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Condition monitoring for mobile machines in underground mines

CONDITION MONITORING OF LOAD HAUL DUMP VEHICLES

- Condition monitoring of LHD vehicles is mostly corrective maintenance
- Many components could be actively monitored to reduce maintenance costs and time and even reduce the risk of accidents

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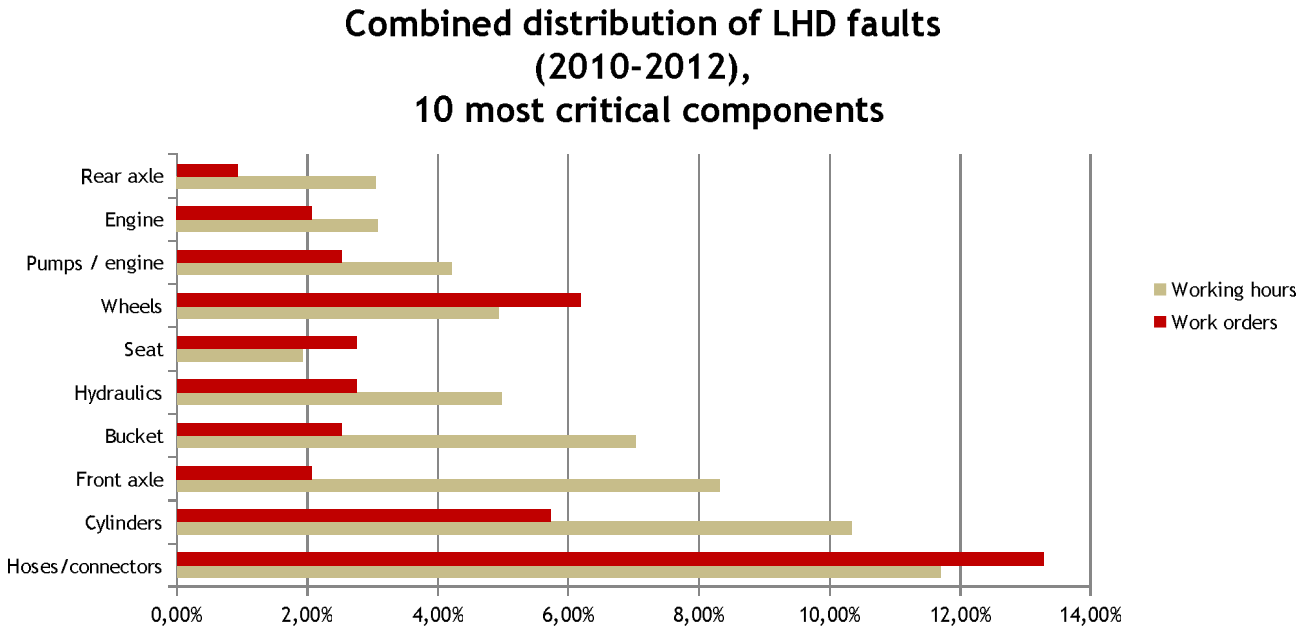
CRITICAL COMPONENTS OF LHD VEHICLES

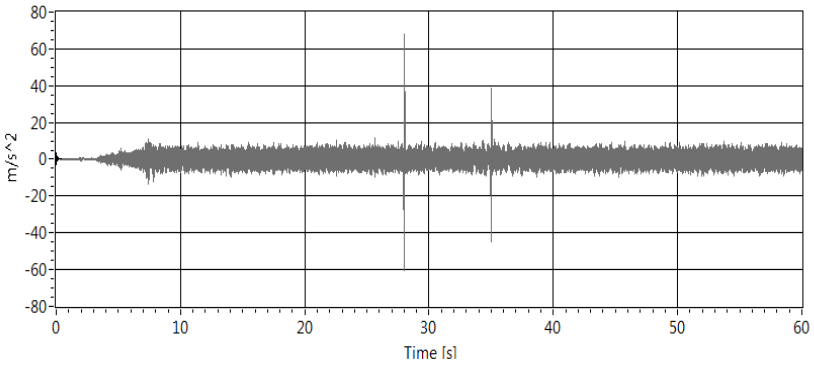


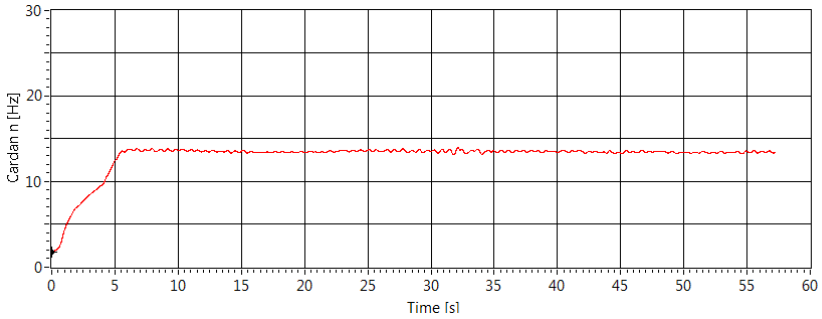
VIBRATION MEASUREMENTS

- A continuous measurement campaign produced exellent data from the front axle of a LHD in the Pyhäsalmi mine during the time period 4.2013 – 3.2015
- Measurements consisted of four externally mounted accelerometers (vertical and horizontal directions near the two planetary gearboxes) and a tachometer (speed of the cardan axle)
- Data was collected with a NI CompactRIO datalogger into a solid-state drive (SSD)
- The harsh environment of the underground mine resulted in several broken accelerometer cables and also two broken SSDs

VIBRATION MEASUREMENTS

- LHD moves at constant speed nearly every morning to its worksite
- Signals from these transition phases proved to be useful for condition monitoring





HÖLDER MEAN / GENERALISED LP NORM AND MIT INDEX

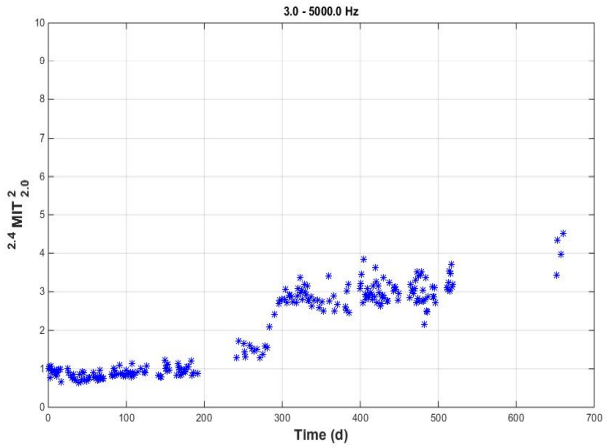
$$\left\|x\right\|_{p,1/N} = \left(\frac{1}{N}\sum_{k=1}^{N}\left|x_k\right|^p\right)^{1/p}$$

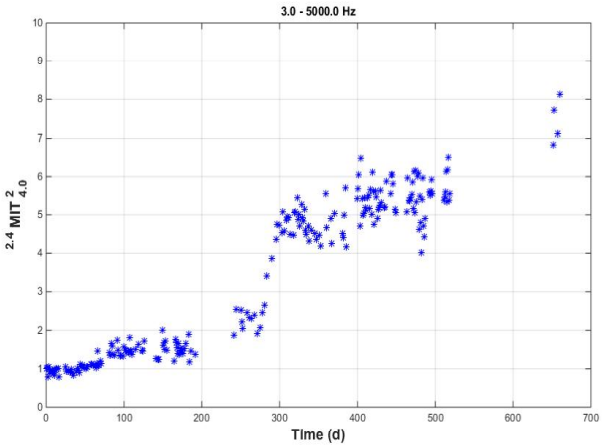
$$MIT_{z_1,z_2,\ldots,z_n}^{p_1,p_2,\ldots,p_n} = \frac{1}{n}\sum_{k=1}^{n} b_{z_k}\frac{\left\|x^{(z_k)}\right\|_{p_k}}{\left\|r^{(z_k)}\right\|_{p_k}}$$

- Order of norm: p
- Samples: N
- Order of derivative: z
- Reference signal (of good condition): ***r***

TREND ANALYSIS OF MIT INDICES

- Right vertical
- Differentiation improves sensitivity to changes in condition





TREND ANALYSIS OF MIT INDICES

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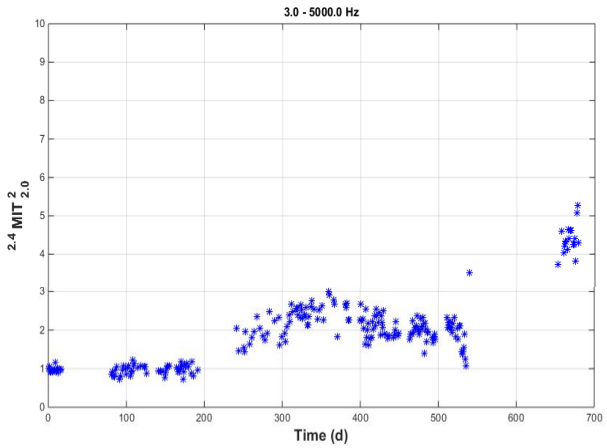
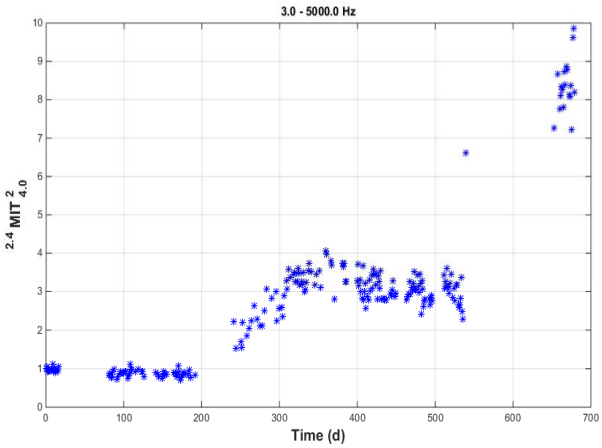
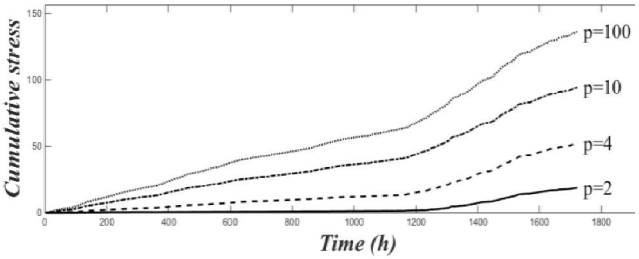
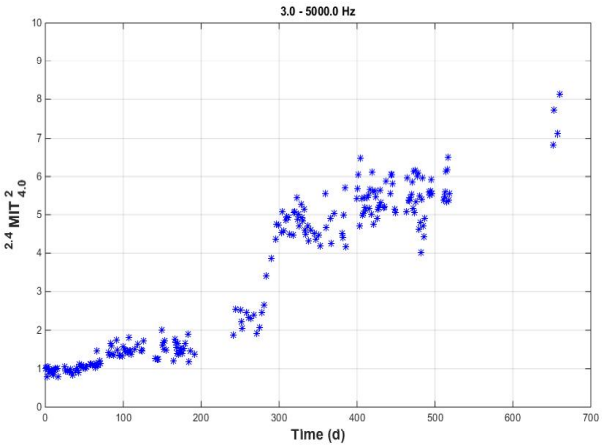




CUMULATIVE STRESS INDEX VS TREND OF MIT INDICES

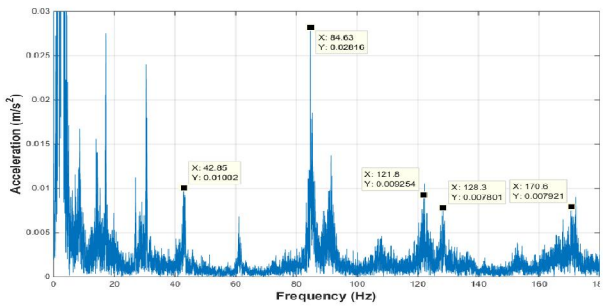
- Right vertical
- Cumulative stress is calculated from the whole work cycle for a period of 131 days (A.Koistinen, E.Juuso, 2015)
- Results are remarkably similar!

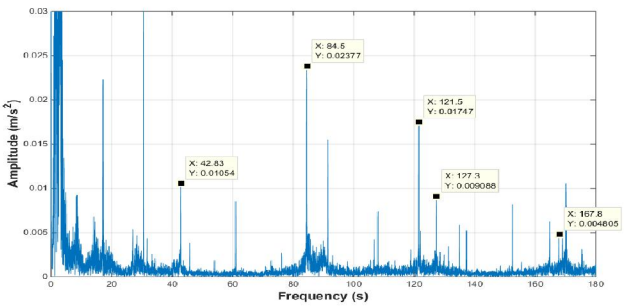




DIAGNOSIS

- Diagnosing the faults behind these changes in condition has proven very difficult
- Variable speed, changing terrain, structural resonances, etc..
- Angular resampling shows the discrete spectral components more clearly
- No clear trend for example for mesh frequencies has been found





CONCLUSIONS

- It is possible to effectively monitor the condition of critical components of LHDs, such as the front axle
- Protection for the accelerometer cables and a wireless data transfer system are needed for a final condition monitoring solution
- Calculations for the stress and MIT indices can be made in the data logger, which reduces data size considerably

- Future research: Combination of other process information (bucket load, oil temperature, etc..) with vibration measurements could provide more detailed knowledge of stress and condition of the axle

PUBLICATIONS

- A.Laukka et al: ”*Condition based monitoring for underground mobile machines*”, MPMM 2013, Lappeenranta, 12th – 13th September 2013
- J.Saari et al: ”*Applied methods of condition monitoring and fault detection for underground mobile machines*”, MPES 2013, Dresden, 14th – 19th October 2013 (will appear in the International Journal of Industrial and Systems Engineering)
- J.Nissilä et al: ”*Condition monitoring of the front axle of a load haul dumper with real order derivatives and generalised norms*”, CM2014/MFPT2014, Manchester, 10th – 12th June 2014
- A.Koistinen and E.Juuso: ”*Stress monitoring of Underground Load Haul Dumper Front Axle with Intelligent Indices*”, IFAC MMM, Oulu, 25th – 27th August, 2015