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Stress monitoring of Underground Load Haul Dumper Front Axle with Intelligent Indices

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Abstract: Maintenance of mining machinery is done by schedule or in the event of break down and this is area where it is possible to cut down in maintenance costs by lowering down time and preventing sudden break downs. Advanced on site signal processing enables early fault detection and improves maintenance planning by optimizing service intervals. This paper studies the stress affecting the load haul dumper front axle. Methods used are stress indices and cumulative stress analysis.

Keywords: Signal processing, nonlinear scaling, intelligent stress indices, vibration analysis, l_p norms.

1. INTRODUCTION

Mining industry is currently using much more resources than in the past to develop modern techniques for maintenance and environmental issues. The Lack of knowledge on the process and equipment prevents the implementation of effective maintenance procedures (Marquez 2006) (Ruiz 2014).There are plenty of areas that can be improved with proper techniques or technologies and research topics waiting to be studied. Modern maintenance can use predictive techniques instead of current corrective ones commonly used by present day mining industry. Predictive maintenance tools monitor vibrations, infrared image, or some other variables that include information about the mechanical condition of machinery for providing data to ensure the maximum interval between repairs and preventing unplanned possibly costly break downs (Mobley 2002).

The maintenance costs can vary from 2 to 20 times the original procurement cost based on past experiment. The maintenance cost includes lost working time, yield, rate, and quality loss, in addition degradation of safety for people, property, and environment. (Dhillon 2008) Investing in condition monitoring (CM) of mining equipment has been slow partly because of the allocation of resources and low interest in developing long-term maintenance schedules. Advanced condition monitoring has been applied widely in other industries already and in the current situation where mines have to make lower mineral contents profitable, it is beneficial to make far-reaching maintenance plan. The initial investment may be higher in condition based maintenance (CBM) but the repayment period is short because of optimal service interval and fewer sudden break downs. Environmental risks and worker safety can also be relevant factors to be considered. (Laukka et al. 2015)

The measurement campaign was conducted on the front axle of an underground load haul dump machine (LHD) in Pyhäsalmi mine. LHDs are used in underground mines to scoop ore from the drift for the primary crusher. The measurement campaign and background is explained comprehensively in (Laukka et al. 2015).

The changes in stress can be seen in vibration signal amplitudes. These changes in vibration can be monitored by calculating generalised norms revealing the stress. Stress is linked to the condition and monitoring of stress can reveal the machinery condition as well. (Nissilä et al. 2014) presented an algorithm for LHD condition monitoring. Another good method for detecting chances from normal operation is by creating a model of a fault free operating state and measure the error of that model (Isermann 1997) (Ruusunen & Paavola 2002). This is a good way for identifying faults and measuring condition but cannot distinguish momentary peaks in stress to be used in the controlling of the machine operation. There were research done concerning the related condition monitoring but the stress monitoring in this area has been non-existent.

2. MEASUREMENT ARRANGEMENT

LHD in this study is mobile operated Sandvik LH621. The drive shafts or gearboxes are not monitored regularly and maintenance is done only after break-down occurs. Maintenance costs can be as high as 70% of the total operating costs of LHD making it a good research subject (Sayadi et al. 2012).

The process of mechanical failure here is very slow and therefore sets some challenging requirements for the measurement setup. The amount of measurement data is huge and the placement of relatively sensitive sensors, media, and cables is not optimal. The calculation of trend indices and features without storing all of the vibration data would simplify the data recording and compress huge amount of vibration data into a few numbers to be sent forward. Selecting of the correct parameters for feature extraction and monitoring of condition (Nissilä et al. 2014) requires recording and analysing of raw vibration data.

Measurements were done with 4 SKF CMPT 2310 vibration sensors mounted in front axle housing. Sensors are placed so

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that they measure horizontal and vertical vibrations on both sides near planetary gearboxes. Tachometer is used to measure the rotation speed of drive shaft for dumper speed. Measurements were collected with National Instruments CompactRIO 9024 controller with NI 9234 vibration measurement module and saved into solid-state drive (SSD). Binary files contained data of one minute length recorded with the sampling frequency of 12800 samples per second. Built-in antialiasing filter ensures that there are no aliases at frequencies below 5760 Hz. (Laukka et al. 2015)

Due to the harsh conditions of measurement location, the vibration recording setup experienced several breakdowns. All of the accelerometers but the number one in right side measuring vertical vibrations (RV) break down during the measurement period leaving gaps in vibration data so the first sensor was selected for the stress calculations. Used measurement period consisted of 131 days where vibration measurements were taken from the whole operating time of the LHD.

3. MONITORING OF STRESS

Harsh conditions in underground mine set high standards for measurement setup reliability because it is vital to obtain measurement information from the entire working time of the LHD. The remote operation of LHD lacks the feeling of vibrations and movement of the machine promoting the need for condition monitoring system (Keski-Säntti 2006). Monitoring of cumulative stress (Juuso 2014) (Juuso & Ruusunen 2013) requires measurement data from every moment of machine use in order to record all the vibrations affecting the index. Discontinuities in measurement data lead to lower end level of cumulative stress and does not give the real operating point in long run. The recording of vibrations during the whole working time requires lots of data storage space but with on-site advanced signal processing (Lahdelma & Juuso 2011a) this amount can be reduced to a few descriptive numbers which can be easily transferred using wireless technologies (Paavola 2011) to the machine operator or for the maintenance crew.

3.1 Fatigue

A single high peak in stress may not be critical for structure but continuous stress that exceeds the certain threshold limit can cause fatigue leading to the higher possibility of a break down. Continuous stress forms microscopic cracks which can be described as material fatigue. These microscopic cracks grow in size when material is under stress and after reaching the critical size, structure fractures suddenly. The material lifetime and fatigue can be evaluated with Wöhler curve (Fig. 1) which is specific for certain material. The curve presents the magnitude of a cyclic stress against the logarithmic scale of cycles to failure. The Wöhler curve is transformed to a linear model with nonlinear scaling. (Juuso & Lahdelma 2012) (Juuso & Ruusunen 2013)

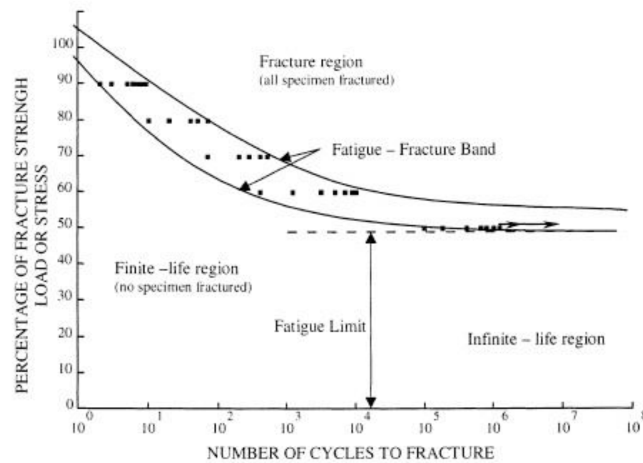

Fig. 1. Wöhler's curve or S-N curve.

The fatigue limit defines the critical stress that the material can withstand without initiated cracks propagating. The probability of the failure comes from the standard deviation of scatter. 10^7 cycles and beyond has been considered as infinite as testing after this point becomes hard and expensive. It was tested in (Bathias 1999) that although alloy withstand 10^7 cycles, it does not guarantee infinite life as fatigue resistance decreased significantly between 10^6 and 10^9 cycles to failure. Ordinary failure typically starts from the surface of the material under pure axial force. Fatigue at the interior of the surface strengthened materials is often caused by low stress with high amount of cycles. If the failure is initiated both on the surface and the interior, the S-N curve can have a stepwise shape. (Bathias 1999) (Boyer 1986) (Nishijima 1999)

3.2 Generalized norms

Features are obtained with generalized l_p norms (1), calculated from the measurement data. The generalized norm is also called as power mean or Hölder mean. These features are used in the forming of the stress index.

$$\|{}^{\tau}M_{\alpha}^{p}\| = ({}^{\tau}M_{\alpha}^{p})^{1/p} = \left(\frac{1}{N}\sum_{i=1}^{N}\left|x_i^{(\alpha)}\right|^{p}\right)^{1/p}, \quad (1)$$

where, $\alpha \in \Re$ is the order of derivation, $p \in \Re$ is non-zero order of the norm, τ is the duration of each sample, x_i is a vibration measurement point, and $N = \tau N_s$ where N_s is the amount of signal values in one second. The l_p norm is defined here for $1 \le p < \infty$. (Lahdelma & Juuso 2008)

The norm (1) combines the trends of strong increase with regard to the power p and the decrease with the power $1/p$. The norm values increase with increasing p. Some common special cases are $p = 1$ (Arithmetic mean), $p = 2$ (Root-mean-square or RMS value), and $p = \infty$ (peak value).

Derivating the vibration signal increases the sensitivity of fault detection to some point with faults causing impacts. (Lahdelma & Juuso 2011a) Applications for indices using derivation can be found in (Lahdelma & Juuso 2011b). In this case, the stress can be monitored straight from the acceleration signal, which simplifies the calculation and lowers the requirements for the signal processing hardware.