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State of art in vibration monitoring systems dedicated to underground mining machinery

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Abstract

Vibration based monitoring systems start to play increasingly important role in underground mining machinery diagnostics. Authors describe current situation on the market in area of systems available to use in underground coal mine. Technical aspects with the systems scheme and functionality are presented. Additionally mining industry specific aspects of monitoring systems are discussed including limited possibilities of direct and visual supervision of system components, varying operating conditions of machinery and the requirement of ATEX compliance. Additionally authors describe experiences with deployments and test in underground mining industry. Summary shows state of the art and proposed directions of development in the area of vibration monitoring systems dedicated to underground mining machinery.

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

Przegląd dostępnych rozwiązań systemów monitoringu drgań maszyn pracujących w podziemiach kopalń

Streszczenie

W artykule zaprezentowano zestawienie dostępnych na rynku systemów monitoringu drgań maszyn przeznaczonych dla górnictwa podziemnego węgla kamiennego. Na podstawie dostępnych informacji przedstawiono zarówno parametry techniczne opisywanych systemów jak również ich możliwości pomiarowe. Dodatkowo w artykule przedstawiono szczególne wymagania, które muszą spełnić systemu przeznaczone dla górnictwa podziemnego ze szczególnym uwzględnieniem ograniczeń technicznych oraz wymogów dyrektywy ATEX. W podsumowaniu autorzy zaprezentowali doświadczenia i problemy związane z wdrożeniami tego typu systemów. Na tej podstawie zaproponowane zostały kierunki dalszego rozwoju systemów monitoringu drgań dla górnictwa podziemnego węgla kamiennego.

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

1. Introduction

Vibration monitoring is now a standard in many branches of industry where maintenance of rotating machines is involved. As vibration monitoring solutions became mature and well tested in many applications like wind turbines, paper-mills and stationary conveyors there is still need to adapt this technology to underground mining conditions. Both research work and industrial implementations of vibration monitoring systems gave some success but with certain limitations what is discussed in 3rd Chapter.

Competition on the market drives the development of vibration based monitoring systems but the rate of change is relatively low compared to other markets (e.g. wind turbines). Some of the problems discussed in this paper are now solved but there is still much space and demand for further development.

2. Need of vibration monitoring

Before implementing vibration monitoring it is always crucial to answer the question – what it can give in terms of increase of productivity and decrease of repair costs and downtimes. This also helps in choice whether to use simple periodic monitoring with hand held devices or is it worth investing in online monitoring system.

There are two main reasons for applying condition monitoring systems - increasing safety and reduction of costs. To estimate the economic benefits connected with applying vibration based condition monitoring on coal mining conveyors, authors performed rough calculation based on following assumptions (derived for polish coal mine industry):

- there are 2-3 longwall faces per level
- minimum coal price in 2014: 65€
- mean coal extraction from face: 3000 T/day (which means about 9000 T per day from level)
- there are about 70 main haulages in polish underground mining

Calculation:

- daily value of extracted coal from face: 3000T x 65€ = 195 000€
- daily value of extracted coal from level: 9000T x 65€ = 585 000€
- cost of 1 day downtime for all main haulages in polish coal mines: 70 x 585 000 = 40 950 000 €

Conclusions:

Experiences from other branches of industry where vibration based condition monitoring is present for a long time show that it gives possibilities of significant downtime reduction. As calculation performed by authors proves, in underground mining industry downtimes costs are significant and it is economically reasonable to implement vibration monitoring systems.

3. Challenges and limitations in underground mining systems

Standard vibration monitoring relies on repeatability of measurement conditions both in terms of machine environmental and operational state. Those factors are very dynamic in underground mining machines and it makes validation of measurement samples critical task. This creates two conflicting demands – low power consumption and limited resources due to ATEX requirements and additional processing for machine state discrimination and analysis.

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.

Another limitation is always the number of the mounted sensors. As a result of compromise between diagnostic and economic criteria it is common practice to mount as small number as it is possible for particular monitored object.

Additionally system have to be rugged, signal paths should be properly shielded and sensors and whole cables should be protected against mechanical damage.

Because of hard environmental conditions and often problems with direct access to hardware components systems should have feature for remote configuration and management. Moreover one of the most important feature of systems should be scalable architecture. In underground mining often distances between monitored objects are long and number of monitored points per one machine may vary.

Above facts are reason for problems with monitoring systems based on hand hold hardware and periodical measurements.

4. Available ATEX solutions

Despite difficulties in complex vibration monitoring of machines operating underground, market offers solutions dedicated for that area of maintenance. Exemplary systems from the biggest underground mining equipment suppliers are presented in this chapter.

4.1. FAMAC VIBRO

FAMAC VIBRO is a part of the system called e-mine developed by FAMUR GROUP. It is a supervisory system managing the coal extraction process. FAMAC VIBRO is component responsible for monitoring condition of gearboxes, conveyor drums and shearer loaders [1, 2]. System consists of three levels:

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

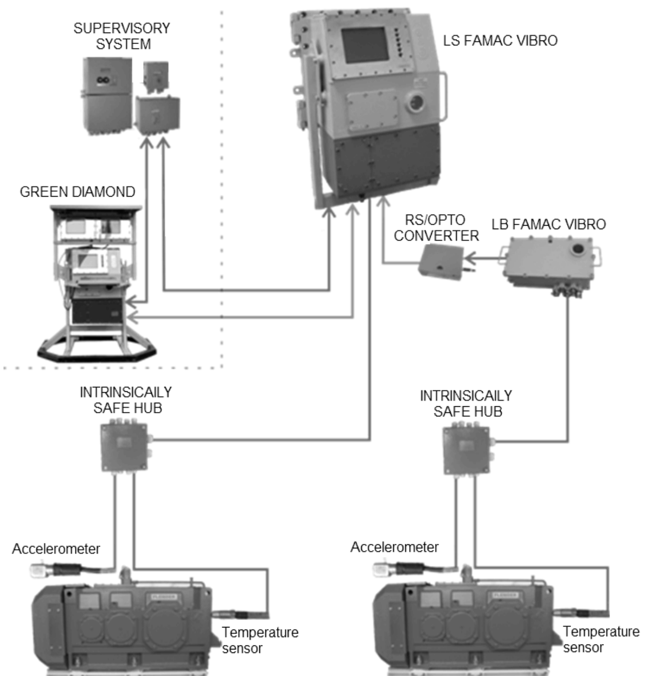

Fig. 1. Architecture of FAMAC VIBRO system
Rys. 1. Architektura systemu FAMAC VIBRO

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:

- LS FAMAC VIBRO – underground local server dedicated to collecting, processing and presenting the data from up to 16 channels. 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 from up to 8 channels 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.

Above facts are reason for problems with monitoring systems based on hand hold hardware and periodical measurements.

One of the biggest implementation of this systems was monitoring of haulage in KWK Wieczorek mine in Poland. Gearboxes and drums of belt conveyors were monitored for a distance of above 10 km.

4.2. Vibraguard

Bucyrus released their vibration monitoring system called Vibraguard with cooperation with vibration experts from DMT developers of MineSafe® [3]. Core hardware component is PMC-D20 controller that enables to monitor up to 8 vibration channels. Embedded processing unit converts incoming acceleration data into spectrum data which is then transferred to dedicated PC. Additional Vibraguard Software enables visualization of vibration parameters on remote locations. This solution enables only monitoring through Bucyrus compatible components.

First installation of the system was at Arch Coal's West Elk mine in Colorado and covered an AFC system, BSL and crusher.

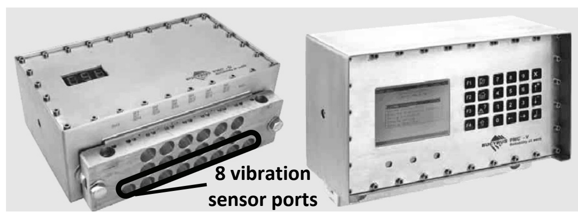

Fig. 2. PMC-D drive control with vibration monitoring (on the left) and PMC-V dedicated for visualization
Rys. 2. Sterownik PMC-D (po lewej) z modułem drgań, moduł wizualizacyjny PMC-V (po prawej)

4.3. SKF & KES

One of the solutions for vibration monitoring for underground mining machinery is adapting standard system available for non ATEX zone. Such approach can be seen in EH-Wibro developed by Kopex Electric Systems (Kopex Group) on top of SKF Multilog hardware and @ptitude software package. Main hardware component is EH-O/06/07.xx based on IMx-S system by SKF [4].

In this solution results of the analysis are then sent to the data server with the @ptitude Observer Monitor application software installed on it. The data can be made available to other systems. The acquired information is also used by the @ptitude Observer Client software that is installed on surface workstations

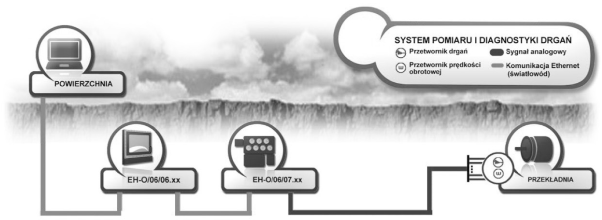

Fig. 3. Exemplary architecture of EH-Wibro system implementation
Rys. 3. Przykładowa architektura systemu EH-VIBRO

4.4. ACARP work

Besides commercial systems vibration monitoring is also applied as a research project in new areas. Example of such work is ACARP project called ”Condition Monitoring and Fault Detection of Longwall Shearer” conducted in Australia [6]. One of its goals was to develop a vibration datalogger suited to longwall shearer mounting in flameproof enclosure and collection of vibration data from shearer ranging arms and provide tool for vibration diagnostics of critical bearings. The data collection hardware called IS Logger and diagnostic software ShearerMon are presented in Fig. 4.

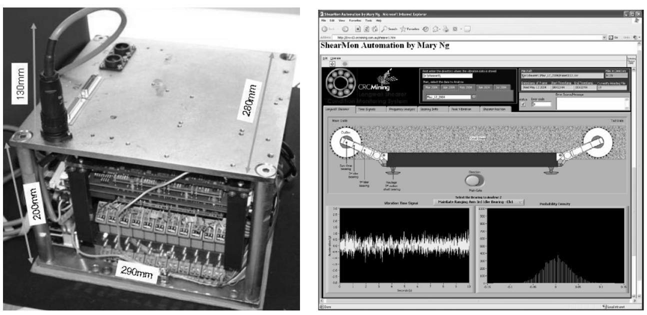

Fig. 3. IS Logger and ShearerMon software
Rys. 3. System IS Logger (po lewej), oprogramowanie ShearerMon (po prawej)

Trials involving data logging during normal operation of the shearer where conducted. Six vibration channels where collected at sampling frequency of 1000 Hz. Sensors where mounted symmetrically – 2 accelerometers per arm and 1 per haulage drive. Data was analyzed in terms of diagnostic information about bearings. Analysis applied to signals showed that operating conditions – especially rapidly changing load during cutting – makes vibration diagnostic very difficult. It was concluded that vibration monitoring system has to be equipped with logic to determine states where shearer arms operate at stable no-load conditions to collect and analyze data at comparable conditions.

4.5. FAG Procheck

Another approach is to use non ATEX compliant system places in non-hazardous (in ATEX meaning). Such solution was implemented in KWK Marcel mine (Fig.5.) . System is based on top of FAG Procehck hardware and software [5]. Monitored gearboxes are placed in hazardous area. ATEX sensors are connected with acquisition modules through ATEX barriers.

This solution is relatively simple to implement, allows to use high-end hardware which allows to use more computing power. One major limitation is fact, that signal IEPE (ICP®) analog signal is transmitted for long distance. Industrial practice shows that maximum length of analog signal paths should not be longer than over a dozen – tens meters. Due to this facts this solution is limited practically to incline belt and cannot be used in most underground coal mines.

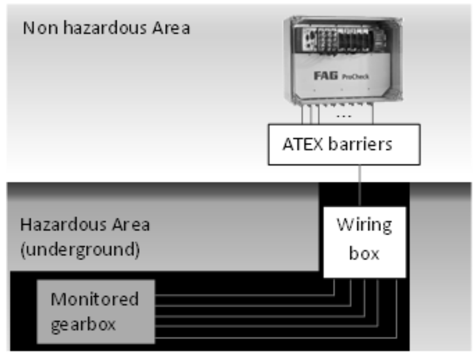

Fig. 5. Scheme of solution implemented in KWK Marcel
Rys. 5. Schemat rozwiązania wdrożonego w KWK Marcel

5. Summary

Review of vibration monitoring in underground mining presented in the article leads to certain conclusions about this specific area. Two main of them are that there is demand for vibration monitoring in underground mines and successful implementation of such monitoring in underground conditions is very difficult task.

Data acquisition hardware has to be equipped with temporal data storage capacity to prevent against data loss in case of communication problems.

Number of channels per data acquisition unit has to be carefully planned during development because in underground conditions using long cables for analog signals is not recommended due to electromagnetic interference problems.

Systems have to be equipped with data validation and state selection logic to perform analyses on valid and comparable data.

Raw vibration data collection besides vibration estimates and frequency spectrum is desired because of the ability to custom analysis and knowledge gain about machine dynamics.

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