The physically interpretable and statistically proved forecast and evaluation of blast vibrations

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ABSTRACT: The authors will present a new, statistically proved blast vibration forecast for use in blasting of rock masses. We derived from momentum theory, that has been proved by advanced technology of measurement, the fundamental parameters which are causally related to vibrations.
There are:

- charge weight W_B of a borehole, including the geometrical quantities borehole length and borehole diameter (kg)
- detonation velocity c_d of the used explosives (m/s)
- distance r emission to immission point (m) with the statistically determined negative exponent n
- factor R_M respectively R_S of rock mass, related to the specific blast momentum or alternatively the used drill and blast technique, with the statistically determined exponent m $\left(mm/kg \, or \, \frac{mm \cdot s}{kg \cdot m} \right)$

The regression relations are given by:

$v_{max} = R_M \left(W_B \cdot c_d \cdot r^{-n} \right)^m$ (1) for measurements of peak particle velocity v

$\varepsilon_{max} = R_s \left(W_B \cdot c_d \cdot r^{-n} \right)^m$ (2) for strain measurements ε

The vibration has to be derived on the basis of statistically proved data base. The borehole charge per delay is not responsible for the quantity of vibrations. Therefore it will be possible to increase and ignite blast designs in terms of the momentum theory. The application of the forecast method opens new ways in quarrying rock masses, so that mining can move the buildings more closely. The procedure has been proved in subsurface as well as in surface blasting. The presentation will show several practical examples including results and assessments.

1 INTRODUCTION

There are various existent empiric relations for problems of blast vibrations according to the quantity of technical literature, but it should be pointed out that these correlations base on parameters which have been changed due to the enormous development of blasting, drilling and ignition techniques in comparison to past time. The estimation possibility dates from Koch's [7] relation which was developed 49 years ago. It defines the basic limitation of charges due to monitored vibrations in relation to the distance between the blast design and the measurement point. During the mentioned time period the blasting, drilling, ignition and monitoring techniques for preparation and supervision of blasting as well as vibration monitoring has been enhanced vastly, resulting in a new form of physical interpretation of the real blasting process according to the momentum theory.

More end more the forecast quality was short of the real obtained vibrations. As a consequence the revision of blast vibration forecast is necessary according to the enhanced development of the subject of blasting techniques. Therefore the in-situ proved momentum theory has been used as a base model for detonative reaction [8, 9, 10, 11, 12] (Fig. 1). The model can be easily transferred into an energetic approach.

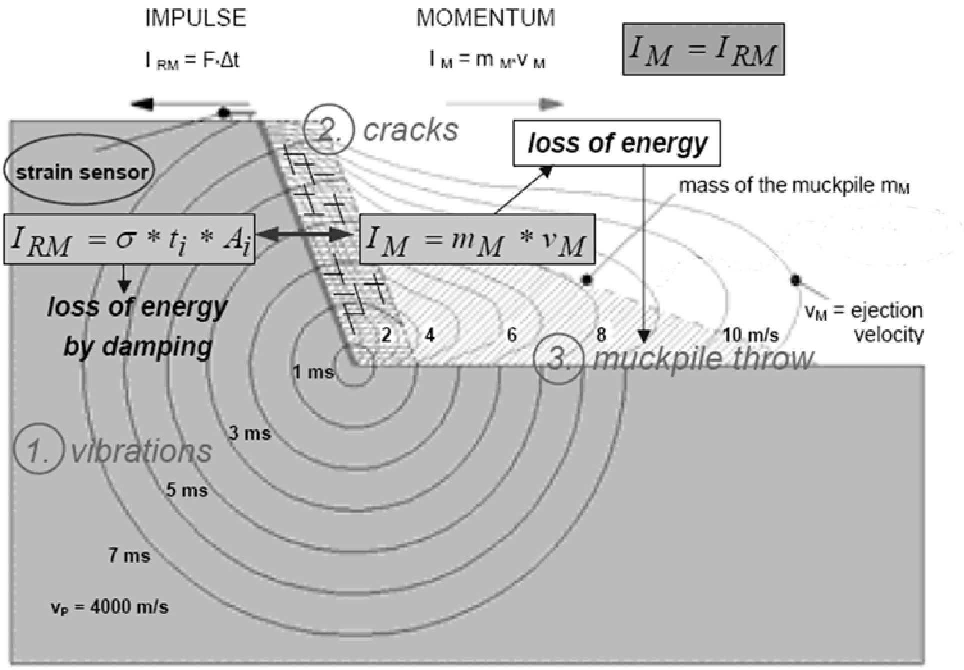


Figure 1. Model of the momentum theory, which is simplified used in blasting.

2 MOMENTUM THEORY

The blast design were ignited due to the conception of the momentum theory attended by an intensive monitoring program. In doing so the emitted shock waves to the rock mass could be interpreted as a momentum effect, which were attenuated by the distance from the blast design to the measurement point within a structure or building as a result of local conditions. In this manner a statistically proved and physical proved vibration forecast was acquired basing on numerous quarries of quarry and pit industry. The application of these coherencies enables:

- unlimited extension of blast designs in quarries
- obvious influence on the lumpiness of the muck pile
- regulation of vibration immissions according to the permitted limits of the DIN 4150, part 3 without influence on the economic efficiency nor extension possibility of the quarry

In the following the most important results, which maintain the mentioned declarations, will be presented.

The front of the shock wave hits simultaneously <u>for each similar borehole</u> into the remaining rock mass during the detonative reaction of the explosives.

The vibrations would depend on the measured strain sensor data having regard to momentum theory, which can be characterised by the following parameters:

- charge weight which is ignited by a detonator in a borehole (W_B)

- borehole length (l_B)
- borehole diameter (d_B)
- detonation velocity of used explosives (c_d)

Several simultaneously ignited charges do not increase the values of strain and stress but mark separated, time shifted single events referring to the measurement point.

The evidence of the assumed physical model for the ejection, fragmentation and vibration due to the momentum theory, led to the following fundamental acknowledgment, which furthermore made the formulation of the proved blast vibration forecast possible.

- The shock wave impacts into the rock mass behind the free face as an impulse or single momentum and causes measurable vibrations.
- Each blast design is a assemblage of the single partial momentum per column load, so that the spacing in the range of meters releases shock waves in a pulse of ms, which do not interfere each other due to the high propagation velocity and the free faces.
- Simultaneously firing of single charges results in increasing cracking respectively fragmentation, depending on the ratio spacing to burden, without increasing of vibration if ignited according to the momentum theory.
- The charge weight per delay of several single charges can not be used as a criteria for vibration forecast [11].
- The charge weight in a blast design should possibly insist of unitary explosives which feature a similar or equal detonation velocity and density.
- The ignition has to be carried out with a uniform progressive firing sequence and coordinated delays of the blasting, whereas the simultaneous ignited charges in a row may directed obtuse-angled to the free face.
- The shock fronts can be interfered or directed by ignition technique, so that the fragmentation and the loosening as well as the vibration immissions will be influenced. Interferences are featured by simultaneous ignition or short delay in the close-up range, which can be used for fragmentation of the rock mass.
- The described processes behind and within a blast design presuppose to the consistent application of wave mechanics in rock mass.

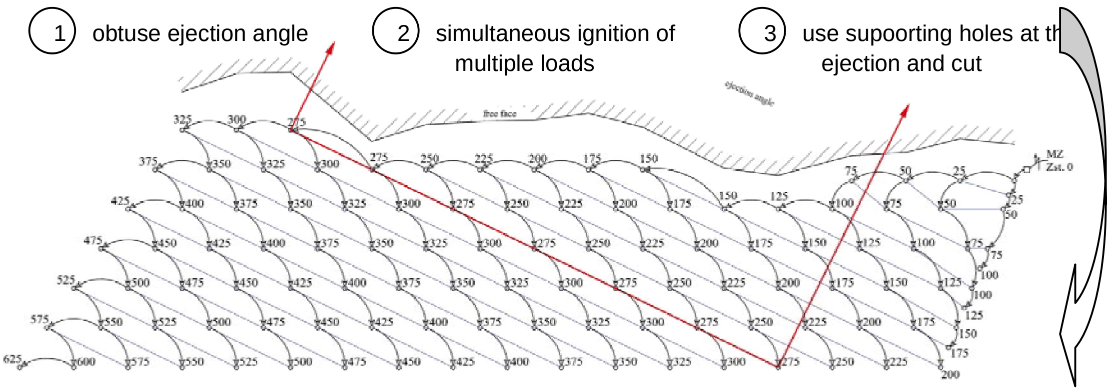


Figure 2. Example of an ignition pattern of a 6-row blasting using non-electric detonators according to the momentum theory.

3 INITIATION SYSTEMS ACCORDING TO THE MOMENTUM THEORY

In aim to apply the new acknowledgment of the parameter effects of a blast design correctly, it is essential to use the ignition sequence for a blast design, which can be derived from the momentum theory. For that purpose known ignition systems, ignition methods and procedures have to be adjusted that way, that the estimated effects of momentum theory

- influence on and reduction of vibration immissions
- extension of blast designs
- improvement of fragmentation
- increase of loosening by ignition method adjustment occur.

Due to the results according to the momentum theory, the following principles yield for the dimensioning of a blast design [12] (Fig. 2):

- Blast designs should normally be planned as multiple-row blasting and can theoretically be unlimited in size, always depending on local conditions.
- The ignition has to be carried out with a uniform progressive firing sequence and coordinated delays of the blasting.
- The combination of several boreholes in one delay will result in obtuse-angled ejection to the free face.
- The cut supporting boreholes should be added corresponding to the ejection angle.
- To avoid wave interferences and resulting vibration problems, the cut has to be carried out from the one side of the blast design only.
- The emission of the shock wave front has to be controlled with the help of combined single charges, so that the shock front is not directed towards existing buildings.

When using electronic detonators with redundant setting, the delay interval has to be adjusted according to the detonation velocity of the explosives, the length of the explosive column load and the delay interval of the rows. It is often questioned, if the different ignition systems generate other low vibrations. Having done several measurements of uniform dimensioned blast designs it can be shown, that there are no significant differences within the induced peak particle velocity using non-electric, electric or electronic detonators [13]. The production blasts in a granodiorite open pit mine using non-electric and electronic blast designs, however, show a increase of peak particle velocity data with electronic detonators in the close-range. With the help of frequency analysis, it could be proved that the resonant frequency of 30 Hz of the little-jointed rock mass was reached at a delay time of the electronic detonators of 46 ms. This resulted in noticeable resonance effects leading to higher vibrations and more extensive fragmentation of the muck pile [13].

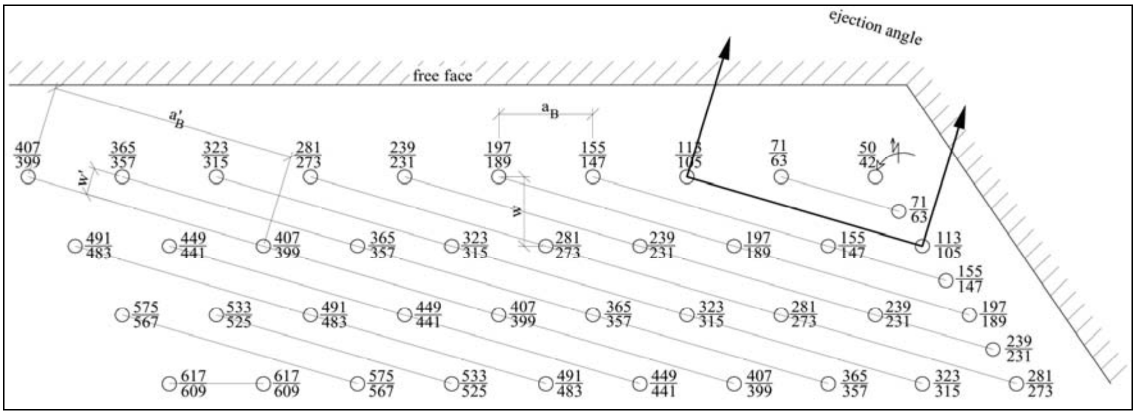


Figure 3. Example of initiation pattern of a 4-row blasting using non-electric detonators with supporting boreholes.

By systematic increase of the delay time from 32 to 46 ms a resonance effect of the rock mass has been initiated. Typical resonance vibrations occurred and the frequency variation was reduced to a value of 30 Hz. Therefore the use of electronic detonators for simultaneous ignition of various charges according to the momentum theory needs an accurate calculation of the delay. Having knowledge of the delay time which generates resonance effects leading to resonant frequency, a electronic ignition can be used for an extensive improvement of fragmentation. In so doing it should be noted that either the buildings may be situated far away from quarry or may not be founded on the bed rock of the excavation level. Due to pyrotechnical caused imprecision and the limited delay intervals the generation of resonance effects by using electric and non-electric detonators is less probable. The electronic detonators are suited for ignition according to the momentum theory because of their high precision considering the mentioned declaration in particular for improvement of the fragmentation of the muck pile.

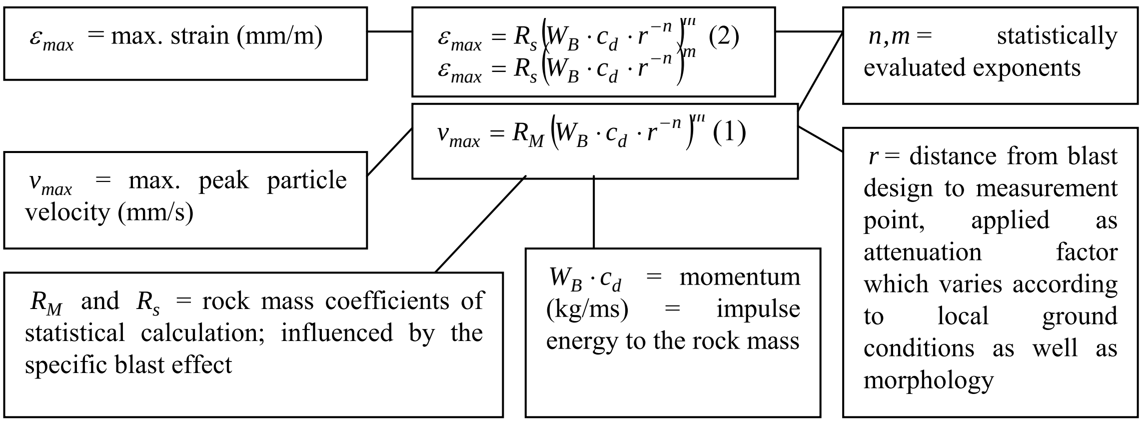
4 THE PHYSICALLY DERIVED MOMENTUM-DISTANCE-RELATION

There are various existent empiric relations for problems of blast vibrations according to the quantity of technical literature, but it should be pointed out that these correlations base on parameters which have been changed due to the enormous development of blasting, drilling and ignition techniques in comparison to past time. The estimation possibility dates from Koch's [7] relation which was developed 49 years ago. It defines the basic limitation of charges due to monitored vibrations in relation to the distance between the blast design and the measurement point. During the mentioned time period the blasting, drilling, ignition and monitoring techniques for preparation and supervision of blasting as well as vibration monitoring has been enhanced vastly, resulting in a new form of physical interpretation of the real blasting process according to the momentum theory.

The ± uniform coherences and the similar results of the previous forecast relation can be attributed by the always distinctive influence of the factor r, which exists in all rock masses. An evaluation of the vibration impact according to the different drilling, blasting and ignition parameters was rarely done in the past [4, 6, 8,16].

As a result of the manifold blast investigations and evaluations in different rock masses the physical explainable formulas (1) and (2) were developed (Fig. 4). The formulation of the relation (2) will be explained exemplarily.

The correlation (2) is statistically determined, dimensioned and applied to the variation of its input parameters. By consequent application of the forecast correlation (2), considering the recommended ignition sequence according to the momentum theory, the blast vibration immissions can be primarily changed noticeably by variation of the face height respectively the borehole length, the borehole diameter and the used explosives.



W_B = charge weight of a borehole

c_d = detonation velocity of used explosives

Figure 4. Statistically determined and physical explainable general momentum-distance-relation of blast vibrations.

The charge weight per delay interval is no longer effective on the vibration immissions. Hence unlimited sized blast designs are possible, using all advantages of multiple-row blasting for fragmentation of the muck pile.

Instead of peak particle velocity measurements strain measurements in mm/s can be used for formulation of the relations. These data show noticeably higher correlation as a result of higher precision [1, 4, 9].

On the one hand the presented vibration forecast includes a lot of previous acknowledgment of the blasting effects to the rock mass. On the other hand it considers the model of the momentum effect of a blast design. With the loss of the factor charge weight per delay interval respectively the reduction of the single charge weight, which is ignited in one borehole, vast advantages establish in practice by application of the forecast correlation.

The simplified procedure of the formulation of the momentum-distance-relation (2) is presented for a basalt quarry. For that purpose various geophones are installed in a minimum distance of 50-100 m behind the blast design toward close-up buildings in a distance of ≥ 300…500 m according to the local conditions. The measuring data are illustrated in a peak particle velocity-distance-diagram and evaluated by regression correlation (Fig. 5).

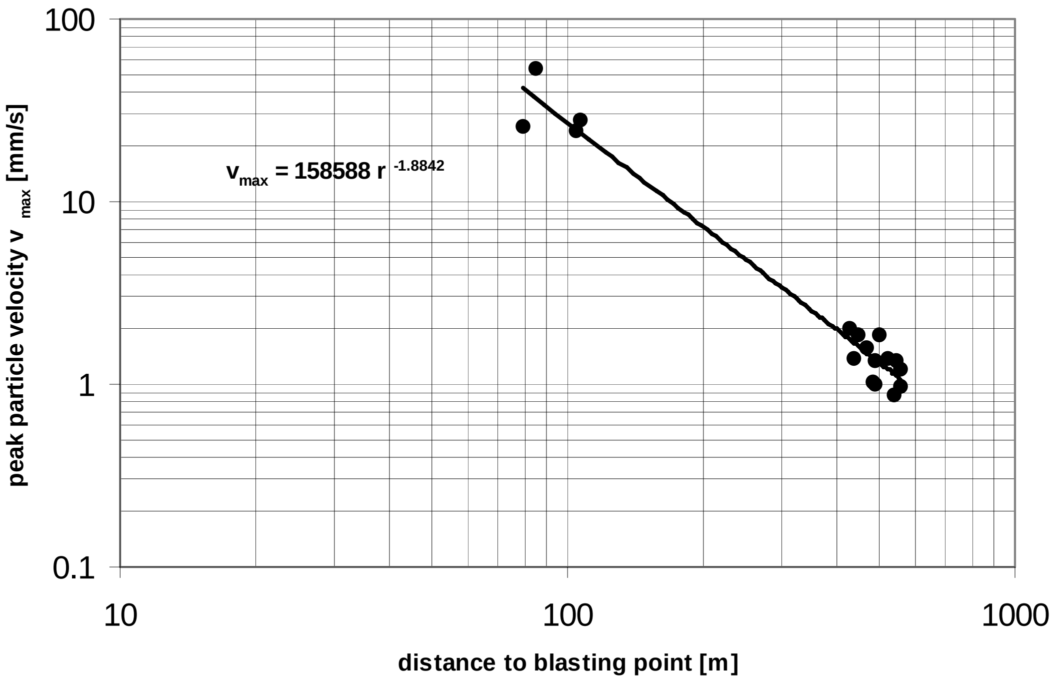


Figure 5. v_{max}-r-diagram of production blasting in a rock mass of columnar segregated basalt.

The measured peak particle velocity data are correlated to the product

$$W_B \cdot c_d \cdot r^{-1,8075}$$

during a next calculating step. Hence, the real momentum-distance-relation due to another correlation result (Fig. 6):

$$v_{max} = 0,52269 \cdot \left(W_B \cdot c_d \cdot r^{-1,8075}\right)^{0,9717}$$

valid for: $r \geq 50 \leq 600m$

$W_B \geq 60 \leq 250kg$

$c_d \geq 3000 \leq 6100\, m/s$

The calculation can be done as well by multiple regression analysis including all parameters.

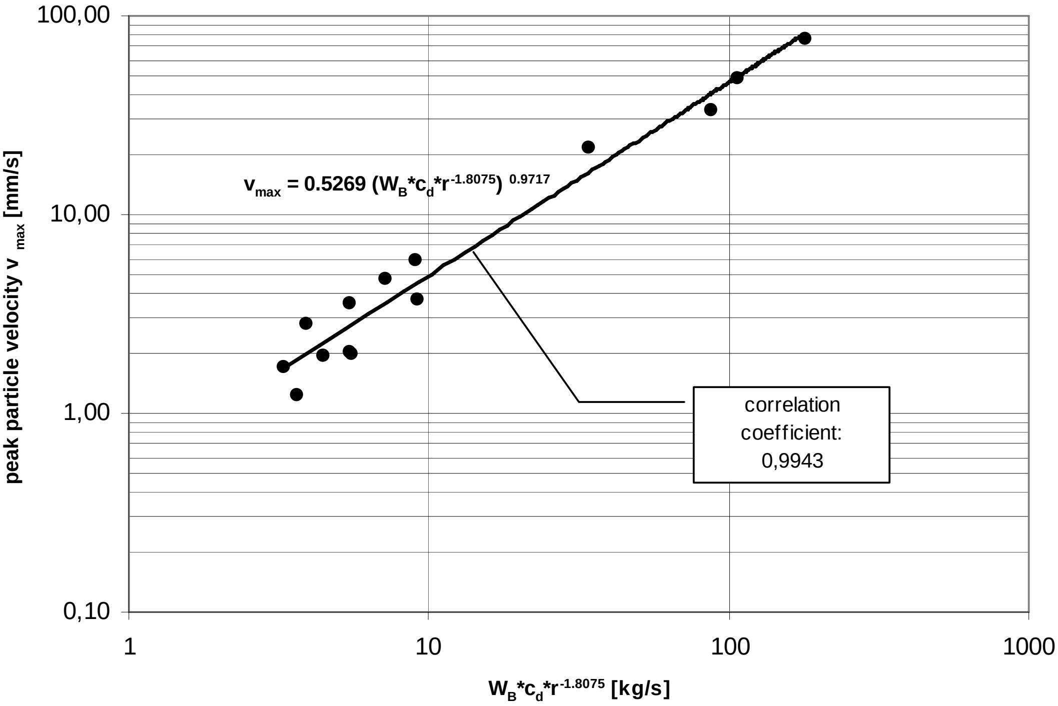


Figure 6. Diagram of the determined relation $v_{max} \sim W_B \cdot c_d \cdot r^{-1,8075}$ (momentum-distance-relation) from a quarry of columnar segregated basalt.

Due to the results the precision and reliability of vibration forecast especially for the close-up range increased. Retrospective calculation of vibration also of single buildings is possible.

Separate forecast relations lead to detailed declarations for single measurement sites of protestors or other problematic sites, which are not refutable by courts either. Last but not least the blasting results in the quarries can be improved systematically and configured more cost-effective due to the evaluated correlations. Having vibration problems the extraction planning will be facilitated by adjustment of the face height and mining direction. The control of the vibration problems enables the complete extraction of the available deposit volume also close-up to residential area.

5 CONCLUSIONS

A statistically proved blast vibration forecast was presented in this paper, which can be applied for rock mass blasting. Based on the verified momentum theory, which is the physical evaluation model of the processes during and after the detonative reaction, fundamental parameters have been found, which are causally related to vibration. The criteria for drilling and ignition pattern in order to improve the fragmentation and compliance of blast vibration immissions were shown. The advantage of strain measurement instead of peak particle velocity measurement is founded in the more precisely correlation of the momentum-distance-relation and the more unambiguous interpretation of the data. The statistical analysis has to observe the rules of mathematic statistics. The authors are gladly available for consulting and assistance in questions of blast technique and vibration problems.

Locate tables close to the first reference to them in the text and number them consecutively. Avoid abbreviations in column headings. Indicate units in the line immediately below the heading. Explanations should be given at the foot of the table, not within the table itself.

REFERENCES

[1] Baumann, I. & Müller, B. 2000. Neues Messverfahren für die Erfassung von Sprengerschütterungen und anderen dynamischen Einwirkungen im Bauwerken. *Spreng-Info, 2nd issue, Mitteilungsblatt des Deutschen Sprengverbandes e.V.*: 19-30.

[2] Baumann, J. & Müller, B. 2007. The dynamic strain sensor: an optical alternative to geophone measurements. *Proc.of the EVACES 2007, Porto, Portugal.*

[3] Bode, J. et al. 2003. Messungen mit Radar- und Dehnungssensoren weisen die Impulswirkung von Sprengungen im Festgebirge nach. *Spreng-Info, 3rd issue, Mitteilungsblatt des Deutschen Sprengverbandes e.V.*: 35-42.

[4] DIN-Taschenbuch 289 2002. Schwingungsfragen im Bauwesen. Berlin-Vienna-Zurich: Beuth-Verlag

[5] Dowding, Ch.H. 2000. Construction vibrations. *NW-University USA.*

[6] Heinze, H. (ed.) 1993. Sprengtechnik: Anwendungsgebiete und Verfahren. 2. Ed.. Leipzig-Stuttgart: Deutscher Verlag für Grundstoffindustrie.

[7] Koch, H. W. 1958. Zur Möglichkeit der Abgrenzung von Lademengen bei Steinbruchsprengungen nach festgestellten Erschütterungsstärken. *Nobel, 24th issue:* 92-96.

[8] Müller, B. et al. 2001. A momentum based new theory of blast design. *10th High Tech Seminar 2001, Nashville, Tennessee, USA*

[9] Müller, B. & Böhnke, R. 2002. Theoretical Simulation and Practical Results at the Optimisation of Blasts in Rock Masses Based on Momentum Theory. *Proc. Fragblast 7 2002, Beijing, China:* 226-235.

[10] Müller, B. & Böhnke, R. 2003. Momentum theory – A new Calculation of Blast Design and Assessment of Blast Vibrations. *Proc. 29th Ann. Conference on Explosives and Blasting Technique, ISEE; Nashville, USA, Vol. II*: 273-283.

[11] Müller, B. & Böhnke, R. 2003. Weltneuheit – Gesicherte Sprengerschütterungsprognose. *Spreng-Info, 2nd issue, Mitteilungsblatt des Deutschen Sprengverbandes e.V.*: 33-41.

[12] Müller, B. & Böhnke, R. 2004. Zünden von Sprenganlagen für Gewinnungssprengungen nach der Impulstheorie. *Spreng-Info, 26 (2004) 3, Mitteilungsblatt des Deutschen Sprengverbandes e.V.*: 19-27.

[13] Müller, B. & Böhnke, R. 2005. Defined blast designs in rock mass. *Proc. 2nd Conf. EFEE 2005, Brighton, United Kingdom*: 307-314.

[14] Singh, P. K., Mohanty, B. & Roy, M. P. 2005. Variation of Characteristic Parameters in Vibration Studies from Production Blasts in Coal Mines. *Proc. 2nd Conf. EFEE 2005, Brighton, United Kingdom*: 551-556.

[15] Persson, P. A., Holmberg, R. & Lee, J. 1994. Rock blasting and explosives engineering. Boca Raton-New York: CRC Press.

[16] Vogel, G. 2000. Zünden von Sprenganlagen. Sondheim v.d. Rhön: Verlag L. Hartmann