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Reliability analysis for mine blast performance based on delay type and firing time

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ABSTRACT

Mining blasts may be defined as the use of explosive charges in a controlled manner by following a tightly controlled timing sequence according to an assigned firing order. Changes of timing between charges may result in an altered firing order and failure of the blasting sequence, which can cause high vibration levels, poor fragmentation, and/or an undesirable rock mass movement direction. Despite the importance of timing in determining mine blast results, there exists a lack of methodologies or tools with which to assess performance of a complete blast based on delay type and timing sequence. This document applies reliability engineering principles to evaluate the performance of a mine blast. The analyses are based on test results of the accuracy and precision of electronic and pyrotechnic detonators for typical firing times used in a surface coal mine, but may be applied to a variety of mines and timing scenarios.

1. Introduction

Reliability is a broad term associated with the ability of a product to perform its intended function. Mathematically speaking, and assuming that a product is performing its intended function at a time equal to zero, reliability may be defined as the probability that a product will continue to perform its intended function without failure for a specified period under stated conditions. Note that the "product" defined in this context could be an electronic or mechanical product, a software product, a process (a mining blast in this case), or a service, Smith [1].

When assessing the performance of blast timing, the current practice indicates that the performance should be evaluated according to the reliability of the individual detonator, e.g. misfire rate, detonator lifetime. However, for a production blast, the analysis should be carried out by taking into account the entirety of the blasting system, meaning all of the detonators involved instead of just one as traditionally performed. In other words, it is necessary to include all interdependent relations in addition to single component reliability. In this paper, the reliability of a mine blast is studied in terms of the success of the timing sequence for the whole production blast and contains the following aspects: (1) Problem definition; (2) Experimental test results of detonator accuracy and precision; (3) Definition of the reliability of a single delay interval; (4) Development of a reliability block diagram for the problem; (5) Reliability analysis for the whole mine blast.

2. Problem description

The arrangement used for analysis is based on a particular blast design commonly used at a surface coal mine in West Virginia. However, the general procedure presented in this paper can be employed to any other configuration or type of mining. At this particular mine, it is common to use the timing arrangement shown in Fig. 1a for pyrotechnic detonator use, and Fig. 1b for electronic detonator use.

For the pyrotechnic configuration as shown in Fig. 1a, there are two charges divided by a deck in each hole. A deck is a layer of non-explosive material in a borehole which separates the explosive column into two parts so that two in-hole detonators are required to initiate the explosive charges. In addition to the in-hole detonators, 25 ms delays are used on the surface to ensure each charge is initiated by delay intervals of 25 ms in sequence. The first-row cross section shows the timing arrangement for a row of four holes, which contains eight charges. The plan view of Fig. 1a shows the full timing and initiation sequence if one row is expanded to three rows. In total, there are 24 charges, and the firing time of each charge referenced to time zero is labeled beside the hole. The timing interval between two rows is selected as 200 ms, which renders

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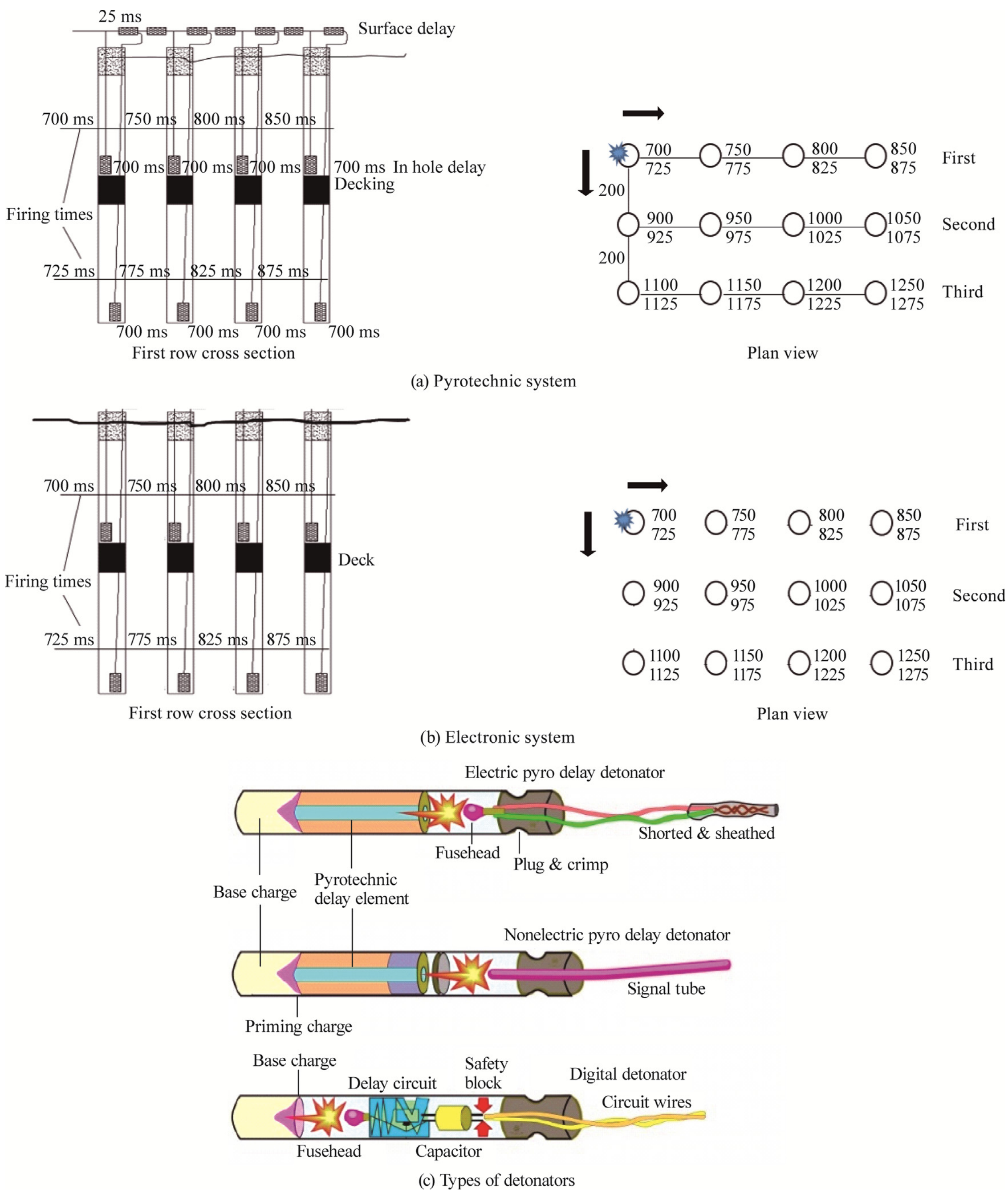

Fig. 1. Timing arrangement of multiple holes [2].

the first hole of the second row and the last hole of the first row to be 25 ms apart. The 200 ms interval is created by using two 100 ms detonators in series for this scenario.

Fig. 1b shows the arrangement of the electronic detonator configuration. In this scenario, each electronic detonator receives the firing signal instantaneously and then detonates according to its programmed time. Thus, each electronic detonator detonates independently. The plan view shows the firing time for each charge in each hole.

In either case (pyrotechnic or electronic), the design timing sequence should be the same (e.g. 700 ms, 725 ms, 750 ms) and the charges should be fired consecutively. For the analysis in this paper, the delay interval is always 25 ms.

Finally, Fig. 1c shows three types of detonators and two types of delay elements (pyrotechnic and electronic). In the pyrotechnic system, the delay is given by the length and burning rate of the chemical component. Therefore, varying the length of this element varies the time delay. In the electronic system, the time delay is controlled by an electronic circuit.

3. Experimental results of accuracy and precision of detonators

3.1. Statistical analysis of test results

The University of Kentucky Explosives Research Team (UKERT), through various studies, has collected data for detonator timing tests. The detail for testing follows the testing setup presented in Lusk [3]. Table 1 shows the results of testing different detonators for the delay times in the problem depicted in Fig. 1.

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