



## Research paper / Praca doświadczalna

# Monitoring the impact of blasting operations on the environment – new solutions

## Monitorowanie oddziaływania robót strzałowych na otoczenie – nowe rozwiązania

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**Abstract:** Blasting operations carried out in open-cast mines generate seismic vibrations, which can adversely influence nearby structures. As a result, open-cast mines undertake measures to define the conditions for the execution of blasting operations, which are safe for the surroundings as well as documenting the level of this impact. Documenting the seismic interference through cyclic control measurements and the assessment of this interference carries one disadvantage, which is its periodic implementation. This drawback is eliminated by applying seismic monitoring.

In Poland, the influence of blasting on the surroundings is monitored by a system called Mine Vibration Monitoring Station (MVMS). The system was designed and built at the AGH University of Science and Technology in Krakow and has been modernized and updated over the last few years. Presently, it is a remotely controlled system which maintains communication via the internet, with data collected at the central server of the University. Evolution of the system and its technical capabilities are presented in the article.

**Streszczenie:** Roboty strzałowe prowadzone w kopalniach odkrywkowych surowców skalnych wzbudzają drgania, które mogą powodować szkodliwe oddziaływanie na obiekty budowlane w otoczeniu. W związku z powyższym kopalnie prowadzą działania skierowane z jednej strony na wyznaczenie warunków bezpiecznego dla otoczenia wykonywania robót strzałowych, a z drugiej strony na dokumentowanie poziomu tego oddziaływania. Dokumentowanie oddziaływania przez cykliczne pomiary kontrolne i oceny oddziaływania mają zasadniczą wadę w postaci okresowej ich realizacji. Ta słaba strona pomiarów kontrolnych jest całkowicie niwelowana przez monitoring oddziaływania.

W Polsce do monitorowania oddziaływania robót strzałowych na otoczenie stosowany jest system Kopalniana Stacja Monitoringu Drgań (KSMD), który został zaprojektowany i zbudowany w Akademii Górniczo-Hutniczej w Krakowie. System ten w czasie kilku lat uległ modernizacji i unowocześnieniu.

Aktualnie jest to zdalnie sterowany system z zastosowaniem łączności przez Internet, dane pomiarowe gromadzone są na centralnym serwerze w AGH. W artykule przedstawiono ewolucję systemu z podkreśleniem aktualnych jego możliwości.

**Keywords:** vibration monitoring, blasting works

**Słowa kluczowe:** monitoring drgań, roboty strzałowe

## 1. Introduction

Firing an explosive material (EM), placed in holes in open-cast mines produces vibrations which may affect buildings in the surrounding area. Because of this, apart from periodic preventive treatment *i.e.* control tests and determination of permissible EM loads, mines resort to continuous impact monitoring in order to effectively and constantly control the impact of para-seismic vibrations.

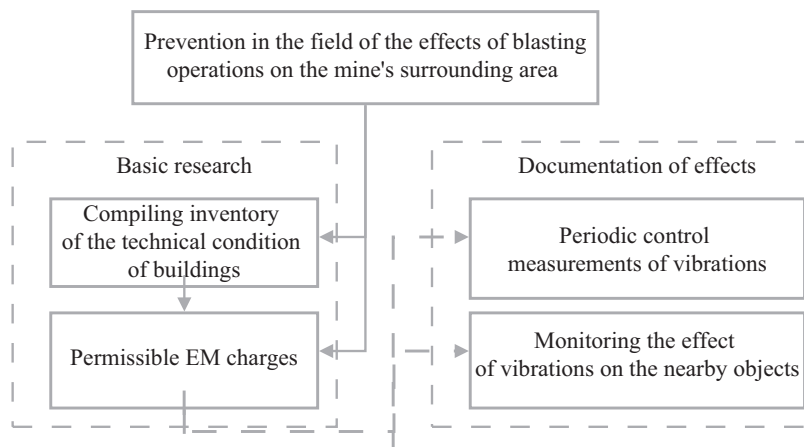
The determination of safe conditions boils down to: indicating limitations on the mass of EM used, application of good quality EM and modern firing systems. Mechanical loading of ANFO or emulsion EM into blast-holes, non-electric and electronic firing are already standard in open-cast mining. The use of modern blasting agents also allows for firing multi-hole EM series with a higher total mass.

Blasting performed by specialized external bodies is also the norm. It is understandable that these companies are striving to reduce the frequency of blasting which involves increasing the mass of EM loads for individual firings. Blasting activities also include designing grid parameters using specialized computer programs and laser technology.

In guidance issued to licensing authorities, local governments often point to the need of minimising the impact of mining works on nearby buildings, which is why the licences contain requirements for monitoring and conducting control tests.

These are not a solution to all the issues of the impact of blasting on the environment and therefore mines increasingly document and record events related to the detonation of EM charges in the process of exploitation. Preventative measures of open-cast mines in the field of minimizing the impact of blasting on the environment can be divided into two main issues (Fig. 1):

- a) basic research – compiling an inventory of the technical condition of the nearby buildings, measurements of vibration intensity and determination of permissible EM charges for firing in the local geological and mining conditions,
- b) documentation of the impact of vibrations on nearby buildings through periodic control measurements or constant monitoring of the intensity of vibrations on selected construction objects.



**Figure 1.** Preventive activities of the effects of open-cast mines in the field [1, 2]

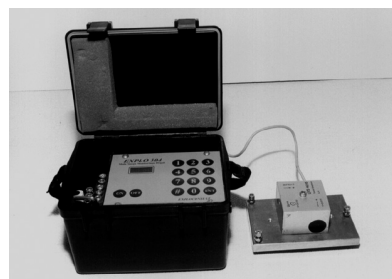
## 2. Monitoring the impact of vibrations on the immediate environment

Cyclic control measurements and assessments of the seismic impact have one disadvantage in the form of their periodic realisation. The duration between measurements is sometimes a year, two years or more. This fact is often raised as an objection to the relevance and effectiveness of such measures by parties in compensation proceedings. This weakness is completely alleviated by impact monitoring.

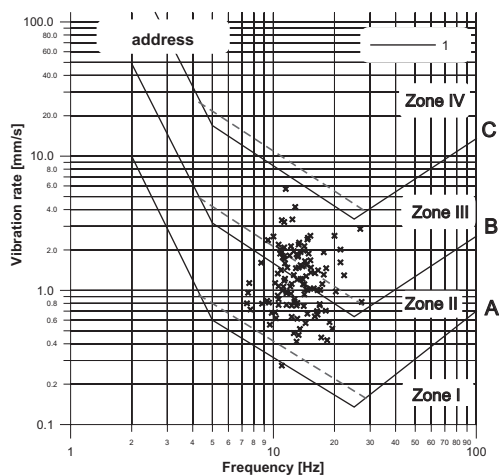
Monitoring is the continuous measurement of vibrations by self-activating recorders on reaching their sensitivity threshold and then archiving the results. This type of activity can be successfully performed by the in-house services of the mining facility. Of course, installing measuring devices on every protected facility is unrealistic, but even at a few points it has both a purpose and justification. A very important element of such measurements is the constant presence of devices in a specific facility and their maintenance-free performance. The devices operate continuously, recording the date and time of occurring events simultaneously.

In open-cast mining, the following measuring systems have been used to monitor the vibrations caused by blasting [2-5]:

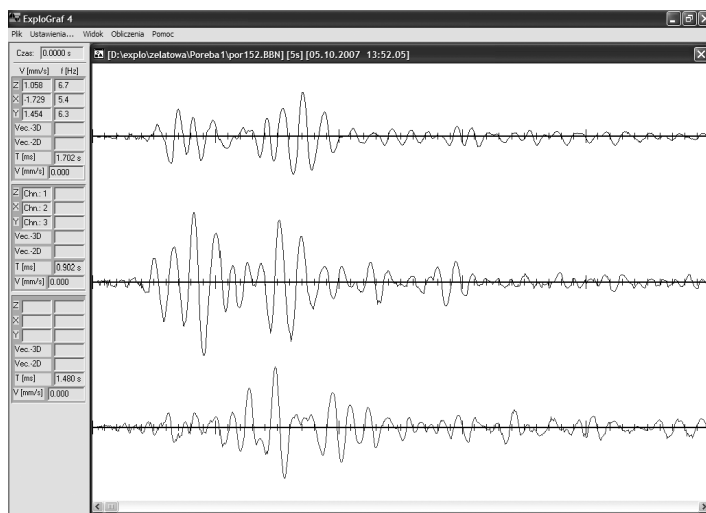
- Small Vibration Monitoring Station – Explo 504,
- Mine Vibration Monitoring Station (MVMS) (pl. *KSMĐ*) – radio transmission,
- MVMS – GSM transmission,
- MVMS – GPRS/APN transmission.



(a)



(b)



(c)

**Figure 2.** Small Vibration Monitoring Station - Explo 504: (a) general view; (b) effect assessment using the SDI-I scale, where 1 – Borders of SDI-I zones; (c) the Explograf dialog box

Explo 504 is a digital recorder equipped with a triple component velocity meter (Fig. 2a). The device allows on-going monitoring of measurement results by the direct reading of maximum values from the display and corrected values in accordance with PN-B-02170:1985 [6] and data transmission in the form of full progress over time figures to enable accurate analysis. The Explograf program is used for data transmission and analysis of the measurement results (Fig. 2c), which simultaneously prepares data for further and more detailed analysis. The assessment of impact on the protected facilities can be performed by a specialized unit, preparing periodic reports and summaries (*e.g.* quarterly) or after finishing the monitoring of a given building.

The use of Explo 504 in one dolomite mine has enabled over a thousand recordings of vibrations induced by blasting in 24 buildings since 1999 in the vicinity of the excavation [2], to be made. The disadvantages of the Explo 504 system include primarily the number of full waveform registrations being limited to 15, which necessitates periodic maintenance of the station through the manual transfer of data to a computer. At the moment only one mine is still using this type of station, which is periodically moved to facilities which are currently closest to the place of detonating a series of EM. In 2002, the MVMS was prepared for operation [2-4, 7]. In its construction (Fig. 3) the same technical solutions were used in the field of measuring (triple component speed meters) as well as in the method of data collection. However, the principal difference is the system of communication and data transmission.



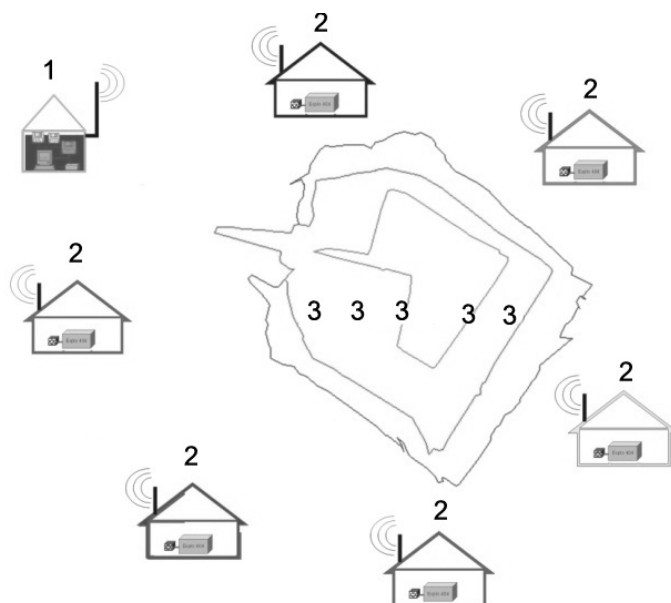
**Figure 3.** Mine Vibration Monitoring Station (MVMS) – general view

A basic modernization of the measuring system was the introduction of data transmission using radio communication, and then GSM communication (communication using mobile phone networks). The schematic diagram of the operation of the MVMS system is shown in Fig. 4 [3].

The introduction of wireless communication allowed remote control of the measuring stations, collecting basic data on the levels of vibration and making preliminary assessments by projecting the measurement results on the Scale of Dynamic Influence (SDI) (direct method).

The use of radio communication in the first solution resulted in significant restrictions on the transmission range to approx. 5 km and strong dependence on the local radio signal range. The disadvantage of the system was the low stability of the radio signal, which caused difficulties in its operation. One of these was the inability to transmit full waveforms, and with limited memory, as in the case of Explo 504, required the periodic presence of a system operator to download data to the computer.

The main advantage of the system, already in the first version, was the introduction of databases for storing measurement results, creating an archive for each station and for the building on which the station was installed. The on-going operation of the station allowed the creation of reports including the assessments of impact for both each firing and for any period of time. As a result, evidence was collected about the effect of blasting on the environment.



**Figure 4.** MVMS Schematic diagram: 1 – MVMS central computer station, 2 – facilities, protected measuring stands, 3 – location of blasting operations

MVMS internal software also collected data on the operation of the system, which allowed for the control of every command given to it by the operator. This was an important element, which eliminated the allegation of failure to activate the system in disputed cases. At the turn of 2012/2013, the last 6 examples of this type of station were modernized.

The second stage of modernization of the MVMS was the introduction of GSM communication – in the case of mobile phone networks, it is possible to transfer data over a distance in the form of maximum values of vibration parameters as well as their full waveforms, which is very important when conducting a thorough impact analysis using band-pass filtering. The second important advantage of this system is an almost unlimited communication range, which creates the ability to send full data over any distance. What constitutes an advantage of GSM systems is obviously a disadvantage and limitation when using short-range radio communication.

The use of GSM communication has improved the communication of the base station with the measuring stations and at the same time enabled the organization of a control and analysis central system at the University's Laboratory of Blasting and Environmental Protection. The laboratory, in accordance with contracts signed with individual mines, has access to the results data and conducts on-going control of intensity and assessment of the impact of vibrations on individual buildings, preparing quarterly reports, while simultaneously archiving data on the server [2, 8].

Archived results of the measurements collected by a MVMS are saved at several system levels:

- a) in the work archive of the MVMS,
- b) in the final report,
- c) in the database of protected facilities (the measurement results are then part of the information about the facility in which the measuring station is installed),
- d) they may also be sent to the central server, where they are subjected to thorough analysis by external teams of specialists.

MVMS management and work with the Nobogsm program are carried out through dialogue boxes (Fig. 5). The program is equipped with a database which allows access to measurement results for each protected facility. The results are described by the date and time of occurrence of the event, maximum values of particle velocity

correlated with the frequency. The initial assessment of vibration levels and the degree of vibration impact are available through the visualisation of the results in the SDI.

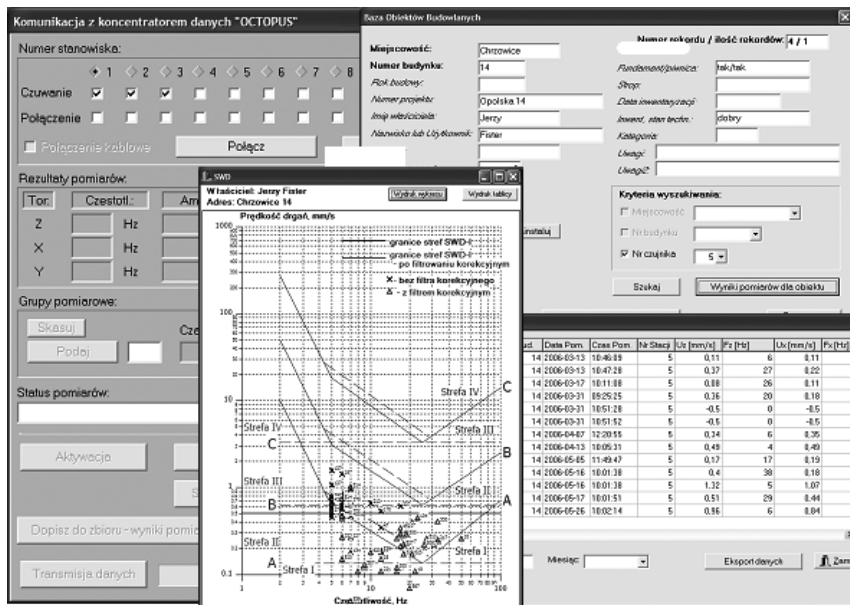


Figure 5. Dialog boxes in Nobogsm

The main disadvantage of this model was the fact that a large amount of time had to be allotted to ensure the correct operation of the system. An operator had to connect to each station separately and issue a specific command, such as «enable standby» or «disable standby», read the results and/or save the results, to ensure that all information was correctly saved and archived.

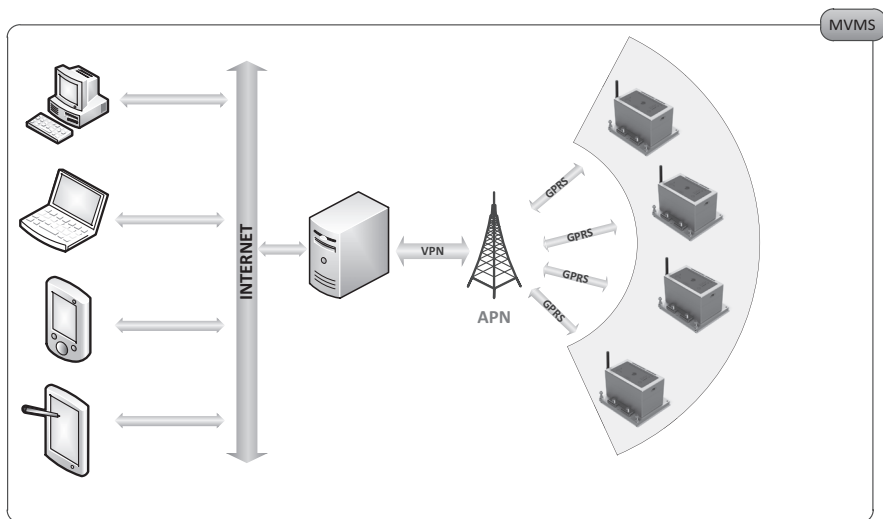
Currently in mines, there are seven MVMS systems in operation which utilise GSM communication. They are equipped with 23 measuring stations which continuously record vibrations induced by blasting in open-cast mines.

### 3. MVMS – new solutions

In 2011, a new version of MVMS was developed (Fig. 6). The main aim of the changes was to make the system more flexible by creating a direct connection between the measuring station and a central server, reducing the need for manual operation, using wireless Internet communication and collecting data on the server with the ability to access it at any time without having to connect to the measuring station. The introduction of new electronic circuits also allowed for operating the service remotely and introducing changes in the measuring station software. The proposed new MVMS model met with great interest and most of the working systems were modernised in 2012 with further modernisations planned for 2013.

The basic unit of the system is the MVMS (Fig. 7), equipped with a 3-axis vibration velocity meter and a number of systems for processing and collecting measurement data. A GSM/GPRS modem is an integral part of the station – it automatically sends collected measurements to the MVMS server located at the University, via APN (*Access Point Name*).

An online service is used for managing the stations and the measurements obtained by them. This allows users to view the measurements taken, generate reports, and manage devices, buildings and system users. Accessing the service website is only possible with a username and password [2].



**Figure 6.** Mine Vibration Monitoring Station – 2012 model: 1 – MVMS server, 2 – Mine Vibration Measuring Stations



**Figure 7.** Mine Vibration Measuring Station – 2012 model

After logging onto the system, the following operations can be performed: checking the station status (including battery status), enabling/disabling system standby, displaying analysis for a given building, restarting the station.

The biggest advantage of the new system is the collection of data from the server: after saving an event in the memory, the MVMS automatically connects and sends the data to the server. In the event of connectivity issues, data transmission is attempted repeatedly until the data is successfully transmitted (until the station receives a confirmation from the server that the data was successfully saved). This is very important, as the Measuring Station itself does not store data; this is only stored on the MVMS server. As a result, in order to conduct analysis or use the database, the system operator only works with the server. The core analytical functions offered by MVMS are:

- a) report on the assessment of vibration impact on an object for a single event (Fig. 8),
- b) vibration waveform analysis (Fig. 9),

- c) analysis using Dynamic Impact Scale for a single event and for a given period of time (Fig. 10),  
 d) export of data in the form of full vibration records, as well as export of data from the database for specialist analysis and assessments.

1 — Data wydruku: 2012-09-02 19:57:17

Kopalniany System Monitoringu Drgań — 24

## 2 — Raport oceny

3 — z dnia 2012-08-09 13:35:27

### 4 — Dane budynku

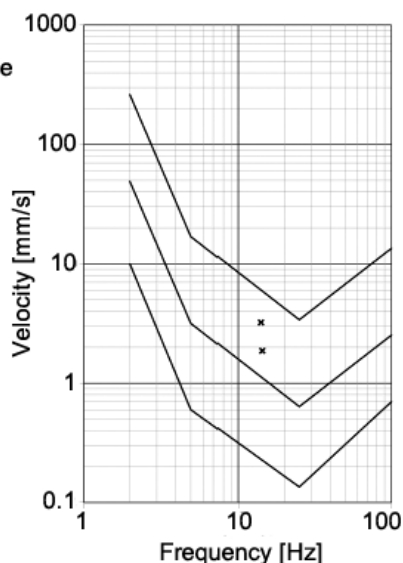
- 5 — Adres:  
 6 — Właściciel: name and surname  
 7 — Data inwentaryzacji:  
 8 — Stan techniczny: good  
 9 — Rok konstrukcji:  
 10 — Materiał: brick  
 11 — Ilość kondygnacji: 2  
 12 — Strop: concrete  
 13 — Fundament/piwnica: No / Yes

### 14 — Dane pomiaru

- 15 — Numer seryjny stacji: 009701  
 16 — Częstotliwość próbkowania: 1000 Hz  
 17 — Czas pomiaru: 5500 ms  
 18 — Próg odcięcia filtra: 100 Hz  
 19 — Zakres pomiarowy: 15 mm/s  
 20 — Temperatura: 32.0 °C

### 21 — Pomiary

	22 Częstotliwość [Hz]	23 Prędkość [mm/s]
X	14.3	1.87
Y	14.1	3.23



**Figure 8.** MVMS – single event assessment report: 1 – Print date, 2 – Assessment Report, 3 – Dated, 4 – Building data, 5 – Address, 6 – Owner, 7 – Date of inventory compiling, 8 – Technical condition, 9 – Year of construction, 10 – Material, 11 – Number of storeys, 12 – Ceiling, 13 – Foundation/basement, 14 – Measurement data, 15 – Station serial number, 16 – Sampling frequency, 17 – Measurement time, 18 – Filter cut-off threshold, 19 – Measuring range, 20 – Temperature, 21 – Measurements, 22 – Frequency, 23 – Velocity, 24 – MVMS



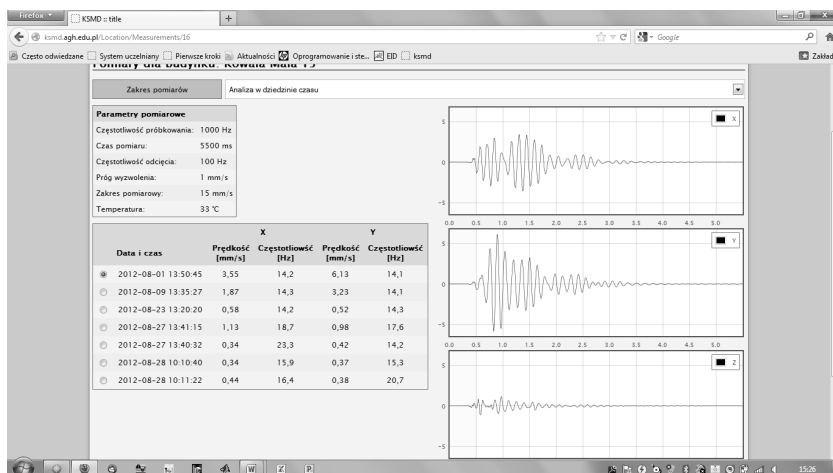


Figure 9. MVMS – vibration analysis in the time domain

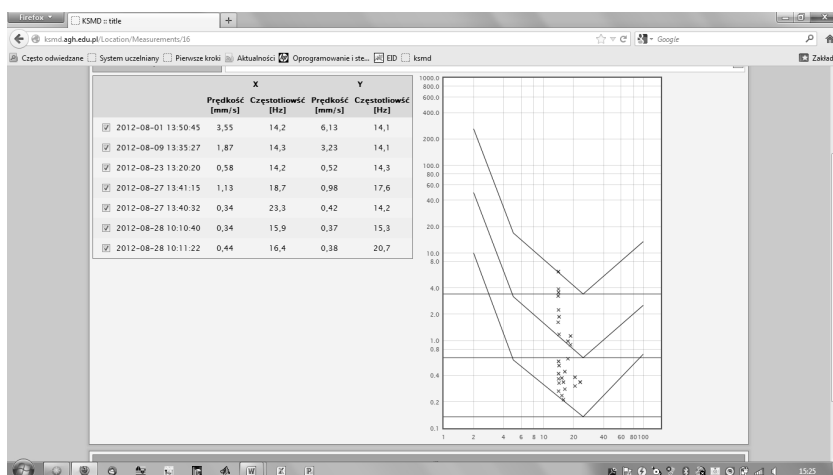


Figure 10. MVMS – vibration impact assessment for a selected period of time

Advantages of the new MVMS:

- continuous measurement of vibration of the building,
- unlimited memory,
- automatic data transmission to the server,
- constant connection to the server,
- automation of the station launch process,
- possibility of connection from any point on Earth,
- archiving full runs of detailed data,
- archiving reports and impact assessments,
- visualisation of waveforms and results of the Dynamic Impact Scale,
- report after each event.

## 4. Conclusions

Documenting the impact of blasting operations on the environment is a solution which allows:

- collecting current information on the intensity of vibrations induced by blasting robots for supervision,
- controlling the impact of vibrations on objects,
- creating a database which can be consulted to provide evidence in a damage claim,
- making ongoing corrections for conditions which limit blasting.

The MVMS as used in mining plants, built with the financial support of open-cast mines, has been gradually modernised and is now a modern system utilising new measurement, analysis and wireless communication technologies. The system was created as a tool for traffic supervision, enabling ongoing control of the effect of blasting on buildings in the surrounding areas.

Monitoring enables control of the level of induced vibrations and quick response to exceptional occurrences.

After modernisation, MVMS allows access to measuring devices from any place, control of the measuring equipment, immediate view of the recorded event and quick assessment of effects.

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