APPLIED REMOTE CONDITION MONITORING OF THE BUCKET WHEEL EXCAVATOR

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Abstract. This paper presents all the benefits of the remote condition monitoring as well as some basic guidelines for its practical implemntation.Remote online monitoring, based on strain and vibration measuremenst of the bucket wheel excavator is given as a practical example of this approach implementation.

Keywords.Vibration, strain, condition measurement, remote monitoring

INTRODUCTION

Most of the today's maintenance managers are continuously seeking new methods and tools that can enable them "to do more with less" in order to enhance and improve a company's existing Maintenance, Repair and Operation (MRO) programs. Referred to as "remote condition monitoring and diagnostic systems," such technologies can help them to cut overall production costs, improve quality, minimize downtime and increase operational efficiency. Thanks to the internet, new diagnostic tools for vibration signal analysis and high speed communication networks, vibration specialists can acquire vibration data not just from on site but also remotely, using internet.

Machine uptime increase i.e. minimization of number of equipment failures is the crucial element for maintaining and raising the productivity of every plant. Failures with random occurrence cause huge losses of production capacity. In some cases these types of failures can lead to the losses of human lives too… Therefore the implementation of some type of maintenance strategy with the purpose of monitoring the operating condition of machine is an absolute must.

There are several different approaches in monitoring the operating condition of machine:

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1. CURATIVE maintenance i.e. "run to failure maintenance" and
2. PREVENTIVE maintenance which can be divided into:
   - Systematic i.e. time based maintenance. Also known as resource based maintenance
   - Condition based maintenance (CBM). It is based on monitoring of specific parameter which directly corresponds to the operating condition of the machine/equipment. Mechanical vibration is one of the best candidate for such a parameter. Condition based maintenance has three complementary levels of implementation:

Protection Surveillance Diagnostic

From the point of data acquisition and analysis periodicity, systems for machine protection, monitoring and diagnostic can be:

1. OFFLINE SYSTEMS: systems for periodic maintenance of machines mean periodic data acquisition and analysis based on time base determined by the vibration specialists and responsible maintenance managers. Periodicity of data acquisition and analysis should be highly dependent on the current vibration levels on the machine.
2. ONLINE SYSTEMS: permanently installed systems for vibration signals acqu-

isition and analysis. Protection system must be an online system.

Above mentioned techniques have their advantages / disadvantages. They can be evaluated from the point of investments and return of investments ratio. Choosing the proper technique requires some analysis of the type and purpose of the monitored machine (Figure 1). For example critical machine requires an online monitoring system with protection, surveillance and diagnostic functions. On the other hand, condition monitoring of simple machines like pumps or fans can be based on portable handheld vibration analyzers and periodic measurements and analysis.

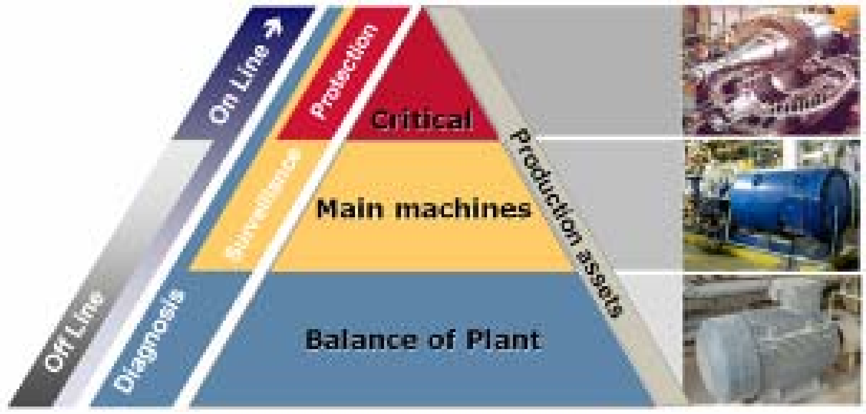

Figure 1. Different approaches to condition based maintenance for different equiment in the plant

Also when choosing the proper maintenance approach for a specific machine group, some additional elements should be evaluated too. This vindicates the concept of remote condition based monitoring. Despite the traditional condition based maintenance methods guarantee the total production improvement through the reduction of maintenance costs and maintaining the invested capital, the basic request for an on site presence of qualified personnel can be sometimes very expensive… Let us take as an example an online monitoring of critical equipment. The price for a multichannel protection and diagnostic data acquisition online system (measuring device + sensors + cables + PC + software + …) can be quite high. On the other hand, if the plant already installed the system on site, the need for further investments is still present: highly skilled and educated vibration specialists are necessary for vibration data analysis, and in the case of offline systems for on site data acquisition too. Well trained and skilled personnel must be present on site. The investments required for the mentioned personnel engagement can be analyzed from an additional point of view, especially in the cases where the company doesn't have plants centralized in one region. We can see an ongoing trend that big multinational corporations have plants all over the world. In order to cut the production costs through the reduction of workers and also through engagement of cheaper working power, big companies tend to physically (geographically) divide the management and administration from the production. They are moving their production in the different parts of the world where they can find cheaper working power. Unfortunately, as a consequence, these structural changes, raise the costs of traditional on site condition based maintenance implementation. As a result a new approach in condition monitoring of machines using internet technologies arise: REMOTE CONDITION MONITORING OF MACHINES. Here the traditional on site maintenance (physical on site presence) is replaced by the web based maintenance of equipment. The main benefit of a computer network, compared to the old fashioned way of on site data collecting, is fast and cheap data acquisition and data transfer from one place to another. By including a high speed computer network into a vibration monitoring system, vibration signals can be transferred into a specific database. Using this database maintenance managers and vibration specialists have a real time insight into a machine condition. Web based condition monitoring can be applied to both offline and online monitoring systems. However it is much more present in online systems since the web based monitoring in the case of offline systems mean only remote database and vibration specialists while some presence of maintenance personnel on site is still required for the purpose of vibration data collecting.

Figure 2 presents one of many schemes for monitoring of distant machines. These machines can be monitored offline or online. Critical machines are equipped with online systems for permanent monitoring which are using TCP/IP protocol for communicating with the database. On the other hand, we are using offline monitoring techniques for the machines which belong to the machine group for balancing the plant (non critical machines). These techniques are based on periodical (one per month for example) data collection and analysis. In the distant diagnostic centers (01dB-Metravib centers or TRCpro) highly skilled and educated vibration specialists are analyzing the acquired data, make the reports and suggesting all the corrective actions on the machines.

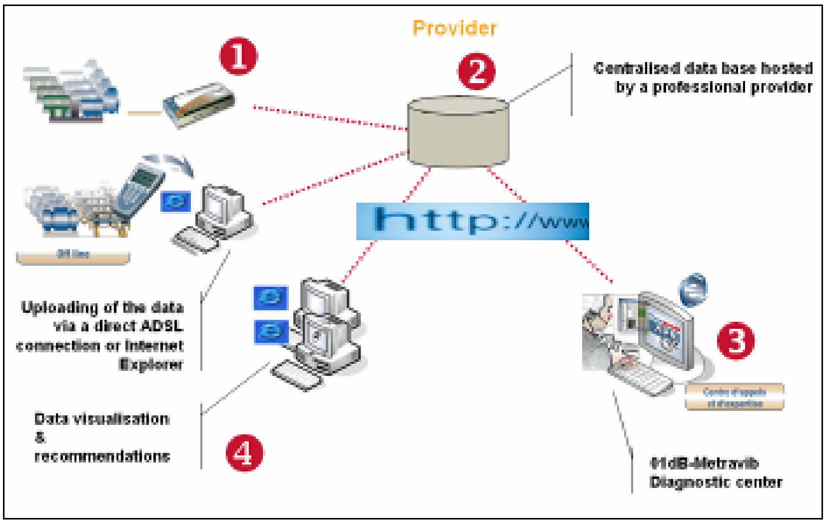

Figure 2. One possible configuration for the web based condition monitoring

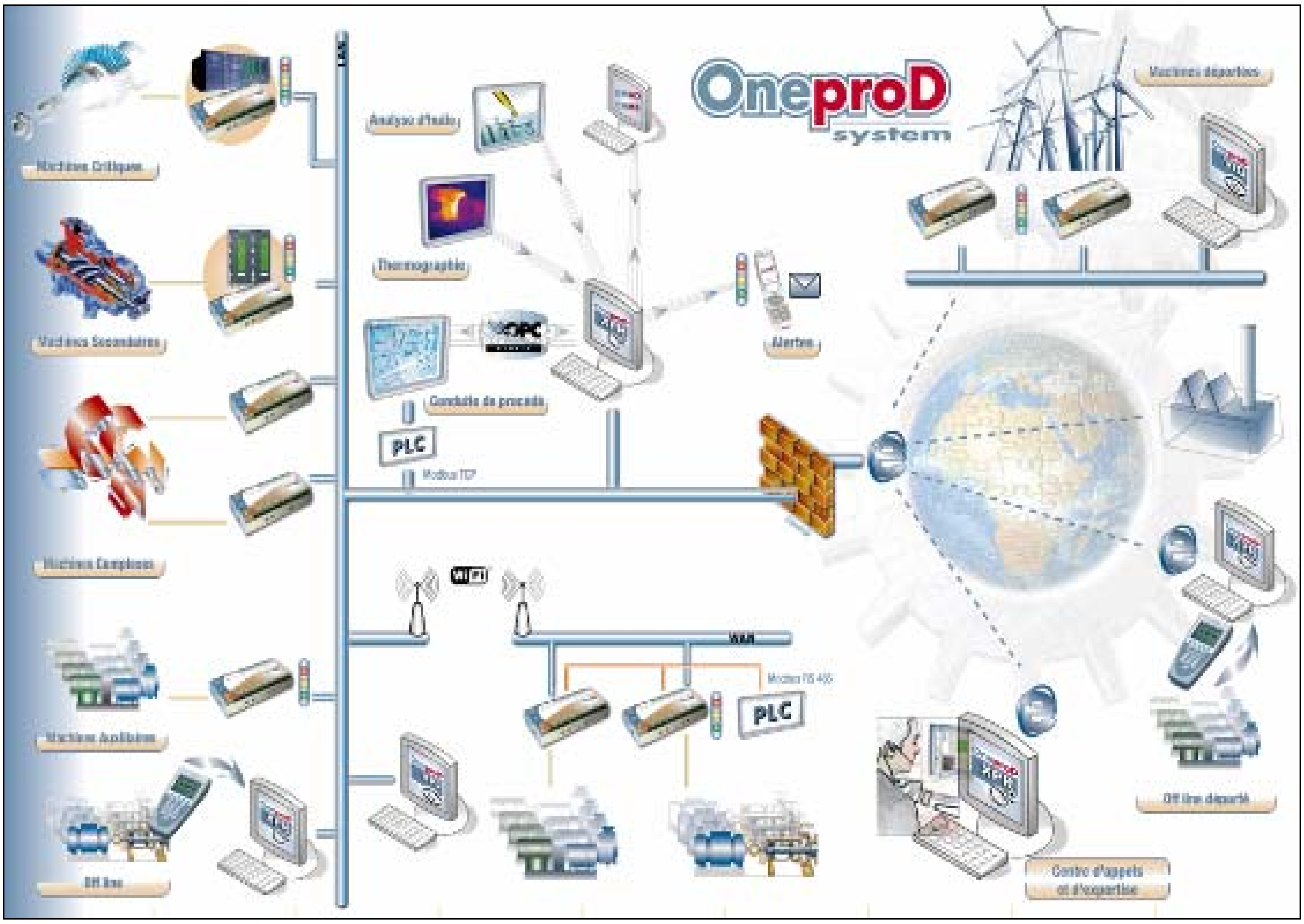

Figure 3.OneproD concept of 01dB-Metravib, AREVA

COMMERCIALY AVAILABLE REMOTE MONITORING SYSTEMS

The company that made maybe the biggest achievement in the development and implementation of remote web based condition monitoring systems is the French company 01dB-Metravib, member of the AREVA group. This web based condition monitoring is the part of their integrated concept of predictive/proactive maintenance named OneproD system.

OneproD system is a concept of condition based monitoring where the multytechnique approach is emphasized. The operating condition is monitored and analyzed using: vibration, oil analysis, motor current signature analysis (MCSA), infrared thermography, process values measurement (temperature, flow…) etc. It is a global offer of expertise and diagnosis, engineering and commissioning, products and related services.

There are many possible ways of OneproD concept implementation: both in offline and online mode, both in traditional and remote mode, using vibration analysis, oil analysis, OPC communication etc, as shown o Figure 3.

For the purpose of web based online monitoring of remote machines the following parts of the OneproD concept are used:

1. OneproD MVX multichannel system
2. OneproD XPR 300 predictive maintenance software with the online option included and Web server installation

OneproD MVX is a PCP/IP based modular system composed of 8, 16, 24 or 32 channels in a single housing. The fact that the system can perform a strategic acquisition (activates measurement and analysis only upon the predefined operating condition occurrence) in combination with an advanced programming capabilities of operating parameters makes this system possible for on site and remote monitoring and diagnostic of complex critical machines. OneproD MVX accepts all types of commercially available sensors (IEPE accelerometers, velocimeters, proximity probes, LVDT, temperature sensors, oil condition sensors etc), voltage and current inputs. It also includes a large number of onboard processing functions for most advanced vibration diagnosis of rotating machines equipped with ball bearings and journal bearings.

Figure 4. OneproD MVX multichannel online monitoring system

Figure 5. SRs 1300.24/2.5 (Glodar 10) bucket wheel excavator

Thanks to the strategic modes of acquisition and TCP/IP and RS485 based communication protocols MVX system can be used for:

1. Conditional acquisition and monitoring of vibrations
2. Standalone monitoring of machines
3. Remote monitoring of distant machines (oil platforms, wind turbines, remote plants etc.)

Suprevsion of vibration and process parameters

CASE STUDY: ONLINE CONDITON MONITORING OF A BUCKET WHEEL EXCAVATOR

Remote condition monitoring is successfully implemented in Serbia on a bucket wheel excavator SR1300.24/2.5 in a Kolubara coal mine.

This project was initiated by Technical Research Center TRCpro and Kolubara Metal. The main motivation for the above mentioned concept implementation were the facts that this excavator:

1. Is a highly critical machine for the coal mine production
2. Experiences high levels of dynamic loads. The designers of the excavator didn't take into account these loads when designing the excavator i.e. the levels of these dynamic loads are much higher than the declared loads.

Therefore a combined system of remote monitoring was proposed and installed. The proposed monitoring system monitors not only vibration signals but also stresses and strains in the critical parts of the excavator's construction. The strain measurements are done using strain gauges while the vibration measurements are based on IEPE accelerometers. Measurement points (both vibration and strains) are shown on the Figure 6.

Figure 6. Measurement locations for strain (red circles) and vibration (yellow circles) measurement

Measurement points for the strain measurements are:

1. Holders of the bucket wheel arms:
   2 measurement points
2. Bucket wheel arms (left side):
   6 measurement points
3. Bucket wheel arms (right side):
   6 measurement points
4. Main column (left side):
   6 measurement points
5. Main column (right side):
   6 measurement points
6. Rotating platform:
   12 measurement points (4 rosetes)
7. Counterweight holder:
   8 measurement points

On the other side, the vibration are measured on the following drives

1. Bucket wheel drive with a gearbox :
   5 radial vibrations and a tacho

2. Rotating platform drive and a gearbox (left and right drives): 10 radial vibrations and a tacho
3. Conveyer belt drive and a gearbox: 5 radial vibrations
4. Drives and gearboxes for the bucket wheel elevation (2x) : 10 radial vibrations

Also the elevation angle of the bucket wheel holders is measured by an analog inclinometer. For the acquisition triggering i.e. for the definition of the operating conditions, digital inputs of the MVX are used:

- *Digital input #1 – bucket wheel drive gripe*
- *Digital input #2 – rotating platform drive gripe*
- *Digital input #3 – elevation drives gripe*
- *Digital input #4 – mowing detection (detection of direction changing left-right and right-left)*

When the digital inputs are in the high level state and when the rotating speed of the drive is above 600 RPM a predefined acquisition and analysis is initiated.

Vibration parameters for monitoring of the drives operating states are:

SCALAR (overal values) parameters:

- *RMS level of vibration velocity according to the ISO 10816*
- *Overal level of vibration acceleration*
- *Defect factor for the ball bearing state evaluation (Defect factor – 01dB patent)*
- *Kurtosis factor*

VECTOR values (signals):

- *Frequency spectra 2 - 200 Hz, 3200 frequency lines*
- *Frequency spectra do 2 - 2000 Hz, 3200 frequency lines*
- *Frequency spectra do 2 - 20000 Hz, 3200 frequency lines*
- *Time waves 0 - 2.56 kHz with 4096 points*

The measurement hardware of the monitoring system is consisted of the above mentioned OneproD MVX in a 32 channel version and of the universal measuring amplifier HBM MGCplus in a 40 channel version. Both measuring systems are TCP/IP based and are connected to the excavator's local local area network. On the same LAN, the dedicated data server with OneproD XPR 300 and HBM CatMan 5.2R5 sofwares installed is connected and placed in the operator's cabin. OneproD XPR software is responsible for the vibration data analysis while the CatMan software acquires and analyzes the strain measurement signals. Local area network from the excavator is, over the dedicated Wireless system, connected to the first AP (access point) which is located at the periphery of the mine. This AP is, using wireless local area network (WLAN), connected to two client computers. One client PC is for the Kolubara metal maintenace group while the other one is for the vibration specialists from TRCpro. Simplified scheme of the described system is shown on the Figure 7.

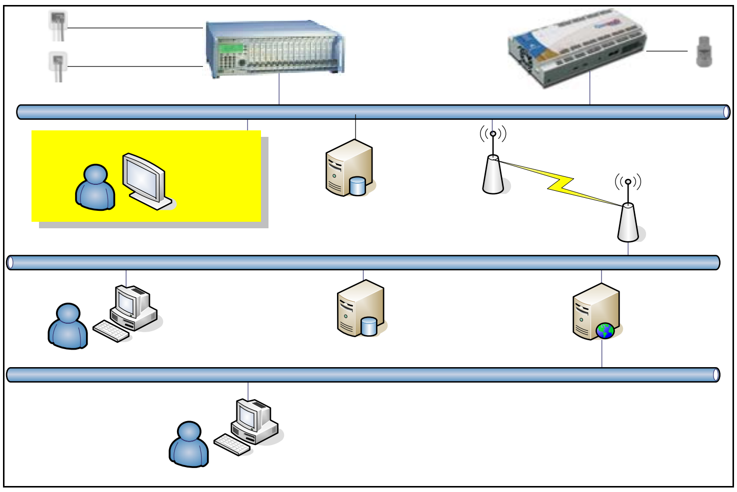

Figure 7. Remote bucket wheel excavator monitoring scheme

The monitoring system's structure defined and installed in the described way enables a realtime insight into the excavator's operating state by:

1. The personnel at the excavator
2. The personnel from the maintenance team of the coal mine
3. The personnel from the Kolubara Metal

Vibration specialists from TRCpro

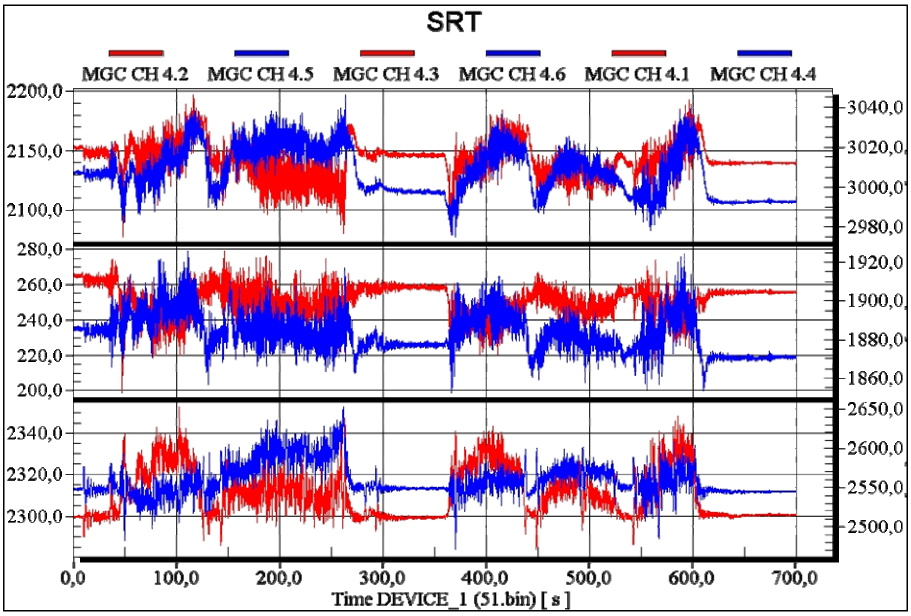

Figure 8. Strains [μm/m] on the bucket wheel holder during the digging process

Just several weeks after being installed, the system gave some very interesting information regarding the levels of the dynamic loads as well as regarding the very progressive development of failures on some ball bearings of the monitored drives and gearboxes.

Figures 8 and 9 show time signals from the strain gauges mounted on the bucket wheel holders during the process of coal digging. From these time signals it can be seen that the dynamic load when the bucket wheel goes into a contact with the coal is around 100 μm/m

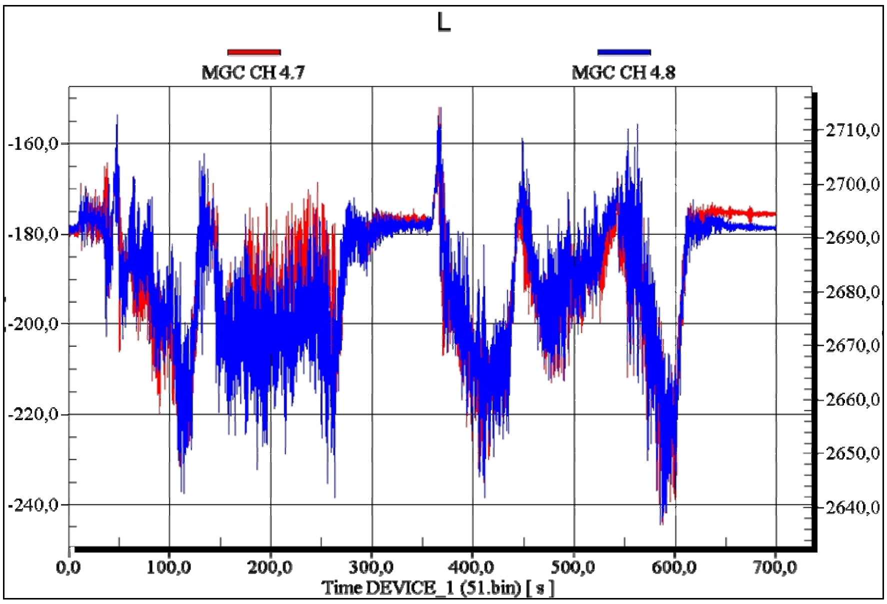

Figure 9. Strains [μm/m] on the bucket wheel arms during the digging process

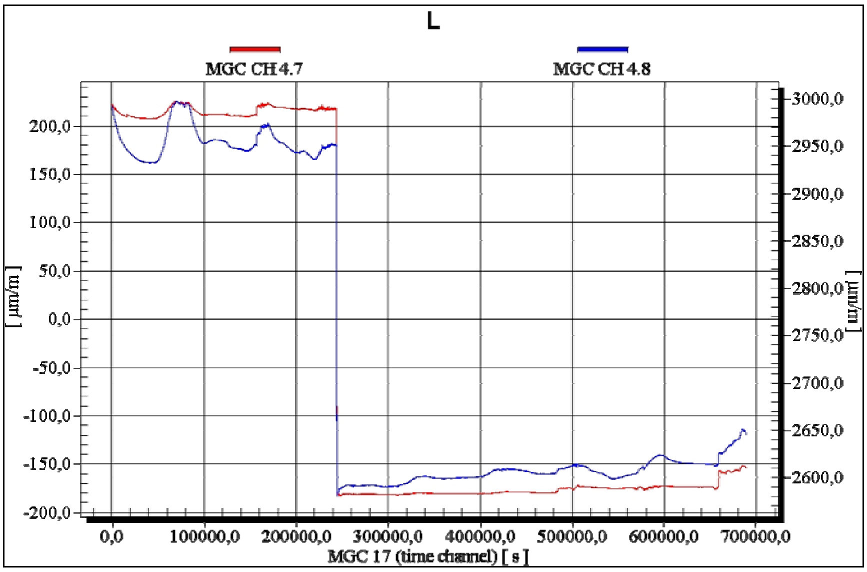

Figure 10. Strains [μm/m] on the bucket wheel arms after the excavator is being supoorted by its own weight

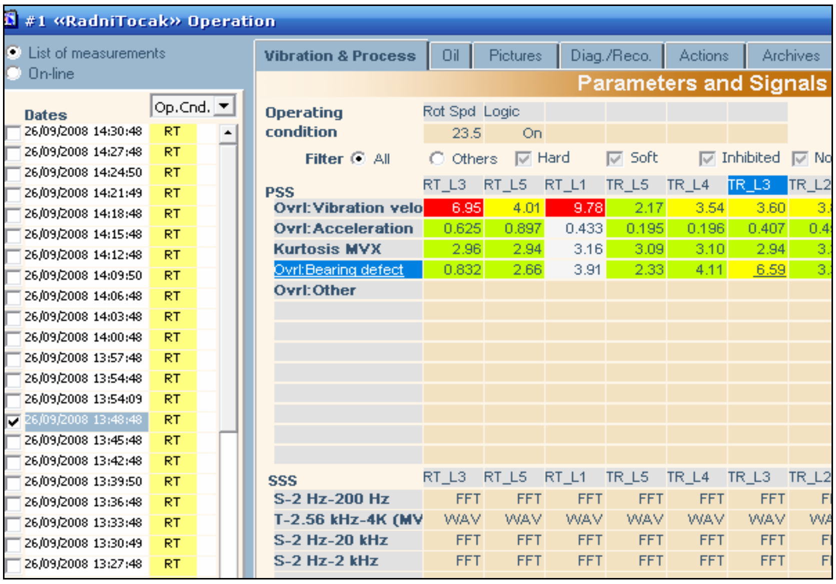

Figure 11. DDG showing a danger levels of vibration velocity at the bearing number 3 of the conveyer belt's drive. State recored on 26.09.2008. at 13:48:48

Figure 10 shows a long timewave (10 days long) from a bucket wheel holder arms after removing the excavator's sprags used during the excavator assembling. As it can be seen from the graph the additional strains generated are 400 μm/m!

Regarding the vibration signals, a realtime insight into the excavator's and its drive's operating state is performed using the so called DDG (double detection grid) where according to the current level of the vibration parameter, the coresponding field is marked with green (OK), yellow (alarm) and red (danger) color.

Detailed vibration analysis on frequency spectrums and time waves is performed after perceiving high levels of scalar vibration parameters. It is based on the knowledge of drive's kinematic parameters (number of rotor bars, bearings type, number of teeth in every stage of the gearbox) and on the current rotation speed. Let us take as an example record from a bucket wheel drive, recorded on 26/09/2008 at 13:48:48. The recorder rotation speed of the motor's shaft is 23.5 Hz i.e. 1410 RPM.

The number of teeth on all gears inside a gearbox is known so that expected frequencies are calculated (table 1).

Table 1. Expected frequencies on the bucket wheel drive

Stage	Part Nr	z1 i z2	i12	RPM 1 [Hz] Input	RPM 2 [Hz] Output	Gear mesh [Hz]
				I		
z1	22740	61	0.88406	23.50	20.78	1433.50
z2	22742	69				
				II		
z3	197114	23	0.43396	20.78	9.02	477.83
z4	197114	53				
				III		
z5	23454	23	0.2	9.02	1.80	207.36
z6	22744	115				
				IV		
z7	22745	35	0.3125	1.80	0.56	63.11
z8	22746	112				
				V		
z9	23455	29	0.18354	0.56	0.10	16.34
z10	22747	158				
				BUCKET WHEEL		
				Nr of buckets	14	
				GM RT [Hz]	1.44793657	

On the other hand if we look at the frequency spectra on the first bearing on the drive (non driving end) we can notice several families of harmonics:

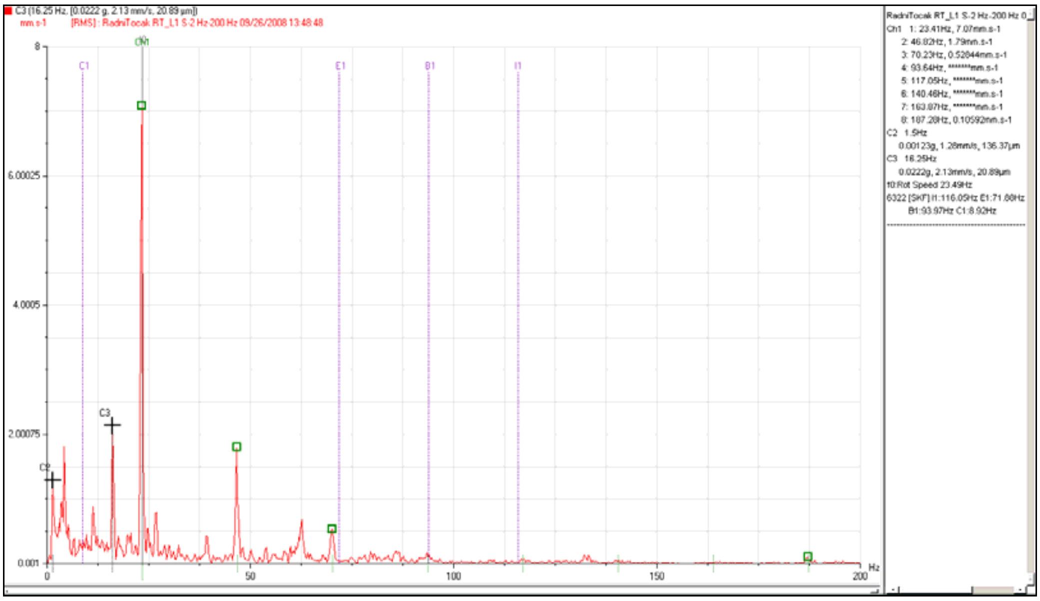

Figure 12. Frequency spectra on the first bearing on the drive

Ch1 – Family of the rotor's speed. In this case it is an evidence of the motor and gearbox misalignment problem.

C2 – Harmonics of the bucket wheel frequency.

C3 – Harmonics of the gearmesh frequency. In this case it is an evidence of the problems at the last gear stage.

EVALUATION OF THE REMOTE MONITORING IMPLEMENTATION VALIDITY

Despite that the above mentioned concept of the remote machine monitoring offers great results in minimizing machine downtimes before its practical implementation, it is necessary to validate this concept using some other factors:

1. Number of the measuring points on monitored machines

2. Machines accessibility
3. The size of the company: is it reasonable to hire a vibration specialist or to apply outsourcing? Generally for a middle sized companies, remote monitoring combined with hiring a vibration specialist is recommended.
4. Machine type: is it a critical machine or not?
5. The value of the equipment to be monitored.
6. The knowledge and experience of the vibration analysis team. Due to the time necessary for their training the condition monitoring results may be not be seen soon. On the other hand if the company hires a remote vibration specialist the results are expected very soon.

REFERENCES

/1/ Mr Ninoslav Zuber, Dr Ličen Hotimir: Prediktivno održavanje opreme na bazi merenja i analize vibracija: tipovi, strategije uvođenja i primene, primer, Power plants 2006

/2/ James Taylor: The vibration analysis handbook, 2003

/3/ R. Keith Mobley: Vibration Fundamentals, 2000

/4/ Curović N., Curović D,, Projektno upravljanje održavanjem, Ćasopis Istraživanja i projektovanja u privredi, br. 13, god. 2006., str. 7-18

/5/ Cyril M. Harris: Shock And Vibration Handbook, 1995

/6/ Cheuk Nga Lun: Modularized web based maintenance system for enhanced efficiency and security, Master thesis, 2006

/7/ J.T. Broch: Mechanical vibrations and shock measurements, 1984

/8/ R.B. Randall: State of the art in monitoring rotating machinery, 2004

/9/ 01db-Metravib technical documentation

DALJINSKO PERMANENTNO ODRŽAVANJE BAGERA SRS 1300.24/2.5 ZA POVRŠINSKI ISKOP UGLJA

Daljinsko permanentno održavanje mašina po stanju rezultat je svakodnevnih promena u području informacionih tehnologija i interneta. Radom je dat prikaz svih prednosti koje ovaj pristup nudi kao i osnovne smernice za primenu istih. Isto tako prikazana je konkretna primena ovog pristupa u praćenju stanja na bageru za površinski iskop uglja.

Ključne reči:vibracija, merna stanja, daljinski nadzor

Rad poslat na recenziju: 02.07.2009. godine

Rad spreman za objavu: 09.07.2009. godine