Condition based monitoring for underground mobile machines

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Abstract

Maintenance operations have significant influence on the economy and performance of mining companies. Unpredicted repairs cause interruptions and breakdowns in production. This means economic losses but, in some cases, also increasing environmental emissions in off-gases and wastewater. Condition based maintenance (CBM) can significantly reduce maintenance costs. Sensors and measurement devices offer a lot of data and assist workers to identify upcoming maintenance needs in advance. Typical measurement variables are for example vibration, temperature, different speeds and pressures. DEVICO project aims to develop a framework for solutions and combine condition monitoring and process data to integrate CBM to control and timing of the maintenance actions. On-line and periodic CM measurements can be combined with process measurements by using signal processing and feature extraction. Case study is conducted in Pyhäselmi mine with Sandvik load haul dump (LHD) machinery. The condition monitoring system is installed on LHD front axle. The choice for the installation position was made based on the feedback and maintenance data gathered from mining companies. This information indicates that the axles are among the most critical parts in LHD machines.

Key words: Data analysis, condition based monitoring, load haul dump, vibration

1 Introduction

1.1 Development needs in the maintenance of mining industry

Maintenance is a critical factor in the economic performance of mining companies, especially in the case of smaller mines. Maintenance costs can be 30-60 % of total operation costs in the mining industry. Currently the focus in maintenance operations is commonly in corrective maintenance. Common reason for this is the lack of knowledge and resources to invest in predictive maintenance and condition monitoring. For example, in paper industry condition monitoring and long-term maintenance schedules are used more widely. Condition-based
maintenance (CBM) program that is designed for the needs of mining industry could reduce the maintenance costs of mines. This program should also be easy to deploy even with a lightweight maintenance organization. One target for development in the DEVICO project is condition-based monitoring in mining industry. The purpose of condition monitoring is to reduce unnecessary breakdowns. In the mining industry, these breakdowns may also cause environmental emissions.

Mobile machines are widely used in the mining industry. Common mobile machines working in the mines are drill rigs and jumbos, excavators, wheel loaders, rigid trucks, concrete sprayers, charging vehicles and bolting machines. Maintenance of mobile machines causes a significant part of total maintenance costs in the mining industry. Load haul dumps (LHDs) are large loading machines that are used in the underground mining to load and move ore from the drift. These machines can be operated remotely. Maintenance can cause up to 70% of total operation costs of LHD machines (Figure 1). Despite high maintenance costs, condition monitoring of mobile machines isn’t widely used. A lot of different kind of data is available from the operation of mobile machines, for example maintenance, operation and production data. Fusion of these different data types is also still clearly under development. (Gustafson & Galar 2012)

![Electric LHD vs Diesel LHD](image)

**Figure 1. Share of operation costs of LHD machines (Sayadi et al. 2012)**

1.2 Condition-based monitoring research

The objective of the DEVICO project in the University of Oulu is to provide certain means for integrating condition monitoring of mobile equipment to the maintenance strategies of a mining company. This can be achieved via development of condition and stress indices which are easily available for the use of maintenance personnel (Figure 2).

Case study is conducted in Pyhäsalmi underground mine with Sandvik LHD machinery. The condition monitoring system is installed on the front axle of LHD machine.
2 Background

2.1 Vibration analysis and signal processing

Reliable condition monitoring can be achieved when advanced signal processing and automatic fault detection are combined (Lahdelma & Juuso 2007). Intelligent stress and condition indices can be developed by using nonlinear scaling. Features are extracted from derivatives of the vibration measurement signals to define normal operation conditions. When this definition is done, the changes in signals and their differences from normal values can be monitored. The condition indices are calculated by comparing the feature values with the values in normal operation. These indices can detect differences between normal and faulty conditions and indicate the severity of these faults. (Juuso & Lahdelma 2010)

Control Engineering Laboratory and Machine Diagnostics Laboratory in University of Oulu have previously developed applications of vibration analysis, e.g. the scraper of a continuous digester, a gearbox of a sea water pump and a turbo compressor system. (Lahdelma & Juuso 2011)

2.2 Fusion of maintenance, process and production data

Generally speaking, data fusion from different functional areas may offer advantages in maintenance operations. If the optimization of functional areas is independently done by different departments, problems may arise. As said in Galar et al. (2012), “low priority equipment problem may have been causing a large problem in achieving a desired or critical process control performance, but was not being corrected because it was not considered very
important in the context of equipment maintenance”. A centralized solution to gather and distribute data to different departments could reduce these problems. (Galar et al. 2012)

Different data from various sources are available from the operation of mobile machines. In this case, the examples of available data are maintenance data (work orders, time used for maintenance), process data (temperatures, pressures) and production data (bucket weights, drive speed). Problematic part of maintenance data is that e.g. estimation of working hours is commonly entered manually. If this is done carelessly, a reliable analysis of data is difficult. An example of combination of production and maintenance data is shown in Figure 3, where the gap in production (left) is explained by maintenance operations (right). (Gustafson & Galar 2012) Also some incompatible technical solutions can cause problems: it can be very difficult to combine together e.g. timestamps and various data formats from multiple sources.

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Figure 3. Combination of production and maintenance data. (Gustafson & Galar 2012)

A need for smooth co-operation between different departments of mine, especially in case when the ore production rate is increasing rapidly, was also identified by Sillanpää (2012). This co-operation also includes the utilization of production and maintenance data.

2.3 Condition monitoring of load haul dump machines

Although there is a lot of process data which is available for different purposes, condition monitoring usually requires additional measurements. Keski-Säntti (2006) conducted study about LHD condition prognostics. Typical measurements from LHD machines include e.g. hydraulic and air pressure sensors. However, these measurements don’t give sufficient information for reliable condition monitoring, as Keski-Säntti (2006) states: “present measurements are not able to produce that kind of data which can be utilized in making reliable prognostics”. A need for vibration measurements for the basis of condition monitoring was identified in the study. Preliminary vibration measurements indicated that different stages of LHD operation can be identified from the vibration signals, e.g. a movement from the service platform to the production area, the loading stage and the transport of ore to the ore pass. One conclusion was that with the synthesis of vibration measurements with other data, the maintenance operations can be prognosticated more reliably. (Keski-Säntti 2006)
If the remote-controlled LHD machines are used, an operator doesn’t have direct feeling of machine vibrations. This kind of experience-based condition monitoring is still common. When this kind of direct feeling is lost, a need for the condition monitoring system is even more evident. (Keski-Säntti 2006)

2.4 Wireless data transfer

One future challenge in condition-based monitoring of underground mobile equipment is wireless communication. Underground mines are challenging environments for wireless communication. Wireless networks are used with load haul dumps to transfer production monitoring data, but condition monitoring via wireless data transfer hasn’t been used widely. The data bandwidth of wireless networks isn’t sufficient for transferring vibration data continuously (Timusk 2008). Development of event triggers for vibration measurements could reduce the bandwidth need significantly. A determination of events when faults can be identified well, e.g. moment when LHD is driving consistent speed, is a challenging task.

One practical possibility could be a system which transfers vibration data from a data logger to the servers when LHD arrives at a service platform, e.g. after the evening shift. In this option, the transfer of production monitoring data doesn’t take up any bandwidth from vibration data. The best solution would be a data logger which calculates condition indices internally and sends only information about these indices to servers, not whole vibration measurement data. As described in Paavola (2011), a bandwidth needed for communications could be reduced if only the descriptive indices are transferred instead of raw data. The adaptation of wireless data transfer is helpful especially when condition monitoring is applied to a moving target in harsh environments, as described in Keski-Säntti et al. (2006).

3 Experimental study

3.1 Project partners

The experimental part of the DEVICO project is done in co-operation with Pyhäsalmi Mine Oy, Sandvik Mining and Construction Oy and SKF. Pyhäsalmi Mine is an underground copper and zinc mine located in central Finland. Pyhäsalmi Mine uses sub-level and bench stoping as a mining method.

Sandvik Mining and Construction Oy is a leading global supplier of equipment, cemented-carbide tools, service and technical solutions for the excavation and sizing of rock and minerals in the mining and construction industries. Sandvik has provided technical support in the DEVICO project.

SKF is a technology provider that is specialized in bearings and units, seals, mechatronics, services and lubrication systems. SKF has provided the accelerometer sensors that are used in the condition monitoring.
3.2 Selection of condition monitoring target

First task in the development of condition-based monitoring for load haul dump was the selection of the target component for condition monitoring. Decision for the target component was made based on the following factors:

1. Faults in monitored component cause long repair times.
2. Repair of a component is done mostly during the corrective maintenance.
3. There is a reasonable way to use vibration measurements in condition monitoring of the component.

LHD-related maintenance data gathered from several mines was analysed for the selection of the target component. Also direct feedback from mining companies and previous studies (Figure 4) was taken into account when selection was made.

![Diagram](image.png)

Figure 4. Criticality assessment of components and subsystems based on event data (Ahonen et al. 2006)

According to the maintenance data, most of the preventive maintenance works are related to simple tasks like oil changing and other little tasks that are not crucial to production. Because of this, preventive maintenance-related information from maintenance data was excluded. A focus was only in the faults that were labeled as a corrective maintenance work.

Maintenance data included information about the amount and repair times of specific faults. The amount of all work orders was counted and divided into the categories by components. This way the number of incidents in each part of the LHD was found out.

There are some components like hoses and connectors in which faults occur frequently, but an average working time caused by an individual fault is quite short. When all faults were summed together (Figure 5), it was clear that the hoses and connectors are reasons for most maintenance work orders and also result in the most working hours. However, the hose faults and other similar failures, which are easy to fix but difficult to measure and predict, aren’t critical concerning condition-based research.
The faults in axles, cylinders and hydraulics result in a high percentage of maintenance working hours although the number of those faults is low (Figure 5). The faults in these components are more difficult to fix and could lead to more significant production stoppages due to long repair times. These components are good alternatives for condition monitoring targets. Based on these factors, the front axle was selected as the condition monitoring target.

![Combined distribution of LHD faults, 10 most critical components (% of work orders/working hours)](image)

Figure 5. Critical components of LHD machine.

### 3.3 Condition monitoring system

The condition monitoring system was installed on a LHD machine working in underground mine environment. The LHD machine is Sandvik LH621 (Figure 6). Vibration measurements are done using National Instruments CompactRIO 9024 data logger and four SKF Copperhead CMPT 2310 accelerometer sensors. The accelerometer sensors have been installed on the front axle. Two accelerometers are installed on the left side of axle and two on the right side. On both sides, there are sensors for vertical and horizontal measurements. The vibration measurements are combined with the measurement of machine drive speed. The drive speed is measured from the drive shaft with a photoelectric sensor. The drive speed can be calculated from the tachometer pulse when a gear ratio is known. The measurement moments can be identified from the drive speed, e.g. when LHD is loading ore from the drift or dumps the ore to the ore pass. Measurement software was developed using LabVIEW development environment.
3.4 Preliminary vibration measurement data

First batch of vibration measurement data was recovered during April 2013. Signals can be examined by using analyzing software in LabVIEW environment. An example of collected data can be seen in Figures 7 and 8. In Figure 7 acceleration signals from two sensors (horizontal and vertical) are displayed with a measurement of drive shaft rotation speed. Figures 8 and Figure 9 display acceleration spectrums with two different drive shaft rotation speeds.

Preliminary analyses indicate that the working stages can be identified from signals. The biggest impacts on the front axle occur during the loading stage. This stage isn’t suitable for condition monitoring, but it can be used to estimate the magnitude of impacts. The best stage for condition monitoring could be the transition to the loading position. In this stage drive speed is quite constant. Driving speed is an important factor when vibration levels are analyzed. As seen in Figures 8 and 9, certain frequency components are over ten times higher when drive shaft rotation speed increases from 9 to 22 Hz. (Saari 2013)
Figure 7. Example of acceleration signals from two accelerometer sensors with drive shaft rotation speed measurement.
Preliminary data analysis indicates that vibration measurements offer a good basis for condition monitoring development. Data collection is in its early stages so more precise analysis is done when more measurement data is available. As discussed in Section 2.1, the identification of the “normal” level of vibrations is needed for the development of stress and condition indices. Because in the case of LHD machines the “normal” operation is dependent on the working stage, there isn’t only one vibration level which can be used as a base level. The best solution could be to identify a certain stable driving stage of the LHD where vibrations are always on the same level. A notable increase in the vibration levels could be an indication of a developing fault. Preliminary analysis indicates that the transition to the loading position could be the best stage for fault identification. Wireless data transfer of condition indices from a data logger to servers could offer maintenance personnel an easy solution to access data.
The load haul dump operators have different ways to operate the machine. Some operators accelerate, brake and load ore more carefully than others. Also the road conditions may change during time. These variables can cause variation in the vibration levels. This needs to be taken into account when the generation of features and indices is done. If there is a driving style which clearly reduces time used for the maintenance, the operators can be encouraged to use such style. The most important information that must be combined to the vibration measurements in future consists of the bucket weights and timestamps for the loaded buckets.

References


