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REMOTE ONLINE CONDITION MONITORING OF THE BUCKET WHEEL EXCAVATOR SR1300 – A CASE STUDY

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Abstract. *Remote condition monitoring of machines is the direct result of constant changes and advances in the field of information technologies and internet. This paper presents all the benefits of this modern approach to condition based maintenance. Also some basic guidelines for its practical implementation, based on strain and vibration measurement on minning machinery are given.*

Key Words: *Vibration, strain, bucket wheel excavator, condition monitoring*

1. INTRODUCTION

Most of 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 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 on site but also remotely, using internet.

2. DEMANDS FOR REMOTE CONDITION MONITORING

Machine uptime increase i.e. minimization of the 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 loss of human lives as well. Therefore the implementation of some

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type of maintenance strategy with the purpose of monitoring the operating condition of any machine is an absolute must.

There are two different approaches to monitoring the operating condition of a machine:

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

Protection *Surveillance* *Diagnostic*

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

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

The above mentioned techniques have their advantages/disadvantages. They can be evaluated from the point of investment and return of investments ratio. Therefore choosing the proper technique requires some analysis of the type and purpose of the monitored machine (Figure 1). For example, a 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.

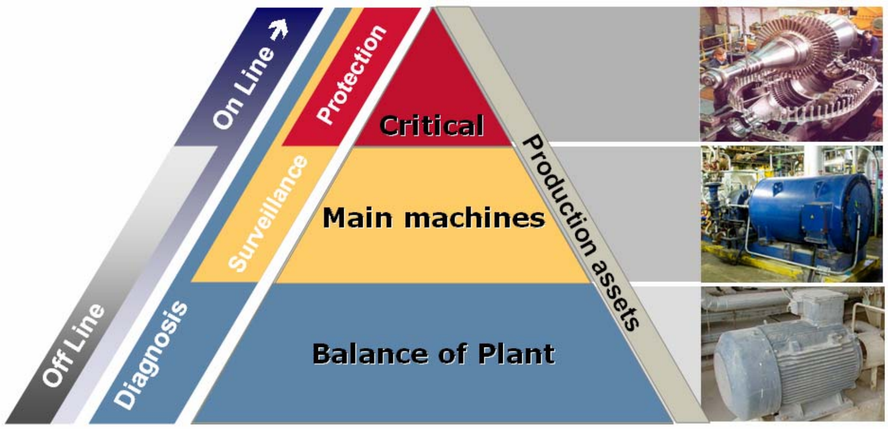

Fig. 1. Different approaches to condition based maintenance for different equipment in the plant

In addition, when choosing the proper maintenance approach for a specific machine group, some additional elements should be evaluated too. This element vindicates the concept of remote condition based monitoring. Despite the fact that 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 sometimes be very expensive… Let us take as an example the online monitoring of critical equipment. The price for a multichannel protection and diagnostic data acquisition online system (measuring device + sensors + cables + PC + software and the like) can be quite high. On the other hand, if the plant has 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 as well. 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 does not have plants centralized in one region. We can note an ongoing trend of big multinational corporations setting up plants all over the world. In order to cut the production costs through the reduction of workers and also through the engagement of cheaper labor, big companies tend to physically (geographically) divide management and administration from production. They are moving their production to different parts of the world where they can find cheaper labor. 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 the condition monitoring of machines using internet technologies has arisen: 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's 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 web based monitoring in the case of offline systems means only remote database and vibration specialists while the presence of maintenance personnel on site is still required for the purpose of vibration data collection.

Figure 2 presents one of the many schemes for the monitoring of distant machines. These machines can be monitored offline or online. Critical machines are equipped with online systems for permanent monitoring which use a TCP/IP protocol for communicating with the database. On the other hand, we use 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 analyze the acquired data, make the reports and suggest all the corrective actions for the machines.

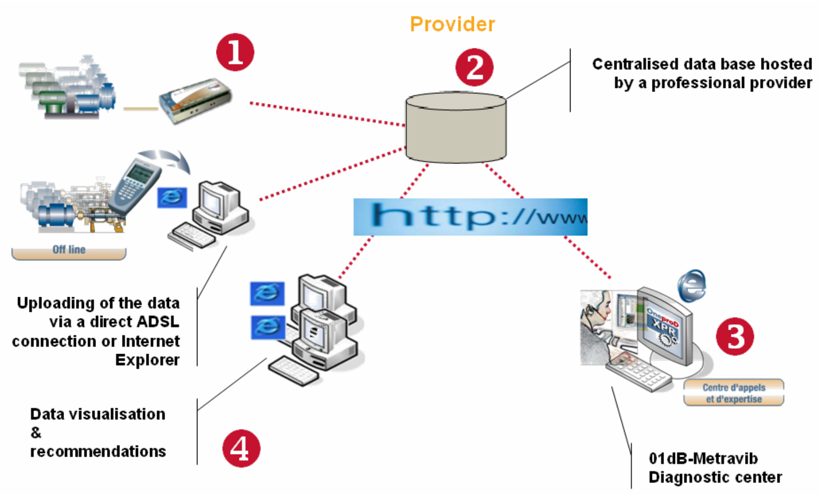

Fig. 2. One possible configuration for web based condition monitoring

3. 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, a member of the AREVA group. This web based condition monitoring is part of their integrated concept of predictive/proactive maintenance called the OneproD system.

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

The OneproD system is a concept of condition based monitoring where the multitechnique approach is emphasized. The operating condition is monitored and analyzed using: vibration, oil analysis, motor current signature analysis (MCSA), infrared thermography, process value 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 to implement the OneproD concept: both in the offline and online mode, both in traditional and remote mode, using vibration analysis, oil analysis, OPC communication etc, as shown in 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 TCP/IP based modular system composed of 8, 16, 24 or 32 channels in a single housing. The fact that the system can perform strategic acquisition (activates measurement and analysis only upon the predefined operating condition occurrence) in combination with the advanced programming capabilities of operating parameters makes this system suitable for on site and remote monitoring and diagnostics of complex critical machines. The 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 the most advanced vibration diagnosis of rotating machines equipped with ball bearings and journal bearings.

Fig. 4. OneproD MVX multichannel online monitoring system

Thanks to the strategic modes of acquisition and the TCP/IP and RS485 based communication protocols, the 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.)

Supervision of vibration and process parameters

4. Case Study: Online Conditon Monitoring of a Bucket Wheel Excavator in the Kolubara Coal Mine

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

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

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

1. Is a highly critical machine involved in coal mine production
2. It experiences high levels of dynamic loads. The designers of the excavator did not 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 vibrations and strains) are shown on Figure 6.

Fg. 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 rosettes)
7. Counterweight holder:	8 measurement points

On the other hand, the vibrations are measured on the following drives

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

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

- Digital input #1 – bucket wheel drive grip
- Digital input #2 – rotating platform drive grip
- Digital input #3 – elevation drives grip

When the digital inputs are in the high level state and when the rotating speed of the drive is above 300 RPM, a predefined acquisition and analysis is initiated.

Vibration parameters for monitoring of the drives operating states are:

SCALAR (overall value) parameters:

- RMS level of vibration velocity according to the ISO 10816
- Overall 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 consists 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 area network. On the same LAN, the dedicated data server with OneproD XPR 300 and HBM CatMan 5.2R5 software installed is connected and placed in the operator's cabin. The OneproD XPR software is responsible for the vibration data analysis while the CatMan software acquires and analyzes the strain measurement signals. The local area network from the excavator is, over the set up Wireless system, connected to the first AP (access point) which is located on 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 maintenance group while the other one is for the vibration specialists from TRCpro. A simplified scheme of the described system is shown in Figure 7.

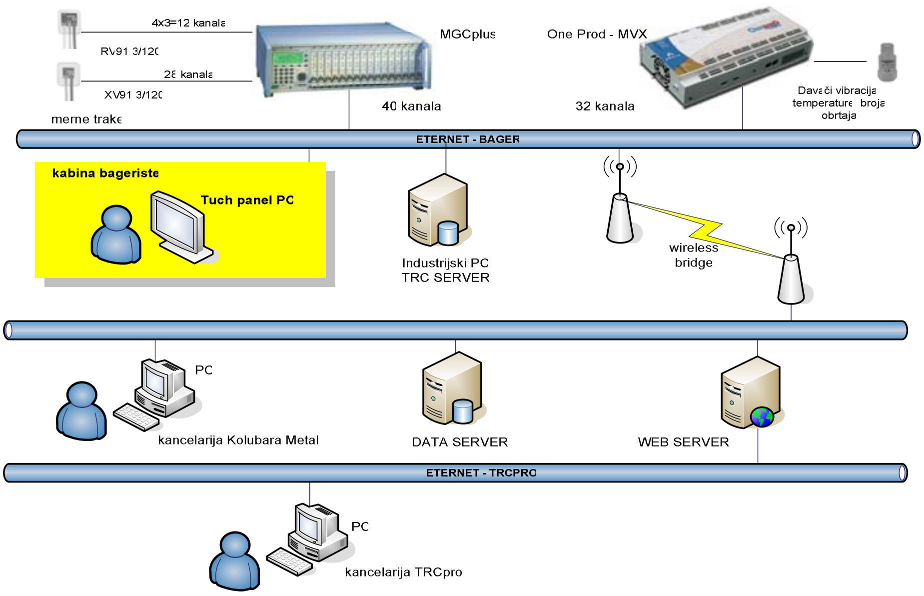

Fig. 7. Remote bucket wheel excavator monitoring scheme

The monitoring system's structure defined and installed in the described way enables a real-time 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 Kolubara Metal
4. Vibration specialists from the TRCpro

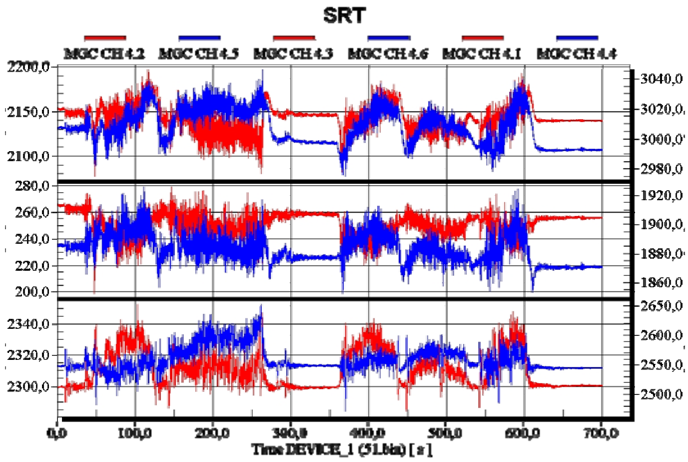

Fig. 8. Strains [µm/m] on the bucket wheel holder during the digging process

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 rwal-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

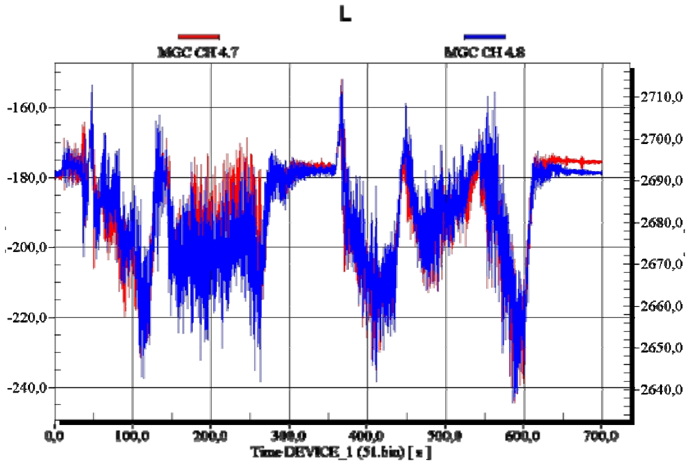

Fig. 9. Strains [µm/m] on the bucket wheel arms during the digging process

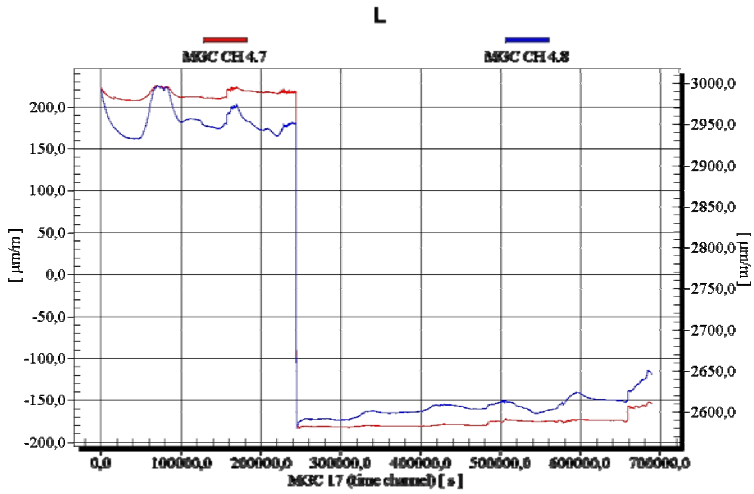

Fig. 10. Strains [μm/m] on the bucket wheel arms after the excavator is being supported by its own weight

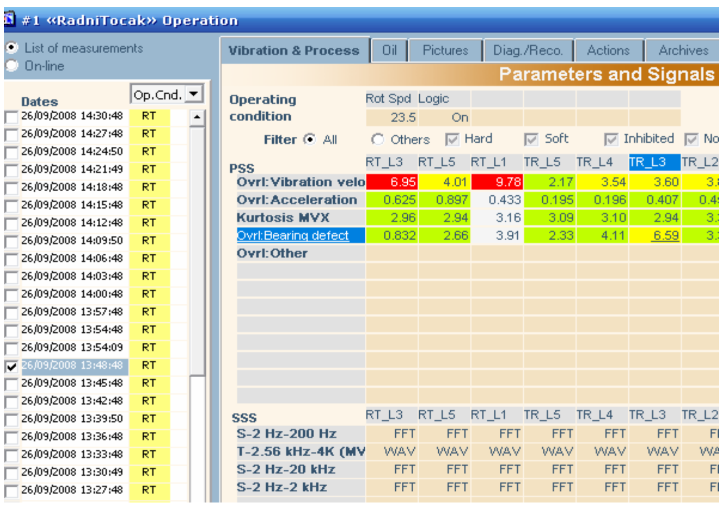

Fig. 11. DDG showing dangerous levels of vibration velocity at the bearing number 3 of the conveyer belt's drive. State recorded on 26.09.2008. at 13:48:48

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

Regarding the vibration signals, a real-time insight into the excavator and its drive operating state is performed using the so called DDG (double detection grid) where according to the current level of the vibration parameter, the corresponding field is marked in green (OK), yellow (alarm) and red (danger).

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

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

Table 1. Expected frequencies of the bucket wheel drive

Stage	Part Nr	z1 and 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:

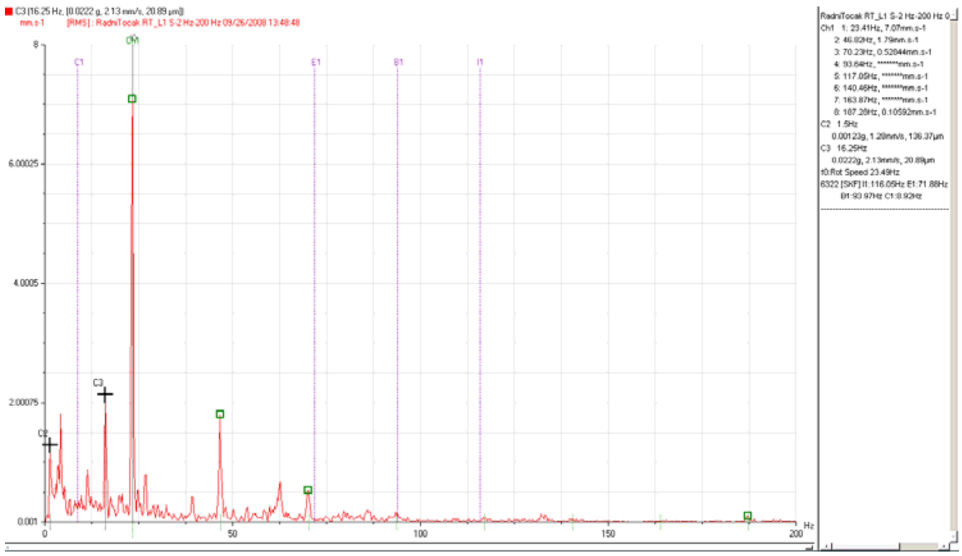

Fig. 12. The frequency spectrum from the L1 working wheel drive

Ch1 – Family of the rotor speed. In this case it is evidence of the motor and gearbox misalignment problem.
C2 – Harmonics of the bucket wheel frequency.
C3 – Harmonics of the gear mesh frequency. In this case it is an evidence of the problems at the last gear stage.

5. 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. The number of measuring points on the monitored machines
2. Machine accessibility
3. The size of the company: is it reasonable to hire a vibration specialist or to apply outsourcing? Generally, for 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 not be seen immediately. On the other hand, if the company hires a remote vibration specialist the results are expected very soon.

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UDALJENO ONLAJN NADGLEDANJE STANJA KOPAČA SR1300 – PRIKAZ SLUČAJA

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Udaljeno nadgledanje mašina je direktna posledica stalnih promena i napretka na polju informacione tehnologije i interneta. Ovaj rad predstavlja sve prednosti ovog modernog pristupa nadgledanju stanja i održavanja. Date su i neke osnovne smernice za praktičnu upotrebu, zasnovane na merenjima opterećenja i vibracija kopača.

Ključne reči: *vibracija, opterećenje, kopač, udaljeno nadgledanje*