CHALLENGES IN MAINTENANCE OF VIBRATION MONITORING SYSTEMS DEDICATED TO UNDERGROUND MINING MACHINERY

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Summary

The paper presents practical considerations connected with implementation of vibration monitoring systems for the underground mining machinery. Technical aspects together with system scheme and functionality are presented. Factors influencing on maintenance and monitoring of the diagnostic system itself are discussed in relation to some examples of troubleshooting strategies. Mining industry specific aspects of monitoring systems including varying operating conditions of machinery and the requirement of ATEX compliance are presented. Certain factors influencing the vibration data connected with monitoring system maintenance as well as the methods of validation of vibration samples are examined. For example, an industrial system FAMAC VIBRO is presented as an implemented complex solution for vibration monitoring of mining machines.

Keywords: condition monitoring system, coal mining machines monitoring, vibration based diagnostics.

IMPLEMENTACJA I OBSŁUGA SYSTEMÓW MONITORINGU DRGAŃ DEDYKOWANYCH DO MASZYN GÓRNICTWA PODZIEMNEGO

Streszczenie

Artykuł prezentuje praktyczne zagadnienia związane z implementacją systemów monitoringu drgań dedykowanych dla maszyn górnictwa podziemnego. Zaprezentowane są aspekty techniczne związane z budową i funkcjonalnością wraz z czynnikami związanymi z eksploatacją i monitoringiem stanu samego systemu. Przedstawiono przykłady często występujących problemów wraz z propozycjami ich rozwiązywania. Omówiono również wymagania stawiane systemom monitoringu przez przemysł górniczy z uwzględnieniem zgodności ze standardem ATEX oraz ciężkimi warunkami eksploatacji jego komponentów. Przedstawiono walidację sygnałów drganiowych jako jeden ze sposobów weryfikacji poprawnego działania systemu. Omówione zagadnienia zilustrowano na przykładzie systemu FAMAC VIBRO – kompletnego rozwiązania do monitoringu drgań maszyn górnictwa podziemnego.

Słowa kluczowe: system monitorowania drgań, monitoring maszyn górnictwa podziemnego, diagnostyka drganiowa.

INTRODUCTION

Recent progress in automation, integrated electronic and IT solutions for underground mining industry has contributed to significant improvements in terms of productivity and economic operation of mines. One of the steps leading to enhancement of the machine availability and productive usage is implementation of reliable and trustable vibration based monitoring system and such trend is seen in areas connected with mining industry [8]. As the mining sector is very specific in terms of the machine operating conditions and the requirements for the applied hardware it is crucial to tune the condition monitoring systems to meet that criteria. Proper solutions for problems like the data transfer between consecutive levels of the system, signal validation, ATEX compliance of the electronic components are crucial when adapting such systems to work in mining environment.

1. CHALLENGES IN DEPLOYMENT

Implementation of successful vibration monitoring system in underground mining is not a trivial task. One of the factors contributing to that fact is that condition monitoring system most often has to be properly integrated with the infrastructure functioning on particular mine. This involves power supply, data transmission possibilities and topology of the mine. It is also common practice to integrate the condition monitoring system with the higher level mine monitoring and managing system [4] – like it is done with FAMAC VIBRO and e-mine® discussed in one of the following chapters.

Mining machinery - including conveyors, demands high amount of mechanical power to be transmitted with high gearbox ratios. Gearboxes often consist of multiple stages including the planetary gears. This contributes to the complicated kinematics of monitored drives and from the vibration monitoring perspective results in high amount of estimates to be calculated and traced simultaneously.

One of the limitations is always the number of the mounted sensors. From the diagnostic point of view more signals from particular machine is better. From the client point of view multiplying the sensor locations increases the costs and requirements regarding the data transfer throughput. As a result of compromise between those two criteria it is common practice to mount two sensors for conveyor drives – one dedicated to monitor input gear stages and another one on the output stage.

After selection of the sensors mounting points on the gearbox it is often important to design additional shielding components protecting them from accidental mechanical shocks.

To ensure the reliable path of the signal to the consecutive acquisition modules it is important to use a proper cable and protect it against corrosion and mechanical failure. A special attention has to be paid to selection of proper hermetic connectors. Also proper placement of the connections should be planned in such manner to enable dismounting and servicing of separate modules without cutting the cables.

Besides mechanical damage of the wires the influence of adjacent electrical equipment should be taken into consideration. Applying proper screening on signal cables is crucial in protection against electromagnetic interference.

2. CHALLENGES IN MAINTENANCE

Monitoring systems designed to improve maintenance of the machines should be treated with proper maintenance strategy itself. As the complexity of the condition monitoring increases the probability of possible malfunctions rises. These may lead to the conclusion that it is proper to introduce the concept of condition monitoring of condition monitoring systems. Such approach is especially needed for vibration based condition monitoring systems applied in mining industry. Maintenance of such systems should be planned at the design stage with consideration of the underground mining specific aspects. Planning of the maintenance of the vibration monitoring systems includes:

- managing the changes in the system structure in the way that not interrupts the current functioning of the system,
- ensuring the proper way to set the system parameters (for example: sample length, sampling frequency, measuring range and sensitivity) without corrupting the integrity of the collected data,
- organizing the system structure in the way that enables robust identification of the components that are not functioning properly.

One of the challenges in vibration condition monitoring of the mining conveyors is integration of the vibration data with information about the machine operating conditions and changes applied to whole asset. For example – mining conveyors drives location changes as the wall system progresses which may influence on the vibration signal. Shortening the conveyor influences the load present in the drive. When abovementioned information is included it builds certain context that should be considered during the decisions about the failure preventive actions.

3. ENSURING QUALITY OF VIBRATION DATA

All concepts and algorithms used in vibration based condition monitoring assume that vibration samples are valid and not corrupted by means of sampling, value range, sensor condition etc. It is natural to assume such conditions in research and well supervised deployment stage of implementation of the system, but experiences show, that approach taken when using system for long time should be different.

To ensure the good diagnosis regarding the machine state in changing operating conditions and limited possibilities of visual inspection of the system by qualified personnel - which is often the case in underground mining industry, it is crucial to deploy consistent and robust signal validation policy.

Target of validation is to extract the correct signals from samples collected by monitoring system. Correct signal is considered as signal that truly represents the machine behaviour. It is presented by acceleration, velocity and displacement waveforms and those waveforms should contain the expected frequency contents. For small datasets it is common to perform validation by using experience of the qualified engineer who can assess the signal validity visually. When it comes to large amount of data produced by complex industrial monitoring systems such approach is inefficient. This generates demand for automation and development of algorithms that are capable of detection of certain aspects of signal invalidity. Those algorithms called rules may be divided in certain groups. Those involve amplitude validation rules where examples of the most robust are [6,7]:

- **Minimum energy rule** – which states that recorded signal should contain minimum level of energy to be considered as valid. This rule can be expressed by RMS value as follows:

$$E_{RMS} = \sqrt{\frac{1}{N}\sum_{1}^{N} x^2[n]} > T_{MinE\_RMS} \quad (1)$$

Use of RMS value instead of energy normalizes the estimator taking into account signal length.

- Perseval's theory based **Energy Conservation Rule.** This rule defines constraints on the difference between signal energy calculated in time and frequency domain. Because of effects specific for digital signals such difference may occur. This rule may be expressed also with use of RMS value:

$$Abs\left(1 - \frac{timedomainERMS}{frequencydomainERMS}\right) = abs\left(1 - \frac{\sqrt{\frac{1}{N}\sum_{i=0}^{N-1} x[i]^2}}{\sqrt{\frac{1}{2}\sum_{k=0}^{N/2}\left(\frac{2}{N}X[k]\right)^2}}\right) < Thres\_P \quad (2)$$

- **N-point rule** – the result of this algorithm is the maximum number of consecutive samples having the same value
- **U-point rule** – indicator of the number of unique values in the signal
- **Z-point rule** – maximum number of consecutive samples having the same sign

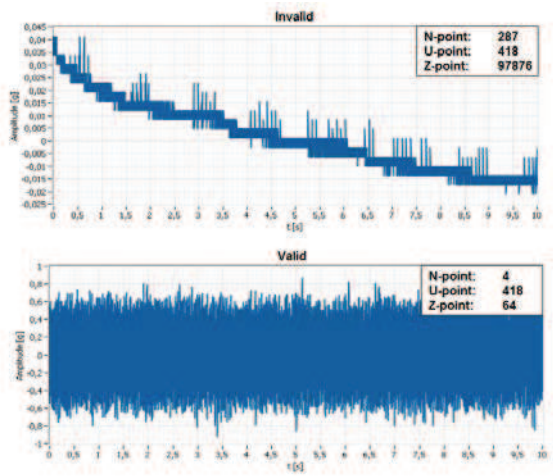

Fig. 1. Examples of invalid and valid signal and results of validation algorithm performed on the samples. Signal recorded by real system deployed in underground mine

As an example of use of these methods to distinguish valid and invalid signals comparison is provided on Fig. 1. It can be clearly seen that invalid sample contains no useful information about monitored machine. The cause of the signal shape may probably be some electrical interferences present during the acquisition. Overall low level of the signal indicates that monitored machine was on idle state. As the comparison of results of validation rules show, it is possible to discard invalid sample by proper setting the limits of the rules output values.

4. ADVANCED SIGNAL ANALYSIS

Most of the progress in vibration signal analysis for machine diagnostics was made in the area of stationary conditions of machinery operation. In mining machines fluctuation of load causes changes in rotational speed and such behaviour of these two parameters makes the process of diagnostic reasoning more difficult. As Fig. 2 shows, conventional vibration estimates values are sensitive to load and speed. Fig. 3. presents additionally that not only is the value of rotational speed important, but in some cases also its direction. Such relation may be specific to particular gear and depend on its geometrical properties and assembly factors.

According to abovementioned facts there is a need of development of advanced signal processing methods allowing to diagnose machine state with consideration of the variability of operational parameters.

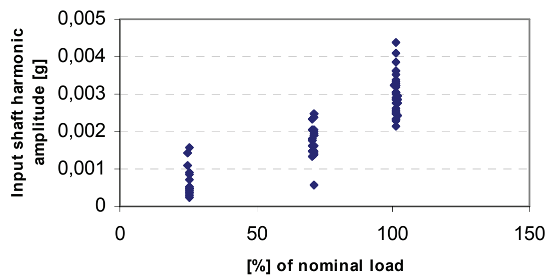

Fig. 2. Correlation between input shaft harmonic amplitude and load obtained for high power gearbox dedicated for conveyor drives

To deal with the rotational speed fluctuations order tracking is introduced. In many cases where there is no possibility of installing a tachometer probe the tacho signal needed for order tracking has to be extracted from vibration data. Methods of speed reconstruction can be based for example on time-frequency analysis or phase demodulation techniques [2, 9].

Besides methods for rotating speed information extraction certain progress was done in the area of the reconstruction of load level information present in vibration signal. Some algorithms use amplitude demodulation of meshing components to obtain the load profile and then perform normalization of the signal [11]. As the load causes speed fluctuation, the amplitude of components used for demodulation can also change due to the shape of system frequency response function. To overcome this, another method was developed introducing the IP (Instantaneous Power) which reflects the global amplitude modulation effects caused by load [5].

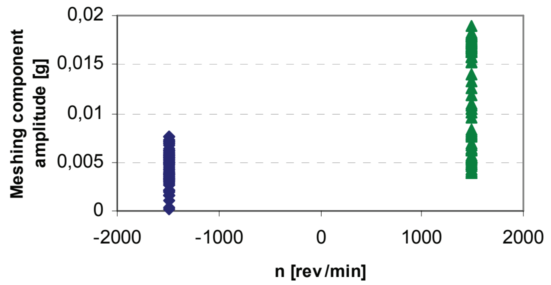

Fig. 3. Differences between meshing component amplitudes for different speed direction

Besides efforts of normalisation there are methods based on grouping the vibration data into clusters containing the same operational state of machine. Those methods can be based on data mining algorithms [3]. After clustering one can assure that vibration estimates are trended within one operational state of machine.

5. DESCRIPTION OF EXEMPLARY SYSTEM

As an example of the vibration based condition monitoring system dedicated to mining machinery FAMAC VIBRO system (Fig. 2.) will be discussed both with its general hardware and software aspects.

FAMAC VIBRO is a part of the supervisory system managing the coal extraction process called e-mine® and it is component responsible for monitoring of gearboxes, conveyor drums and shearer loaders [5]. System consists of three levels:

- Underground visualization,
- Surface visualization,
- Service provided by FAMUR's Diagnostic Center.

Core component of the e-mine® system is the Green Diamond – underground server designed to coordinate processes assigned to the local station – FAMAC LS. Such approach results in architecture allowing to monitor machines located in big distances like it is in the sequence of conveyors. Besides the Green Diamond other parts of the system are [5]:

- LS FAMAC VIBRO – underground local server dedicated to collecting, processing and presenting the data. Its main function in to transfer data to the Green Diamond and also to the other supervisory systems to ensure the adequate response when warning or alarm is present,
- LB FAMAC VIBRO – this is the component used in extended systems for collecting data and transferring it to local station,
- RS/OPTO converter - is the component providing signal conversion to fiber optic.
- Intrinsically safe data hub,
- Accelerometers compliant with the explosive atmosphere requirement,
- Temperature sensors.

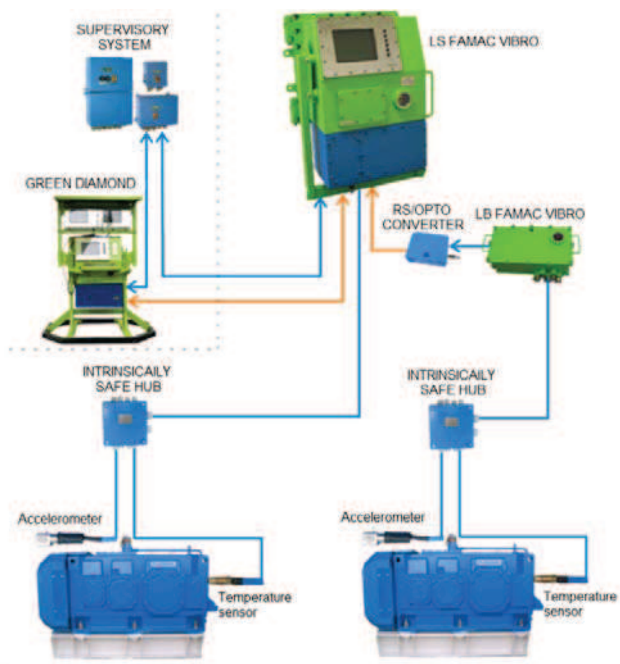

Fig. 4. Architecture of the system

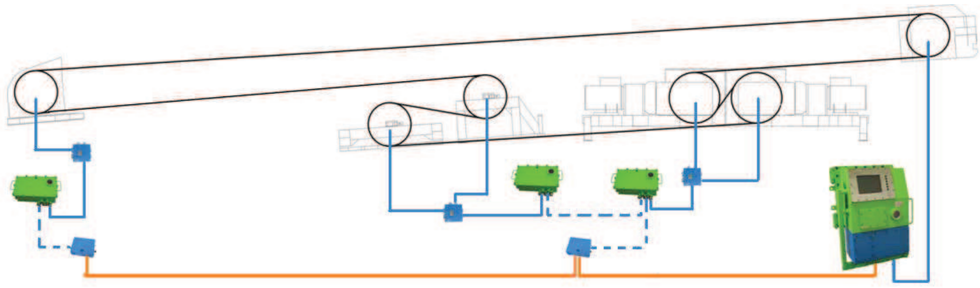

Fig. 5. System scheme for belt conveyors

Signals collected from the machines including vibration and temperature are transferred to the local station. Optical fiber is used at that stage to ensure ATEX compliance. Such approach also provides high data transfer rate which is crucial in sending raw vibration samples collected by the system [8]. Besides raw vibration data certain estimates are calculated by dedicated software module basing on the machine kinematics and are written to the database. Integration with the e-mine® system enables to correlate the vibration data with the state of certain assets.

Analyses performed on the signals are separated in two levels. First – standard level is implemented on software included with systems itself. It contains robust and basic analysis including RMS and Peak-to-Peak values giving the information about general condition of machine. Second level of analysis is provided by Diagnostic Center.

Precise vibration based diagnostics of mining machines requires more advanced methods. Recent developments in that area showed importance of aspects as signal preprocessing for local damage detection [10] or optimum methods for demodulation band selection [1].

Analysis and research on that areas and are conducted by Famur's Group Diagnostic Center.

6. CONCLUSIONS

Deploying and maintaining a vibration based condition monitoring system on underground mining machinery is complex task. The advantages of preventive maintenance including the reduction of the production downtime and protecting the machines against catastrophic failure cause, that number of mines implementing such systems on their assets increases.

One of the examples of successful implementation of vibration based condition monitoring system in underground mine is FAMAC VIBRO system deployed in KWK Wieczorek. System has over two years of service. Many issues connected with hardware design of the system and standard online vibration analysis have been solved so far.

Increasing interest of potential clients contributes to development of new generation of solutions. However there is still a lot of uncovered ground in the area of optimal diagnostic methods selection especially when taking into account influence of variable operating conditions.

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