycle time. In shallow mines, short cycle times may be a challenge in terms of very limited measuring times. For the hoist at the Renström mine however, this is not a problem.

This case study describes a friction hoist application in the Boliden mine Renström. The Renström mine is one of Sweden’s deepest mines, with its deepest part exceeding 1300 meters. The ore is polymetallic and contains zinc, copper, lead, gold and silver, which is extracted using the cut-and-fill method.

The hoist was installed in July 2013, at which time the condition measurements started, providing good baseline measurements on a brand new hoist. The hoist basically consists of a frequency controlled motor, a two-stage gearbox, a drum, the wires and two skips. The skips are mounted at the tail end of the wires with a lifting capacity of approximately 5 tons each.

*Image 1. The friction hoist at the Renström mine. The motor, gearbox, drum and wires can be clearly seen.*
2 Conclusion and summary

Condition of the mine hoist

During the period from initial measurements in July 2013 until January 2014, four observations were made:

1) Thanks to the good quality readings, it became clear that the gearbox data provided by the supplier did not match the actual measurements. It turned out that the supplier sent the wrong drawing. This has since been updated with a new and correct drawing.

2) The 1 X vibration peak of the drum is higher than expected for such a low-RPM application (50 RPM). The peak is slightly higher than 2 mm/s; possibly caused by the wire oscillation, but the peak is exactly at 1 X so it is most likely an unbalance or maybe an eccentric drum.

3) There are also signs of outer race damage on the drive side bearing of the drum. The damage is still very small, but can be clearly seen in the measurements. Most probably an early stage 1 damage.

4) A number of occasions with relatively high random impacts close to the coupling between gearbox and drum were observed.

With the exception of 2), 3) and 4) above, the hoist is running very smoothly with low and stable readings in general.

We recommend continuous monitoring and trending of the suspected unbalance/eccentricity of the drum and the small bearing defect in the drive side drum bearing. We also recommend setting up viewing of “trends” via Internet and E-mail alarms to enable rapid response if readings indicate a major change of equipment condition.
3 Application description

The friction hoist has a cycle time close to 120 seconds (the time to lift one skip from 900 meters up to the surface. During the 120 seconds the drum is rotating close to 100 revolutions.

Delivered by ABB, the 400 kW motor has a gearbox with a total ratio of 13.609:1.

Fig 7. Close-up of the drum; the wires and non-drive side drum bearing visible.

4 System setup

4.1 Measuring equipment

The total number of transducers used for this application is fifteen; ten shock pulse transducers to cover the bearings, and four vibration transducers to cover gear mesh frequencies in the gearbox, unbalance in the drum and other low frequency vibrations. The combination of vibration and shock pulse technologies is optimal for this type of application. The shock pulse transducers pick up bearing related signals very clearly and the readings are crisp and easy to interpret. The normal gear mesh frequencies do not affect the shock pulse transducers, while vibration transducers pick up the gear mesh. As long as the gear teeth are in good condition and no impacts are emitted, the shock pulse transducers will not react, but the slightest irregularity in the contact surfaces between the gearbox teeth will trigger an immediate response. To conclude; the shock pulse and vibration combination covers this application in a very efficient way.
The RPM is measured on the motor drive shaft, one pulse per revolution.

An 18-channel Intellinova Compact online system with a local database is used. The customer provides VPN access to enable SPM personnel to analyze readings.

The time to complete one cycle - lifting one skip from 900 meters up to ground level - takes 120 seconds. The hoist accelerates quickly and the drum quickly reaches a stable 51.3 RPM.

Using 120 seconds and 51 RPM leads to the conclusion that one hoist cycle equals 102 revolutions of the drum. Selecting a measuring time of 20 revolutions for all measuring points at the slowest shaft ensures enough readings without using triggered measurements. All other shafts will make more revolutions so on them, the measuring time is less critical. Even though some measurements may be lost if the measurement window happens to hit a rapidly changing RPM due to acceleration or retardation, most of the readings will be taken during stable RPM conditions.

![Fig 8. Transducer positions.](image)

Number of revolutions for each shaft and selected measuring time, assuming a 120 second cycle time and a drum RPM of 51.3:

<table>
<thead>
<tr>
<th>Shaft</th>
<th>Ratio</th>
<th>Max. revolutions for one cycle</th>
<th>Selected measuring time HD (rev’s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1397,6</td>
<td>268,8</td>
</tr>
<tr>
<td>B</td>
<td>20/67</td>
<td>417,2</td>
<td>134,4</td>
</tr>
<tr>
<td>C</td>
<td>(20/67)×(16/65)</td>
<td>102,6</td>
<td>19,2</td>
</tr>
</tbody>
</table>

Studying the ratio of the maximum cycle time above and the selected measuring time reveals that the likelihood of finding a long enough measurement window with stable RPM is high.
4.2 Measuring technique(s)

In order to cover bearing condition both in the motor and gearbox as well as in the drum bearings, we use shock pulse transducers (type 44000). Combining these shock pulse transducers with the SPM HD technology renders superior capability to detect bearing condition. We also use four vibration sensors (SLD144B): one on the motor, two on the gearbox (horizontal and vertical) and one on the support bearing for the drum (horizontal). The shock pulse transducers do not detect low frequency signals from unbalance, misalignment, soft foot etc., so the purpose of the vibration transducers is to cover that type of low frequency movement.

Using shock pulse transducers for bearing condition assessment in a gearbox is very efficient. The multiple gear-mesh frequencies in a gearbox significantly affect normal vibration transducers, making the spectrum and overall values hard to interpret. The shock pulse transducer however is not affected by the gear meshes (if there are no gear damages), so the readings are very clean and crisp showing only bearing condition. The reason is that normal mesh frequencies are too low in frequency to be detected by the shock pulse transducer (see gear mesh calculations below). If a crack or surface imperfection were to occur in one or several gear teeth, then due to the shocks the shock pulse transducer would react.

<table>
<thead>
<tr>
<th>Gear mesh frequency 1 at 698.2 RPM (motor) (20 and 67 teeth mesh):</th>
<th>(698.2/60)*20 Hz = 232.7 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear mesh frequency 2 at 698.2 RPM (motor) (16 and 65 teeth mesh):</td>
<td>(698.2/60)*(20/67)*16 Hz = 55.6 Hz</td>
</tr>
</tbody>
</table>

4.3 Condmaster setup

The parameters measured and trended are HDm for all shock pulse measurements (a moving average filter with ten readings has turned out to be useful to avoid false alarms caused by single impacts) and vibration velocity RMS (here too a moving average of ten values is used). Due to the relatively high 1 X readings on the drum, a trend showing the 1 X symptom trend was added.

The measurement interval is set to thirty minutes for each measuring point. The long cycle time of 120 seconds gives plenty of time to measure, resulting in many readings per day on all measuring points. The number of readings per day is fifteen, on average. This is more than enough, so fewer readings per day might be considered to avoid the database growing too rapidly - two readings a day for example might suffice.
4.3.1 Measuring point setup

SPM HD measuring points

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>No. of spectrum lines</th>
<th>Fmax</th>
<th>SEF*</th>
<th>RPM factor</th>
<th>Rev’s (measuring time)</th>
<th>RPM range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3200</td>
<td>100 Orders</td>
<td>5</td>
<td>1</td>
<td>268,8</td>
<td>500-800</td>
</tr>
<tr>
<td>2</td>
<td>3200</td>
<td>100 Orders</td>
<td>5</td>
<td>1</td>
<td>268,8</td>
<td>500-800</td>
</tr>
<tr>
<td>3</td>
<td>3200</td>
<td>100 Orders</td>
<td>5</td>
<td>1</td>
<td>268,8</td>
<td>500-800</td>
</tr>
<tr>
<td>4</td>
<td>3200</td>
<td>100 Orders</td>
<td>5</td>
<td>1</td>
<td>268,8</td>
<td>500-800</td>
</tr>
<tr>
<td>5</td>
<td>1600</td>
<td>100 Orders</td>
<td>5</td>
<td>0,298507465</td>
<td>134,4</td>
<td>150-239</td>
</tr>
<tr>
<td>6</td>
<td>1600</td>
<td>100 Orders</td>
<td>5</td>
<td>0,298507465</td>
<td>134,4</td>
<td>150-239</td>
</tr>
<tr>
<td>7</td>
<td>1600</td>
<td>100 Orders</td>
<td>Off</td>
<td>0,07347876</td>
<td>19,2</td>
<td>37-59</td>
</tr>
<tr>
<td>8</td>
<td>1600</td>
<td>100 Orders</td>
<td>Off</td>
<td>0,07347876</td>
<td>19,2</td>
<td>37-59</td>
</tr>
<tr>
<td>9</td>
<td>1600</td>
<td>100 Orders</td>
<td>Off</td>
<td>0,07347876</td>
<td>19,2</td>
<td>37-59</td>
</tr>
<tr>
<td>10</td>
<td>1600</td>
<td>100 Orders</td>
<td>Off</td>
<td>0,07347876</td>
<td>19,2</td>
<td>37-59</td>
</tr>
</tbody>
</table>

*) Symptom Enhancement Factor

Vibration measuring points

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>No. of spectrum lines</th>
<th>Unit</th>
<th>Fmin</th>
<th>Fmax</th>
<th>Window</th>
<th>Averages</th>
<th>RPM factor</th>
<th>Time interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3200</td>
<td>Vel</td>
<td>2 Hz</td>
<td>100X</td>
<td>Hanning</td>
<td>4</td>
<td>1</td>
<td>30 minutes</td>
</tr>
<tr>
<td>3</td>
<td>3200</td>
<td>Vel</td>
<td>2 Hz</td>
<td>100X</td>
<td>Hanning</td>
<td>4</td>
<td>1</td>
<td>30 minutes</td>
</tr>
<tr>
<td>7</td>
<td>3200</td>
<td>Acc</td>
<td>2 Hz</td>
<td>300X</td>
<td>Hanning</td>
<td>2</td>
<td>0,07347876</td>
<td>30 minutes</td>
</tr>
<tr>
<td>9</td>
<td>1600</td>
<td>Vel</td>
<td>0.5 Hz</td>
<td>100X</td>
<td>Hanning</td>
<td>-</td>
<td>0,07347876</td>
<td>30 minutes</td>
</tr>
</tbody>
</table>

The difference in line resolution and number of averages is an adjustment of the measuring time to the available cycle time.
5 Case descriptions

5.1 Case #1; Incorrect gearbox data

Using the vibration sensor at measuring point no. 3 on the input shaft of the gearbox, applying HD Order tracking revealed a very clear peak in the spectrum at exactly 20 X. The gearbox drawing indicated 19 teeth in the spectrum so something was obviously wrong. When the supplier sent the correct drawings, it was confirmed that there is in fact a 20 teeth gear on the input shaft.

Fig 9. A clear vibration spectrum, clearly displaying the 20 X peak with harmonics.
5.2 Case #2; Relatively high 1 X signals

The 1 X symptom since July 2013 to January 2014 displaying a stable trend. At 51.3 RPM the 1 X is relatively high. We recommend to continue to monitor the 1 X symptom looking for developing trends.

Fig 10. The 1X peak with harmonics in the spectrum.

![Graph showing 1X peak with harmonics.]

Fig 11. 1 X symptom trend applying a moving average filter of ten values. The readings are stable.

![Graph showing moving average filter of 1X trend.]

5.3 Case #3; Outer race defect on the drum drive side

A small but clear outer race damage on the drum bearing drive side (measuring point nr 9). The defect is small, in its initial stage (stage 1), barely visible. The spectrum is crisp and clear with harmonics. This bearing can run for a long time (years?) before a replacement is needed.

Fig 12. An SPM HD spectrum perfectly matching outer race defect frequencies. The levels are very low with a HDm value of 10 dB.

Fig 13. A Color Spectrum Overview screen shot. Note the harmonics of BPFO occurring and disappearing.
The BPFO symptom value shows a pattern of alternating high and low values. This pattern indicates that the load zone is changing depending on which one of the skips carries a load and which one is empty. Looking at the picture of the drum and wires (see Figure 14 below), it can be seen that when the upper wires are carrying the load, the load zone of the bearing changes to a more upward direction and vice versa. This indicates that the defect is located in one of these load zones. We do however not now which load zone it is.

**Fig 14.** Load direction when upper (see left) respectively the lower (see right) wire is carrying the load.
5.4 Case #4; Random high impacts from coupling between gearbox and drum

From time to time, we have observed relatively strong impacts; double or single peaks close to the coupling between the output shaft of the gearbox and the drum. The personnel at the site have also heard sharp impact noise from the hoist. This is not clearly visible in the HDm trend, because the random impact rejection filter reject this type of single or double impact, but in the SPM HD time domain it is visible. Please note that the Symptom Enhancement Factor (SEF) is set to 0 (i.e. is turned off) for this measuring point, so the time signal below is actually showing the “raw” shock pulse signal.

Fig 15. An example of a strong impact shown in this SPM HD Time signal, November 5 2014. Measuring point nr 8, output shaft of the gearbox.
6 Appendix

Trends for all measuring points; HDm trends first, followed by vibration trends and finally the 1 X trend. All trend graphs are stable with a low level except the 1X symptom trend which is stable but with slightly elevated readings.

6.1 HDm trends

Measuring point no. 1; HDm trend motor NDE. Timespan: July 2013 to January 2014.

Measuring point no. 2; HDm trend motor DE. Timespan: July 2013 to January 2014.
Measuring point no. 3; HDm trend, gearbox input shaft DE. Timespan: July 2013 to January 2014.

Measuring point no. 4; HDm trend, gearbox input shaft NDE. Timespan: July 2013 to January 2014.

Measuring point no. 5; HDm trend, gearbox intermediate shaft DE. Timespan: August 2013 to January 2014.
Measuring point no. 6; HDm trend, gearbox intermediate shaft NDE. Timespan: August 2013 to January 2014.

Measuring point no. 7; HDm trend, gearbox output shaft DE. Timespan: October 2013 to January 2014.

Measuring point no. 8; HDm trend, gearbox output shaft NDE. Timespan: October 2013 to January 2014.
Measuring point no. 9; HDm trend, drum DE. Timespan: October 2013 to January 2014.

Measuring point no. 10; HDm trend, drum NDE. Timespan: October 2013 to January 2014.
6.2 Vibration trends

Measuring point no. 2; Vel RMS trend, motor DS. Timespan: October 2013 to January 2014.

Measuring point no. 3; Vel RMS trend, gearbox input-shaft DE. The level change is due to frequency range adjustments. Timespan: July 2013 to January 2014.
Measuring point no. 7; Vel RMS trend, gearbox output-shaft DE. Timespan: October 2013 to January 2014.

Measuring point no. 9; Vel RMS trend, bearing drum DE. Timespan: July 2013 to January 2014.
6.3 Symptom trend

Measuring point no. 9; 1 X symptom trend of the drum, bearing drum DE. Timespan: October 2013 to January 2014.