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Performance Analysis of the Explosion Applications Realized with Electronic Ignition System at Different Times in the Same Field

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Abstract: In the modern world, the mining and construction sectors are developing rapidly and the need for engineering structures and substructures is increasing day by day. The quarries have been brought to an important place in the world within the scope of mining activities while the products needed by these structures are obtained especially from the quarries. Quarries are generally operated by forming benches according to the open pit mining method. In this production method, considering the state of geological structures in the field, the rocks (limestone, basalt, etc.) loosened by drilling and blasting applications are subjected to size reduction, loading and transportation processes. Therefore, the main objective of the present study is to compare the performance of blasting applications of electronic ignition system together with developing a model that can analyze the performance of ignition systems. In the evaluation of blasting performance, issues such as bulk particle size distribution, crushing and grinding processes, environmental effects, increase in production amount after blasting and cost of blasting were taken into consideration.

Keywords: Drilling, blasting, electronic ignition system, quarry.

Introduction

Environmental problems such as vibration, air shock, dust formation and psychological problems caused by blasting applications are frequently encountered in mining fields and quarries. For this reason, blasting applications should be carried out in a way that eliminates or minimizes the negative effects that may be experienced by anticipating the environmental impacts. In blasted excavations, it is very important to increase productivity and to reduce production costs. With the technologies developed for the ignition systems, it has become possible to give the desired delay time to the capsules by the user, to intervene in the hole functions, to follow each stage in blasting applications and to control the entire ignition system before blasting. In addition, in blasting operations, it is becoming more and more important to analyze the performance of blasting applications by reviewing the variables of both field and blasting systems.

Ignition Systems

In blasting operations applied in mining and quarries, selection of explosive material and ignition system is one of the controllable parameters. In terms of cost and detonation performance, the selection of the appropriate ignition system for the field is a very important factor. In order to achieve the expected success in blasting applications, it is also necessary to make the right choices in hole geometry, explosive material selection and machine/equipment use.

Ignition systems constitute the beginning of blasting operations, but the selection of the ignition system that is not properly determined is sufficient to adversely affect a blasting operation alone (Alpaydin et al., 2012).

Today, the ignition methods used for blasting applications are divided into three main groups (Bilgin, 2003).

- Non-electric ignition methods: Safe cord-ordinary capsule, detonating cord, non-electric shock tube capsules.
- Electric ignition methods: Non-delayed and delayed types of electrical capsules.
- Electronic ignition methods: A microchip has been added to the capsule as in the computers, so that the desired delay time can be given to the capsule.

Electronic capsules are fully programmable capsules. These capsules are capable of bi-directional communication. Each capsule has an identification number (ID) printed on the microchip and assigned by the manufacturer. Delay times are defined in the capsules so that the user controlling the blasting application can test all stages of the capsules (Fig. 1) (Infomine, 2009).

Additionally, the performance of electronic detonators has gradually been increased for various purposes such as vibration control and improved fragmentation (Lee et al., 2019).

Ground Vibration and Air Shock Monitoring Systems

Some of the technical features required by ground vibration and air shock monitoring systems are as follows.

Fig. 1 Electronic capsules (Unitronic 600).

A typical example of the ground vibration and air shock monitoring device is given in Figure 2. It consists of transverse, longitudinal and vertical sensors, microphone, charge, printer, computer connection system, control and memory, storage and transportation units. The seismograph (Instantel) device can measure three-dimensional vibrations (PPV; mm/s), as well as it can calculate the vector sum of 3D movements. These movements are longitudinal (Long (L)), lateral (Transverse (T)) and vertical (Vertical (V)) movements. In addition, vector resultant particle velocity (VS) and top particle velocity (PPV) values are presented in the seismograph device chart. These values can be displayed at any time with the digital indicator on the device and the recorded data can be transferred to the computer environment for detailed analysis.

The frequency of the geophone used in the study is 4 Hz. device features are given in Table 1.

Fig. 2 Instantel micromate vibration measuring device.

Table 1 Instantel micromate device features.

Channels	Microphone and Triaxial Geophone (ISEE or DIN)
Distance	Up to 254 mm/s (10 inches/s)
Response standard	ISEE or DIN 45669-1
Solution	0,00788 mm/s (0,00031 inches/s)
Accuracy (ISEE / DIN)	+/- 5% or 0.5 mm / s (0.02 inch / s), whichever is greater, 4 to 125 Hz / DIN 45669-1 Standard
Transducer Density	2,0 g/cc (127 lbs/ft^3)
Frequency Range (ISEE / DIN)	Ideal flat response between 2-250 Hz, 0 - (- 3) dB / 1 to 315 Hz
Maximum Cable Length (ISEE / DIN)	1000 m (3280 ft)

The device can record instantly or continuously in applications. It has the ability to record 150-200 applications in broad or summary information during each activity. The measurement limits of the device are in the range of 100-148 dB for noise and 0.1127 - 253.9746 mm/s for particle velocity. The desired ranges within these values can be adjusted from the digital display. The information of the user, the duration of the event to be recorded, the working area, the recording format (single or continuous) and the desired units can be programmed in a predetermined manner (Bagdatli, 2013).

Concept of Performance Analysis

When the definitions of performance are examined in the literature, it is seen that there are different definitions. According to Kenger (1986), performance is defined as the performance of a given job in a certain time period and with a certain working speed. Bozkurt, et al. (1998) stated performance as “job performance” and the degree of success in any job. Bilgin (2004) defined performance as a result of a planned and purposeful activity.

As it can be understood from the different interpretations in the relevant literature expressing performance and the definitions given above, it is necessary to have a defined target in order to talk about the concept of performance. In this sense, performance is defined as where the works carried out for the intended target are located and whether the target is achieved or not (Atakus, 2006; Oyman, 2010; Peru, 2010).

Performance Parameters

In the present study, as a result of the literature researches about performance parameters, the three most accepted performance parameters are mentioned.

a. Effectiveness, b. Efficiency, c. Effectivity.

However, a separate value which is obtained by multiplying effectiveness, efficiency, effectivity and defined as the performance index value of the ignition system has been used in the present work. Thus, it is thought that a more accurate judgment can be reached about the whole system. This can be explained by the fact that the performance of the ignition system cannot be high, even if the expected performance dimensions are at the highest level.

a) Effectiveness

It helps to determine the degree of achievement of the objectives defined by the enterprises. Effectiveness is also defined as a degree of competence (Oluc, 1978).

Effectiveness is a comparison between the goals that enterprises desire to achieve and what they achieve. This comparison can be shown by Equation 1.

Effectiveness = Realized Result (Output) / Expected Result (Output)…………………………………..…(1)

If the results obtained from the equation are greater than 1, the enterprise is more effective than it should be and, if it is less than 1, it shows a lower performance than expected (Oluc, 1978).

In the present study, the concept of effectiveness was evaluated in two different ways and adapted to the system. In the first case (E1), it was used to determine the performance of vibration levels caused by blasting applications at different times by electronic ignition systems. In the second case (E2), it was used to determine to what extent the blasted particles formed after blasting applications met the objectives of the enterprise in terms of particle size distribution. Since the highest production efficiency is aimed at the enterprises, the effectiveness ratio is expected to converge to 1. However, in blasting applications, it is very possible that the effectiveness ratio converges to 0, since it is desired to minimize vibration values and particle size of blasted heap. This situation can be explained as a target of all enterprises in terms of low vibration values due to blasting applications and minimizing environmental impacts. In addition, due to the optimum heap particle size obtained after blasting, both loading, transportation, crushing-grinding and energy costs will be considerably reduced (Ercins, 2018).

b) Efficiency

Efficiency is a performance parameter that shows the extent to which an enterprise makes use of the resources used in production or how it uses the production resources in the process of producing or providing services. Efficiency also explores the ability of enterprises to make the most of their resource potential. The calculation of efficiency is determined from Equation 2 given below (Akal, 2005).

Efficiency = Consumed input/ Potential input……(2)

Potential greater than 100% indicates a higher efficiency level. A ratio of less than 1 is indicative of inefficiency or low efficiency. In the present study, the concept of efficiency is associated with specific charge which is defined as the amount of explosive (kg) required to disintegrate 1 m^3 of rock with a unit of kg/m^3. Thus, in order to determine which ignition system or which blasting application is more efficient, the application with a smaller specific charge value should be considered. Because it is desirable to have a high amount of production, which is accepted as output in enterprises, and to have a low specific charge in blasting applications in mining operations. For this purpose, by adapting the efficiency criterion given in Table 2 to the system, it is aimed to obtain more detonated material against the amount of explosive material to be used at optimum level (Ercins, 2018).

c) Effectivity

Effectivity is the ratio between the product produced and the factors involved in production, in other words, the amount of values produced and the amount spent and required during production (Kucukberksun, 1983).

Guran (2005) defined effectivity as the relationship between the amount of output produced and each unit input used in terms of the services or products produced. Effectivity is a result of the ratio of outputs to inputs, which is expressed in Equation 3 below (Celep, 2016).

Effectivity = Physical output / Physical input……….(3)

In this study, the effectivity analysis is based on the cost of drilling and blasting and it is accepted that if this cost is lower or if the total amount of material released after blasting is high, the effectivity will be higher.

In the calculation of effectiveness and effectivity values, the formulas shown in Table 2 and in the literature were used and it was stated that the application with smaller value or closer to zero had more performance than the results obtained. However, the effectivity criterion is adapted to the system differently from the formula given in the literature (Equation 3) and this situation is explained as follows (Ercins, 2018).

In the performance analysis, there may be an inverse relationship between some inputs and outputs or some of the inputs may decrease / increase depending on the increase/decrease of the output. The solution developed in the literature to solve this problem is the "normalization" of the available data. In this case, the data set must be converted to a range of 0 to 1. When the data set is converted to a range of 0 to 1, the inputs that change in the opposite direction will be reduced in the same direction (Cherchye, 2001; Bayazitli et al., 2004).

The aforementioned normalization situation is adapted for the efficiency criterion in the present study. In order to maintain the integrity of the study and to prevent the mathematical meaningless results of the performance index values (PID1, PID2) obtained by multiplying the effectiveness, efficiency and effectivity criteria, the effectiveness values should be in line with the results obtained from the efficiency and effectivity formulas. In this way, however, it can be said that the effectiveness, efficiency and effectivity values each perform better as they approach zero separately. In this context, the effectivity values obtained were converted into a range of 0 to 1 (1/effectivity values) and their performance was determined. The multipliers forming the performance index values are only in the same direction and the performance index values approach to zero (Ercins, 2018).

The formulas adapted to determine the performance parameters of blasting applications are given in Table 2.

Table 2. Adapted performance parameters for blasting (Ercins, 2018)

Performance Parameters	Theoretical General Description	System Application
Effectiveness, E1, (for vibration)	Actual result	Vibration value measured in blasting (mm / sec) / Expected vibration value (mm/sec)
E2, (for heap particle size)	Expected result	Average heap particle size (cm) / Expected (desired) average heap particle size (cm)
Efficiency, V1, (Specific charge)	Consumed inpu / Potential input	Specific charge defined after blasting (kg/m³) / Calculated specific charge before blasting (kg/m³)
Effectivity, V2, (Cost)	Output / Input	1 / [(Material exposed after blasting (m³) x Material unit cost ($/m³)) / Total drilling and blasting cost ($)]

Within the scope of the present study, vibration, particle size and cost factors where the measurements and analyses of the electronic ignition system are made, and examined. In this sense, effectiveness, efficiency and effectivity concepts were calculated separately for each factor and they were also compared with each other.

Electronic Ignition Applications

A mine company, in which an electronic blasting application was performed at its site, requested that no information about its companies be used in line with its own management principles. Therefore, no information about the field and geological structure could be given, but the blast and pattern data for blasting applications are listed in Table 3.

Table 3. Blast and pattern data (Ercins, 2018)

Blasting No	Blasted Rock Density (ton/m³)	Slice Thickness (m)	Distance between Holes (m)	Length of Hole (m)	Total Number of Holes	Amount of Explosive per Delay (kg)	Measurement Distance (m)
1	2,70	2,5	2,5	7,5	208	17,5	240
2	2,70	2	3	8	208	17	87,14
	2,70	2,5	2,5	7,5	268	17,5	249
3	2,70	2,5	2,5	7,5	268	17,5	140
	2,70	2,5	2,5	7,5	268	17,5	154,67
	2,70	2,5	2,5	12	105	37,5	130
4	2,70	2,5	2,5	12	105	37,5	207
	2,70	2,5	2,5	12	105	37,5	259
	2,70	2,5	2,5	12	182	32	130
5	2,70	2,5	2,5	12	182	32	193
	2,70	2,5	2,5	12	182	32	226
	2,70	2,5	2,5	6,8	24	14,5	205
6	2,70	2,5	2,5	6,8	24	14,5	180
	2,70	2,5	2,5	6,8	24	14,5	160
	2,70	2,5	2,5	7,6	112	17,85	104
7	2,70	2,5	2,5	7,6	112	17,85	228
	2,70	2,5	2,5	7,6	112	17,85	259
	2,70	2,5	2,5	7,5	132	17,3	152
8	2,70	2,5	2,5	7,5	132	17,3	188
	2,70	2,5	2,5	7,5	132	17,3	191
	2,70	2,5	2,5	6	128	13	152
9	2,70	2,5	2,5	6	128	13	175
	2,70	2,5	2,5	6	128	13	201
	2,70	2,5	2,5	10	50	30,5	122,5
10	2,70	2,5	2,5	10	50	30,5	361
	2,70	2,5	2,5	10	50	30,5	290

The hole pattern of the blasting applications in the field is given in Figure 3.

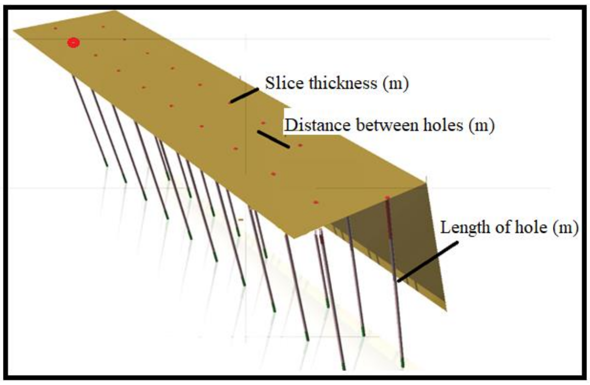

Fig. 3 Hole pattern in the field.

Data obtained from blasting applications by electronic ignition in the mine area (Table 4). The first performance index value given in this table (PID1); the effectiveness value (E1) and efficiency (V1) and effectivity (V2) values calculated for the vibration level, the second performance index value (PID2); is calculated by multiplying the effectiveness value (E2) and efficiency (V1) and effectivity (V2) values for the heap particle size.

In the same field, blasting applications carried out at different time intervals, 4 and 5 blasting electronic ignition applications are compared in Table 4 as an example, it is seen that application number 4 is more effective in terms of providing low vibration value. Similarly, it can be said that the application value 4 is more effective in providing the appropriate bulk particle size and the efficiency value is better in providing a lower specific charge value. When the performance index values obtained from multiplication of effectiveness, efficiency and effectivity values are compared, it can be stated that application 4 is more efficient than application 5. In this way, other blasting applications in the field can be compared in themselves.

Results and Discussion

The electronic ignition system is a preferred and widespread system in terms of optimizing the heap particle size by determining the delay times between the holes and inside the holes by the user and minimizing the damaging potential of the vibrations during blasting works. In addition, the common use of electronic ignition systems and lower unit costs will positively affect the performance of electronic ignition.

Because of the conformable use of electronic ignition systems and lower unit costs, more effective, more efficient and high-performance blasting applications will be possible. High performance means that vibration values during blasting are minimized and rock fragmentation is more suitable for the desired particle size.

Table 4 Data of Electronic Ignition Applications (Ercins, 2018).

Blasting No	Measured Vibration Value(mm/sec)	Desired Max. Vibration Value (mm/sec)	Average Particle Size (cm)	Desired Max. Particle Size (cm)	Specific Charge before Blasting (kg/m^3)	Specific Charge after Blasting (kg/m^3)	Calculated Material to be Exposed before Blasting (m^3)	Measured Material Exposed after Blasting (m^3)	Material Unit Price ($/m^3)	Total Drilling and Blasting Cost ($)	Effectiveness, (Vibration) (E1)	Effectiveness, (Heap Particle Size) (E2)	Efficiency (V1)	Effectivity (V2)	Performance Index Value (PID1)	Performance Index Value (PID2)
1	1.270	5	25.599	80	0.373	0.333	9750	10889	4.5	12053	0.2540	0.3200	0.8917	0.2460	0.0557	0.0702
2	1.778	5	25.599	80	0.354	0.332	9984	10537	4.5	12003	0.3556	0.3200	0.9379	0.2531	0.0844	0.0760
3	2.413	5	27.051	80	0.373	0.351	12563	13407	4.5	14864	0.4826	0.3381	0.9390	0.2464	0.1116	0.0782
	4.699	5	27.051	80	0.373	0.351	12563	13407	4.5	14864	0.9398	0.3381	0.9390	0.2464	0.2174	0.0782
	1.778	5	27.051	80	0.373	0.351	12563	13407	4.5	14864	0.3556	0.3381	0.9390	0.2464	0.0823	0.0782
4	4.191	5	24.301	80	0.500	0.466	7875	8587	4.5	8987	0.8382	0.3038	0.9317	0.2326	0.1816	0.0658
	5.080	5	24.301	80	0.500	0.466	7875	8587	4.5	8987	1.0160	0.3038	0.9317	0.2326	0.2202	0.0658
	3.302	5	24.301	80	0.500	0.466	7875	8587	4.5	8987	0.6604	0.3038	0.9317	0.2326	0.1431	0.0658
5	4.318	5	24.939	80	0.427	0.482	13650	12296	4.5	13059	0.8636	0.3117	1.1293	0.2360	0.2302	0.0831
	5.969	5	24.939	80	0.427	0.482	13650	12296	4.5	13059	1.1938	0.3117	1.1293	0.2360	0.3182	0.0831
	4.826	5	24.939	80	0.427	0.482	13650	12296	4.5	13059	0.9652	0.3117	1.1293	0.2360	0.2573	0.0831
6	0.508	5	28.840	80	0.341	0.329	1020	1063	4.5	3489	0.1016	0.3605	0.9651	0.7294	0.0715	0.2538
	1.778	5	28.840	80	0.341	0.329	1020	1063	4.5	3489	0.3556	0.3605	0.9651	0.7294	0.2503	0.2538
	1.270	5	28.840	80	0.341	0.329	1020	1063	4.5	3489	0.2540	0.3605	0.9651	0.7294	0.1788	0.2538
7	2.540	5	25.324	80	0.376	0.353	5320	5670	4.5	7751	0.5080	0.3166	0.9386	0.3038	0.1448	0.0903
	1.270	5	25.324	80	0.376	0.353	5320	5670	4.5	7751	0.2540	0.3166	0.9386	0.3038	0.0724	0.0903
	1.270	5	25.324	80	0.376	0.353	5320	5670	4.5	7751	0.2540	0.3166	0.9386	0.3038	0.0724	0.0903
8	1.524	5	25.786	80	0.369	0.353	6188	6474	4.5	8633	0.3048	0.3223	0.9563	0.2963	0.0864	0.0913
	3.429	5	25.786	80	0.369	0.353	6188	6474	4.5	8633	0.6858	0.3223	0.9563	0.2963	0.1943	0.0913
	2.540	5	25.786	80	0.369	0.353	6188	6474	4.5	8633	0.5080	0.3223	0.9563	0.2963	0.1440	0.0913
9	1.397	5	27.058	80	0.347	0.322	4800	5204	4.5	8027	0.2794	0.3382	0.9285	0.3428	0.0889	0.1077
	2.667	5	27.058	80	0.347	0.322	4800	5204	4.5	8027	0.5334	0.3382	0.9285	0.3428	0.1698	0.1077
	2.159	5	27.058	80	0.347	0.322	4800	5204	4.5	8027	0.4318	0.3382	0.9285	0.3428	0.1374	0.1077
10	2.159	5	23.943	80	0.488	0.396	3125	3856	4.5	5199	0.4318	0.2993	0.8105	0.2997	0.1049	0.0727
	1.397	5	23.943	80	0.488	0.396	3125	3856	4.5	5199	0.2794	0.2993	0.8105	0.2997	0.0679	0.0727
	2.159	5	23.943	80	0.488	0.396	3125	3856	4.5	5199	0.4318	0.2993	0.8105	0.2997	0.1049	0.0727

In order to control and optimize blasting applications, each application must be measured and recorded with a vibration measuring device. Based on the recording values obtained from the measurement results, studies should be conducted for performance analysis and the issue of how to perform the next blasting with more performance according to the results obtained should be studied. In addition, by calculating the cost of blasting, the specific charge value should be continuously controlled. As a result of the continuity of the works, there will be a decrease in blasting, loading, crushing, transportation and energy costs.

By the help of the present study, the performance of blasting applications with electronic ignition system in the field has been converted into numerical expressions. Thus, blasting applications at the same site at different times can be compared with each other. Consequently, the optimum blast pattern values and optimum amount of explosive material can be determined for the application area and the blasted material can be obtained at the highest level. Thus, total production costs will be reduced compared to unit costs.

Conclusion

With the results obtained from the performance values of the blasting applications carried out with electronic ignition systems at different times at the same site, studies will be provided on which of the blasting performed is more efficient for the field and how the subsequent blasting applications should be performed with higher performance. In order to perform these studies, optimum blasting performance value can be achieved by changing the rock and pattern information of the field. As a result, there will be an improvement in blasting, loading, crushing, transportation and energy costs.

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