Investigation of Delay Time Precision in Pyrotechnic Detonators

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ABSTRACT

Despite advancement of initiating devices, use of electrical detonators with pyrotechnic composition is common in Indian mining and construction industry. The cost benefit achieved by electrical detonators over shock tube initiation system and electronic detonators is huge. Delay detonators made with pyrotechnic delay compositions have inherent scattering in their delay timings. It is desirable to use precise detonators to achieve better fragmentation, less vibration and noise. Overlapping of delay period is undesirable from production as well as safety point of view.

In order to assess delay accuracy of electrical pyrotechnic detonators of a domestic manufacturer, randomly selected fifty units from each delay period (0 to 6) from the same batch of detonators that were found suitable for use in underground coal mines in respect of their incendivity, handling & electrical safety, performance and water resistance characteristics were evaluated. Overlapping possibilities amongst delay periods were evaluated by calculating Winzer index and graphical methods.

The findings reveal that significant scattering exist in all the delay periods. Scattering increases with higher delay periods. Overlapping possibilities between delay period 5 and 6 is found to be significantly high. Winzer index for the pair of delay period 5 and 6 is found to be very close to the threshold value for overlapping.

Keywords: Permitted delay detonator; Overlapping; Inflammable mixture; Delay time; Blasting off-the-solid; Pyrotechnic composition.

1. INTRODUCTION

Blasting off-the-solid is the most commonly used method for development of galleries in Bord and Pillar method of underground coal mining. In this method, only P_5 explosives are used with permitted delay detonators in accordance with the safety requirements stipulated by the regulatory bodies. These detonators are designed to initiate multiple charges of high explosives in succession with a single application of firing current in the blasting circuit. Delay detonators should initiate explosive charges in a timely order so that the rock fragmented by the previous delays gets a chance to move out before the next round of delays are fired.

In permitted detonators, delay timing is provided using delay element made up of pyrotechnic composition. Pyrotechnic detonators have inherent scattering in their delay timings. This technology is limited in precision because of restriction of manufacturing capabilities and the effect of physical factors introduced in blasting such as length time lapsed since manufacturing, temperature and preconditioning due to stress pulses from surrounding holes (Cunningham, 2000 & Rossmanith, 2000).

In India, permitted detonators are evaluated in respect of their incendivity, handling and electrical safety, performance and water resistance characteristics as per IS:6609 (Part-III) (Verma and Roy, 2003) and guidelines issued by Directorate General of Mines Safety (DGMS) for granting approval for use in underground coal mines. These guidelines do not emphasize on the delay accuracy.

In order to get an idea of the accuracies available from current pyrotechnic delay detonator technology, firing accuracies of permitted copper coated millisecond delay detonators used in blasting-off-solid were evaluated. This paper presents findings of the study on the firing accuracy of delay detonators manufactured by a domestic manufacturer. Fifty detonators of each delay numbers (0-6 delays) with nominal delays ranging from zero ms (instantaneous detonator) to 150 ms, spaced at 25 ms intervals were tested for timing accuracy. These detonators were selected randomly from the same batch of detonators which was found suitable for use in underground coal mines in respect of their incendivity, handling and electrical safety, performance and water resistance characteristics (Verma and Roy, 2003). Dual-Input, digital oscilloscopes (Fluke make) are used for measuring firing times.

The data reported in this paper include average firing time, standard deviation, and the fastest and the slowest firing times for each delay period. Test results indicate that the timing accuracy of delay detonators utilizing pyrotechnic delay elements have significant scattering over the measured nominal values. In this paper authors have determined Winzer Index (S-value) for each delay period and analysed overlapping possibility between adjacent delay periods.

2. PYROTECHNIC COMPOSITION AND DELAY ACCURACY - A REVIEW

In a typical pyrotechnic delay detonator, electrical energy from the firing source flows through the insulated leg wires to the bridge wire embedded in the electric match assembly. The bridge wire activates the heat sensitive pyrotechnic ignition material of the match assembly which in turn initiates the delay element. The delay element initiates the primer charge which in turn detonates the base charge. The primer charge is a sensitive high explosive and the base charge is Pentaerythritol tetranitrate (PETN) or a similar high explosive. The delay element in a delay detonator contains a pyrotechnic mixture and its delay time is governed by the mixture composition, grain size and loading density of the powder. A plastic or rubber plug is securely crimped at the open end of the metallic shell to form a water-resistant closure. A firing current of 1.5 to 2.5 A is recommended for optimum performance. A firing current of over 10 A is undesirable and may cause the detonator to malfunction through arcing (Bajpayee et al., 1985).

For successful and efficient blasting, delay detonators should get fired in the sequence as they are intended. But, if scattering in delay timings of the detonators is more, it may cause out-of-sequence firing of blast holes. Inaccuracies in firing delays cause shooting out of sequence (overlap), blown out shots, excessive fly rock, uneven back breakage, excessive ground vibration and air blast. Blowing out of shot holes in underground coal mines is considered to be hazardous as the explosive flame may ignite the possible inflammable mixture of coal dust or methane – air mixture (Verakis, 1989 and Taylor and Gay, 1958). The importance of delay accuracy in reducing ground vibration and airblast has also been emphasized by industry.

Chiappetta et al. (1989) conducted an extensive study of 26 full-scale production blasts and demonstrated that accurate delays helped in reducing ground vibration and airblast, and improved fragmentation. Therefore, measured delay times of permitted delay detonators should be within a defined range of their nominal values to avoid overlapping possibilities and improved blasting results.

Winzer (1978) conducted a study on the firing times of delay detonators and their relationship to blasting performance. This study reveals that considerable scatter existed in firing times and in some cases the firing times of adjacent period delay detonators were reversed. In response to Winzer's findings major manufacturers began developing more accurate pyrotechnic delay detonators (Rholl and Mark, 1988).

In a study of delay detonator accuracy, Winzer et al. (1979) derived an index to quantify the probability of overlap between successive delays. The Winzer index, ‘S’ is defined as:

$$S = \frac{T_{n+1} - T_{n} - r}{\left[S_n^2 + S_{n+1}^2 \right]^{1/2}}$$

Where

T_{n+1} = average delay time period for (n+1) delay number,
T_n = average delay time period for n^{th} delay number,
r = required firing time interval between adjacent number,
S_{n+1} = standard deviation of periods of n+1 delay number, and
S_n = standard deviation of periods of n^{th} delay number.

According to Winzer, $S < 3$ indicates significant probability of overlap between adjacent delay periods.

In an experiment conducted by CMRI (now CIMFR), India (Nabiullah et al., 1989 and Singh and Roy, 1993) numbers of commercial delay detonators were assessed for delay accuracy. They found significant overlapping possibility in many types of detonators and recommended to evaluate detonator, selected randomly before use in rock blasting.

In recent past, researchers have carried out extensive work to put delay accuracy in proper perspective. The explosive industry is responding to this requirement by manufacturing more accurate delays. The improved accuracy has been credited with more efficient fragmentation, increased production, better control of muck displacement and reduced vibration and flyrock (Bajpayee et al., 1985). Therefore, precisely controlled production of delay elements is eminent in manufacturing technology of pyrotechnic detonator to ensure accurate timing

3. EXPERIMENTAL TECHNIQUE

A new set-up is designed and fabricated for measurement of delay timing of electric detonators. Schematic circuit diagram of the setup is given below as Fig. 1.

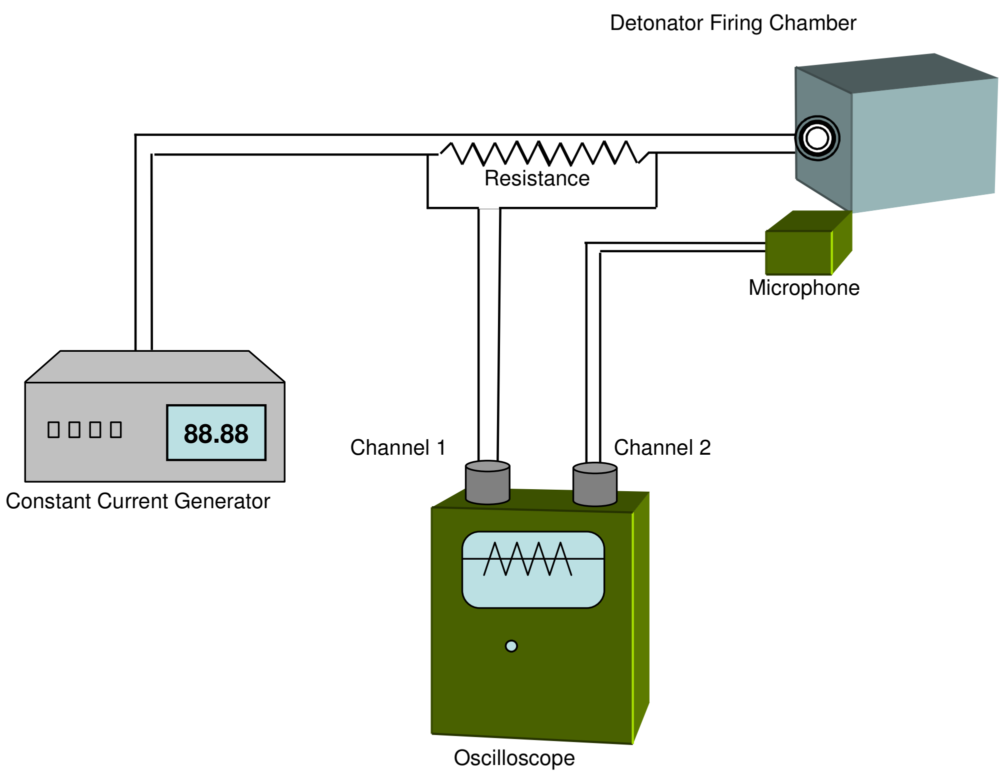

Fig. 1: Schematic circuit diagram of set-up for measurement of delay timing

Constant current generator (CCG) unit, a two-channel digital oscilloscope and a microphone are the major components of the measurement set-up (Fig. 1). CCG unit supplies current in the range of 0.2A to 3.0A with increment of 0.1A for 4ms irrespective of the resistance of the electric circuit attached in its output circuit. This unit is provided with a safety gate to protect against the inadvertent firing of the detonators. Digital oscilloscope having real-time high sampling rate of 2GS/s is used in the set-up for reliable and accurate measurement. Microphone, kept at 0.8m (2.6 feet) near the firing chamber in all the trials, generates an electric pulse by receiving the sound generated from detonator firing in the firing chamber.

To measure delay timing, intended detonator is kept inside the firing chamber and lead wires of detonator are connected to CCG unit and other components are also connected as shown in Fig. 1. After necessary adjustment for balancing the resistance of the output circuit, direct current of 1.20A is supplied to the detonator circuit for 4 ms as specified by DGMS, India. The magnitude and time of current supply to detonator is recorded and shown as peak in channel-1 as shown in Fig. 2. As soon as detonator is fired, sound so produced is recorded by microphone connected in another channel and is displayed as another peak in channel-2 of the oscilloscope. The time elapsed between the start of current supply and the time when detonator detonated is the delay time of detonator and it can be worked out by moving cursor between the peaks. Oscilloscope display of the recordings for the measurement of delay timing of delay number 3 (nominal delay of 75 ms) is given in Fig. 2 to make it more illustrative.

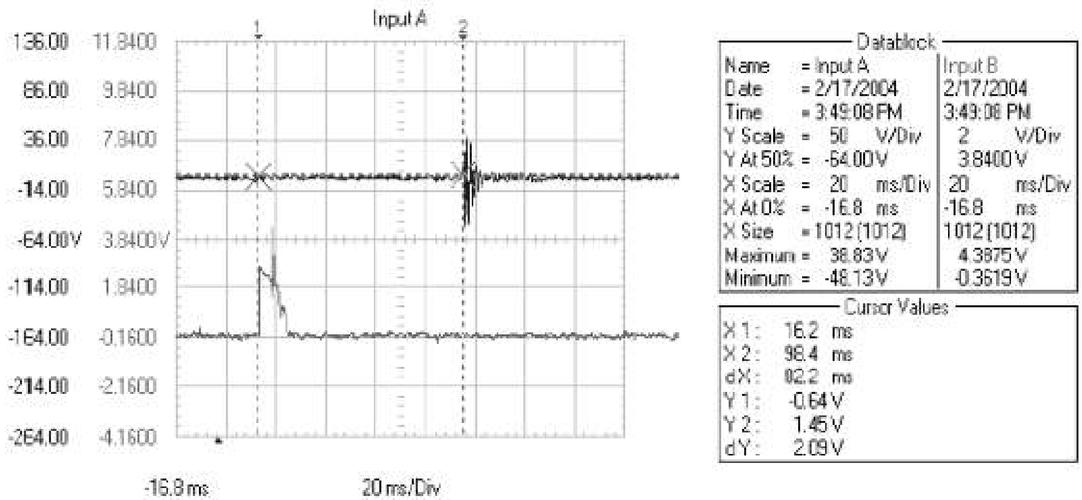

Fig. 2: Results of oscilloscope recording of delay timing of delay number 3

4. RESULTS AND DISCUSSIONS

Measurement of fifty numbers of permitted electric detonators is carried out one by one with the help of the set-up detailed in Fig. 1. Measured values of the delay time of all the detonators of each delay period (0-6 delays) are plotted against number of trials in Fig. 3 to get an idea of scattering of the measured delay time. Figure 3 clearly reflects increase in scattering and deviation from the nominal declared delay times with increase of delay period. Detonators with less delay timing exhibit good accuracy and less scatter, whereas higher delay periods yield relatively large variations in firing time and exhibit more scattering.

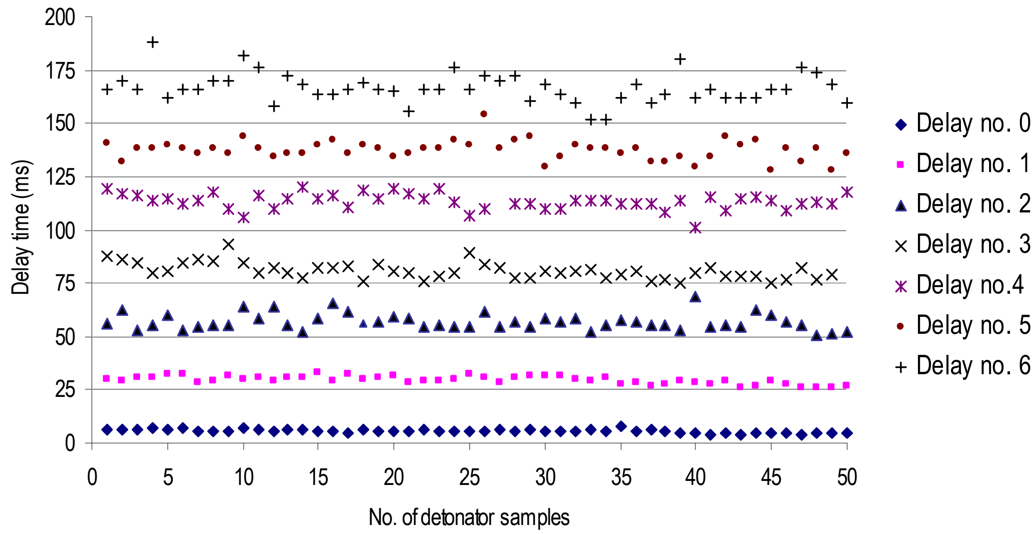

Fig. 3: Plot of measured delay time with number of trials

Measured delay values of these detonators are analysed statistically. Table 1 summarises maximum, minimum, nominal, average value of measured delay time with standard deviation for each delay period.

Table 1: Results of statistical analysis of measured delay time

Delay no.	Nominal declared delay interval (ms)	Statistical analysis of measured delay timing				Number of detonators outside the nominal declared range
		Minimum (ms)	Maximum (ms)	Average (ms)	Standard Deviation	
0	5-8	4.0	8.2	5.63	0.82	Nil
1	25 ± 10	26	33.2	29.75	1.92	Nil
2	50 ± 10	50.8	68.8	56.88	3.87	8
3	75 ± 10	75.2	93.6	80.95	3.88	6
4	100 ± 10	100.8	120.0	113.17	3.78	37
5	125 ± 10	128	154.0	137.38	4.57	37
6	150 ± 10	152	188.0	166.65	6.83	43

It is evident from the graphical and statistical analysis of measured delay timing of these detonators as given in Fig. 3 and Table 1 respectively, that measured delay time of all the delay detonators are higher than their respective nominal value. There is no deviation in the negative side of delay timing in any delay period. The delay timing of significant number of delay detonators, particularly of delay numbers 4 to 6, are found to be out side the declared range.

Measured average value of delay time for each delay detonators is plotted against respective nominal average declared delay time and is shown in Fig. 4. It is found that for all delay detonators (delay numbers 0 to 6) the measured average value of delay time is higher than that of the nominal declared value.

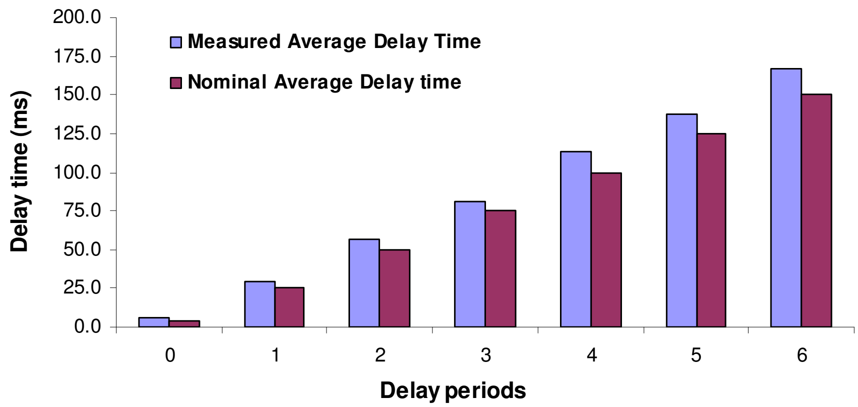

Fig. 4: Comparison of measured and nominal average delay time

In order to assess possibility of overlapping between detonators of two consecutive delays period, maximum value of measured delay timings of a delay period is plotted against the minimum value of measured delay timing observed with next higher delay and plotted in Fig. 5. No overlapping of delay timing was observed between delay period 0-1, 1-2, 2-3, 3-4 and 4-5. However, a few cases of overlapping were observed between delay periods 5-6.

Figure 6 is a plot of multi frequency table developed using measured delay time data of all the 700 pyrotechnic detonators. Ideally, the detonators should occupy a singly vertical column for assigned nominal values of delay time as in case of delay series 1. Figure 6 reveals that the scattering in delay time of each series of detonators is such that it tries to occupy the time slot of subsequent series. Excepting delay series 1, all the values of measured delay time are scattered more in higher delay series. Delay series 4, 5 and 6 have shown greater tendency of scattering. It is also noteworthy that the large number of detonators of delay series 4 and 5 are firing in same time slot of 115- 135 millisecond. Similarly in case of detonator series 5 and 6 are firing in the same time slot of 140 -160 millisecond. This may lead to phenomenon of overlapping.

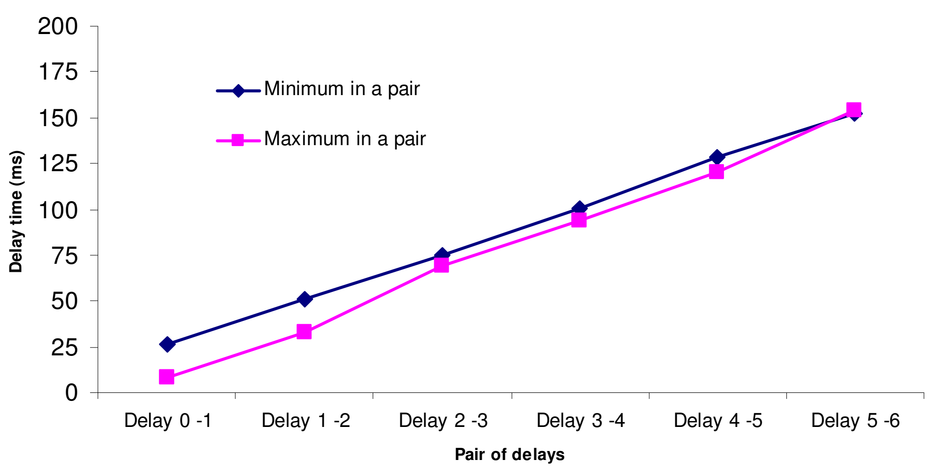

Fig. 5: Plot for overlapping possibility between two consecutive delays

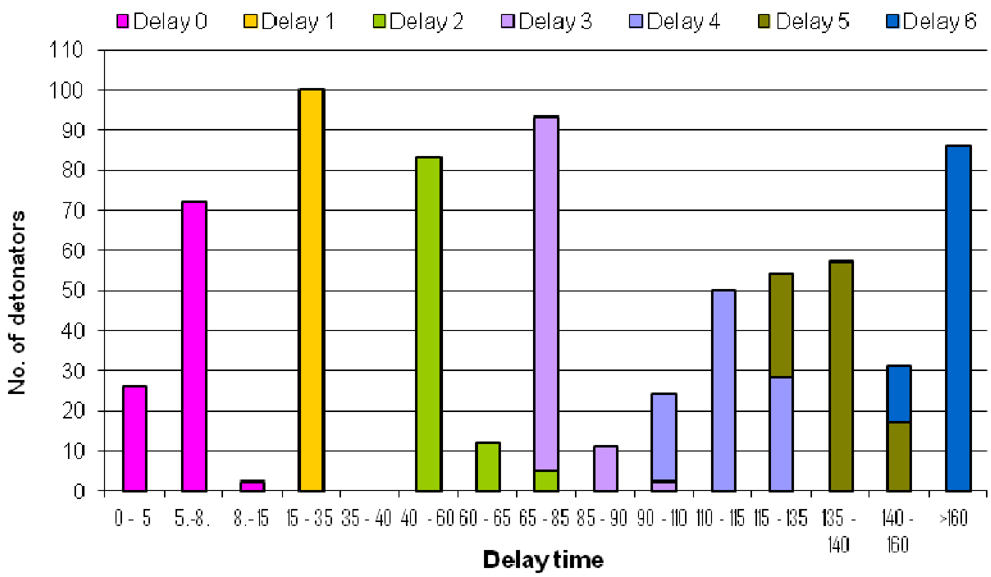

Fig. 6: Plot of mutually overlapping delay time amongst consecutive delays

Winzer index of all the delay periods is shown graphically in Fig. 7. These values also corroborate the finding of the study, the highest overlapping possibility between delay period 5 & 6. The index for these two detonator periods was found to be less than 3 and index of 3 being the threshold value for overlapping between any two consecutive delay periods.

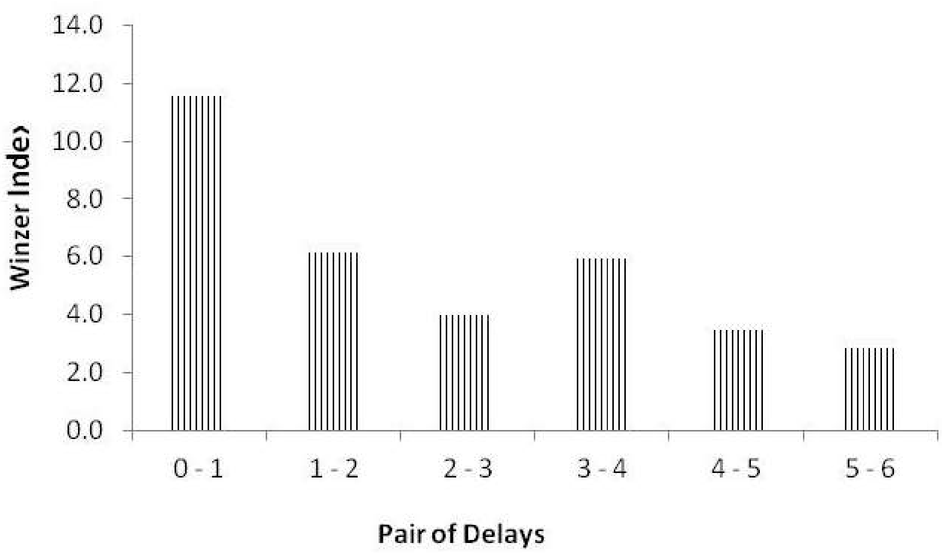

Fig. 7: Plot of Winzer Index for pair of delay periods

5. CONCLUSIONS

In order to assess the accuracies available from permitted delay detonator technology, fifty units each of domestically manufactured delay detonators of all the delay periods (0-6 numbers) were evaluated.

It is evident from the graphical and statistical analysis that the measured delay time for the each delay detonator is higher than their declared nominal value. Further, none of the detonator in any of the delay period recorded deviation in the negative direction.

Although, significant number of detonators particularly of delay numbers 4 to 6 were found to be having their delay time more than the declared nominal range, highest overlapping possibilities between two consecutive delays were observed with delay period 5 and 6 detonators. Winzer index also corroborates the highest overlapping possibility between delay period 5 and 6. The index is found to be 3.56, being very close to value 3, the threshold value for overlapping between any two periods. Therefore, evaluation of permitted detonators with respect to their delay accuracy shall be made mandatory before granting approval for use underground coal mines to eliminate danger of methane or coal dust explosion in underground coal mines.

The production of delay elements must be precisely controlled to ensure accurate timing. More caution with respect to accuracy during manufacturing of pyrotechnic detonator is required so that the measured delay timing of different delays may be within the range of nominal declared values to eliminate overlapping possibilities and improve over all safety and production in the mines.

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