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Determination of the Rate of Ignition of Nitrocellulose by Resistance Wire for the Igniter of KV 150 M2

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Abstract: STN EN 14034 Standard defines the requirements of an igniter for the determination of the explosion characteristics of dust clouds. In order to allow the correct adjustment of the triggering of the igniter (filled with nitrocellulose) by a resistance wire, measurement of the time from the instant of triggering of a real igniter of nitrocellulose were performed by high-speed movie camera recording. This article describes the parameters and results of this igniter.

Keywords: nitrocellulose, ignition, resistance wire

1 Introduction

The research described in this article is oriented towards the determination of the rate of ignition of nitrocellulose with the aim of studying the possible application of a new type of ignitor and its working charge.

STN EN 14034-3+A1:2012-01 Standard defines the requirements for ignition of a dust mixture in an enclosed test space as follows: the ignition source comprises two chemical igniters each having an energy of 5 kJ. The igniters are fired by electrical fuse heads. The power supply circuit for the chemical igniters shall be capable of firing the fuse heads in less than 10 ms. The two chemical igniters shall be placed at the centre of the explosion vessel, firing in opposite directions [1].

Issues concerning the charge in the chemical igniters have been studied, for example, in Refs. [2-4]. In these studies, the authors concentrated on different types of cheap igniters, which meet the conditions specified by the standard. Since this standard, in its most recent update, does not define the composition of the pyrotechnic powder, we have selected nitrocellulose as a working charge in an amount sufficient to produce 5 kJ of energy. This substance is commercially available and not expensive. Its application necessitates partial modification of the conditions specified in the standard.

The modification of these conditions concerns the fact that instead of a fuse head, a resistance wire of defined length and parameters is used as the source of ignition [5]. In this article we deal with the determination of the time for ignition of nitrocellulose by a resistance wire.

This value is important for synchronization of the igniter time parameters mentioned in this article and activation of the dust dispersion system. This igniter could then be used in accordance with EN 14034-3 + A1: 2012-01.

2 Materials and Methods

High speed movie camera recording was selected for measuring the rate of nitrocellulose ignition by a resistance wire.

The nitrocellulose used for the requirements of the igniter was produced by cellulose nitration using a mixture of 96% sulphuric acid and 65% nitric acid, in the volume proportion 2:1; nitration was conducted at a laboratory temperature of 22 °C during 4.5 h [6]. After neutralisation of the acids and drying of the nitrocellulose, the heat of combustion was determined (in a calorimeter) as 3850 kJ/kg.

As the power source for the resistance wire, a 320 VA transformer was used, supplying power equivalent to 6.4 A at 48 V AC voltage to the ignition circuit. The diameter of the resistance wire was 0.05 mm and its resistance for a 68 mm length was 12 Ω. These values would cause instantaneous heating of the wire, and its burning through would occur within about 35 ms. The scheme for the source and resistance wire connections is shown in Figure 1.

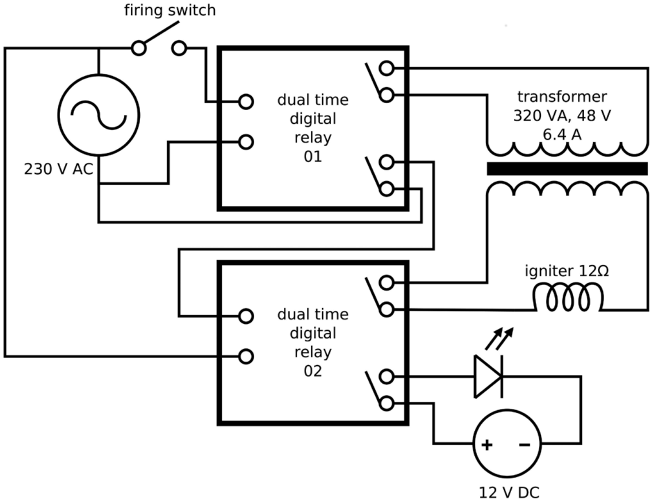


Figure 1. Power source and resistance wire connections, delay time of relay 2 is 0 ms

An aluminium tube of diameter 40 mm and length 80 mm was used as an igniter. The resistance wire was situated in the centre of the tube, and connected to the power source. Its location ensures direct contact with the nitrocellulose. This arrangement is shown in Figure 2.

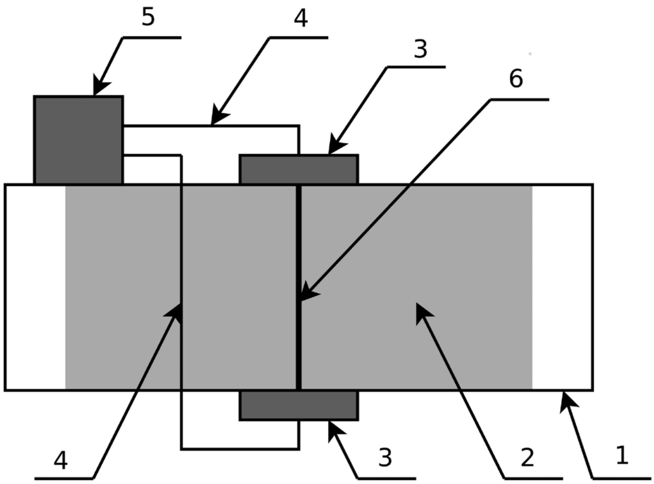


Figure 2. Plan of igniter body: 1 – aluminium tube of igniter, 2 – nitrocellulose charge, 3 – resistance wire holder, 4 – supply conductors, 5 – supply conductor holder, 6 – resistance wire

According to the requirements of STN EN 14034 Standard, each part of the igniter must have a standard calorimetric energy of 5 kJ. At the above-mentioned heat of combustion, it was necessary to load 2.6 g of nitrocellulose in the igniter: this amount of nitrocellulose will produce approximately 10-11 L of gas at 300 °C. This amount of gas is negligible compared to the entire volume of the test chamber (300 L).

The rate of ignition of the nitrocellulose was recorded by a high speed movie camera. We had available a movie camera with a speed of 10 000 frames per second at a resolution of 1280 × 720 pixels, which is sufficient for the determination of the rate of ignition. The start of the ignition was controlled by the digital timing relays and indicated by an LED. The accuracy of the determination of the ignition rate was up to 0.1 ms. The arrangement of the components in the experiments is shown in Figure 3.

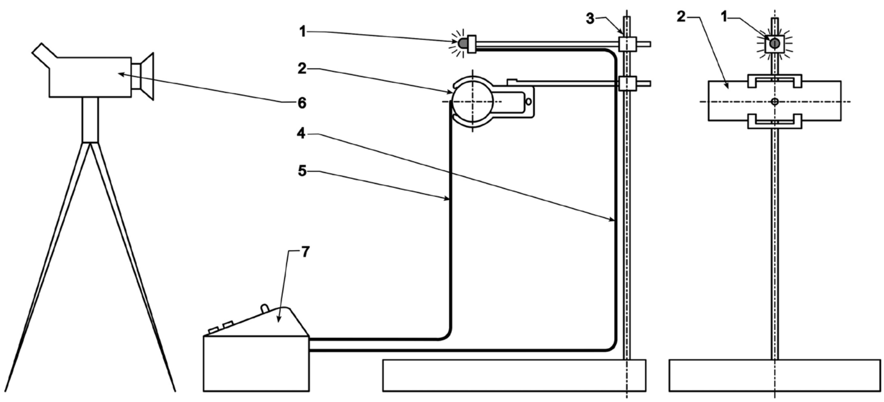


Figure 3. Arrangement of experimental apparatus: 1 – checking diode, 2 – igniter, 3 – stand, 4 – conductors for checking diode, 5 – conductors for igniter, 6 – movie camera, 7 – power source

3 Results

Based on the camera record performed at 10 000 fps (video frame rate 1/10 000 s; shutter opened continuously, with natural lighting; initiation of the ignition controlled by the digital timing relays and indicated by the LED – accuracy 0.01% of circuit closed time; circuit closed for 1 s), the rates of ignition of the nitrocellulose were calculated.

The entire camera record was converted to individual frames (images) using MPlayer program: **mplayer –vo jpeg video.avi** and the rate of ignition of the nitrocellulose (and other processes) was then calculated from the frame numbers using the following formula:

$$t = n \cdot 0.1 \tag{1}$$

where t is the time (ms) corresponding to the number of frames n (ms/frame).

The results of the measurements based on a study of the video-records are given in Table 1.

Table 1. Frames from the video-record with significant events for nitrocellulose ignition

Camera	Number n of frame
Igniter	
Frame range	–2498 to (–1149)
LED on	–2376
First visible flame on the right side of igniter	–1939
First visible flame on the left side of igniter	–1917
The same size of flame on both sides of igniter	–1727
Nitrocellulose ignition	
Frame range	–2795 to (–1487)
LED on	–2439
Visible heating of resistance wire	–2319
Burning of resistance wire	–2075
First visible ignition of nitrocellulose	–2133

Table 2. Results of ignition rate measurements

Process	Time [ms]
Time to visible heating of resistance wire	12.0
Time to glow of resistance wire	36.4
Time to first visible ignition of nitrocellulose	30.6
Time to first visible flame on the right side	43.7
Time to first visible flame on the left side	45.9
Time to same size of flame on both sides of igniter	64.9

Table 2 shows that the time of nitrocellulose ignition is 30.6 ms, and the time of flame flashing from the igniter tube is about 45 ms. These values must be subsequently used in proposals for the dispersal of dusts and their ignition. The average flame speed in a tube of diameter 40 mm was:

$$\bar{v} = \frac{s}{t} = \frac{0.040\ \mathrm{m}}{(0.0437 - 0.0306)\ \mathrm{s}} = 3.05\ \mathrm{m{\cdot}s^{-1}} \tag{2}$$

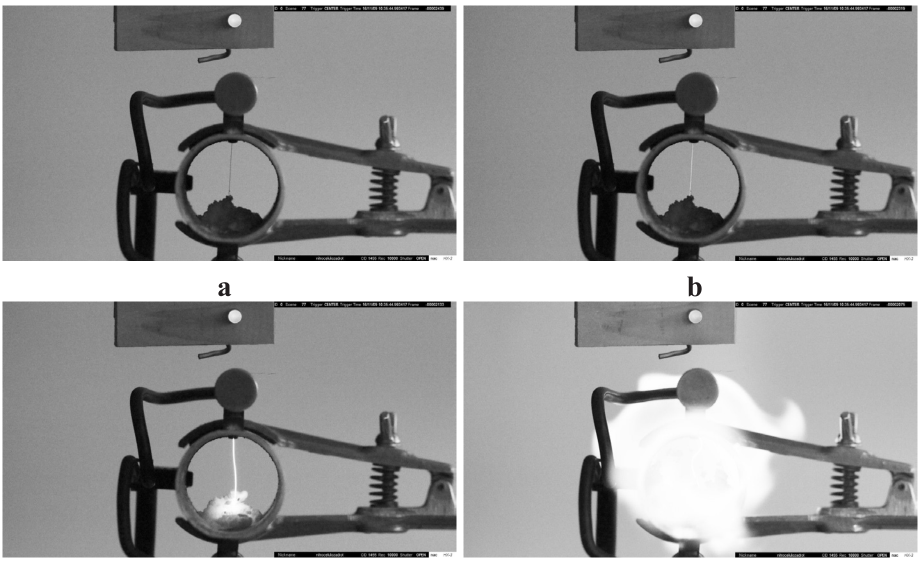
where $\bar{v}$ is the average speed of the flame, s is the half length of the igniter tube and t is the time from the ignition of nitrocellulose to the first visible flame.

The time t from switching of the igniter to flame flashing from the tube of diameter 40 mm and various lengths was:

$$t = 30.6 + \frac{s}{\bar{v}} = 30.6 + \frac{s}{3.05\ \mathrm{m{\cdot}s^{-1}}} \tag{3}$$

where s is the half length of the tube.

Photographs of the records of the ignition of nitrocellulose wound on the resistance wire are shown in Figures 4 (a)-(d), and the course of nitrocellulose ignition in the igniter body is shown in Figures 5 (a)-(f).



a **b** **c** **d**

Figure 4. The course of nitrocellulose ignition in contact with the resistance wire: (a) switching on of the trigging circuit, frame –2439, (b) visible heating of the resistance wire, frame –2319, (c) first visible ignition of nitrocellulose, frame –2133, (d) burning through the resistance wire, frame –2075

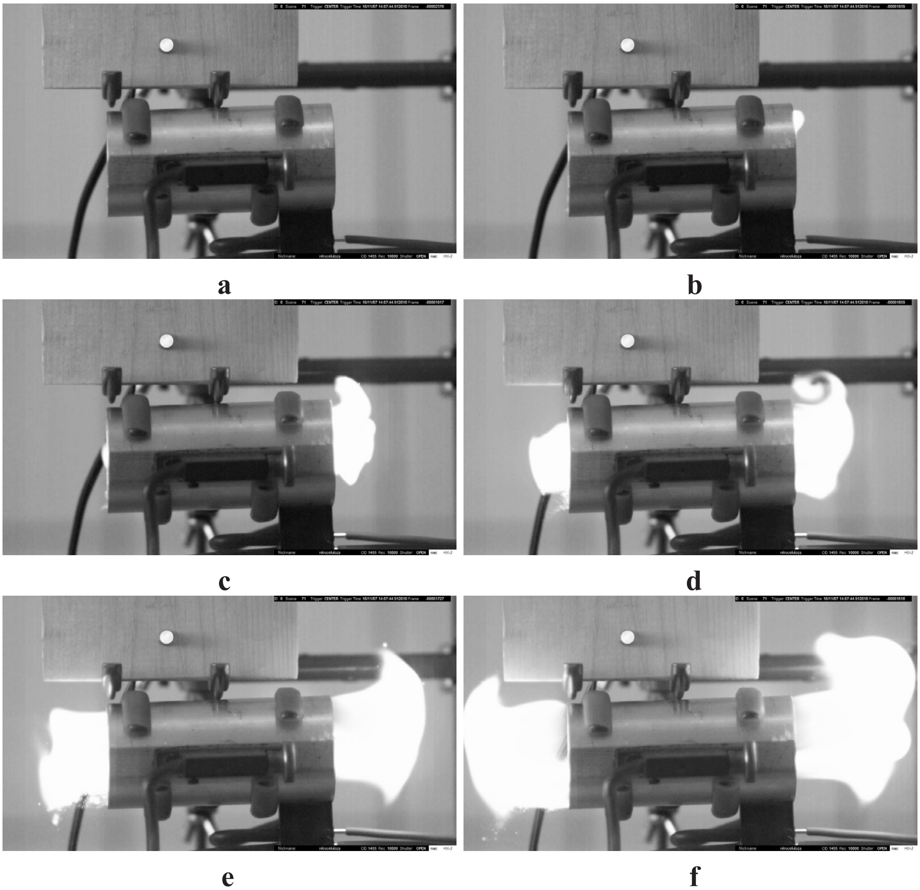


Figure 5. Nitrocellulose ignition in igniter body and flame flashing from the igniter tube; frames: (a) –2376, (b) –1939, (c) –1917, (d) –1859, (e) –1727, (f) –1618

4 Conclusions

The STN EN 14034-3+A1:2012-01 Standard specifies the ignitor parameters for the study of the explosion characteristics of dust clouds. Since it does not specify an exact chemical composition of the working charge, nitrocellulose seems to be one of the possible alternatives. However, for its application in the study of dust explosions it is necessary first of all to determine the time parameters of its ignition.

In this article we have focused on ignition of cellulose by use of a resistance wire. We have determined the time parameters by the use of a high-speed movie camera recording with a frequency of 10 000 frames/s. Measurements of the rate of nitrocellulose ignition (from a resistance wire), performed by analysis of high-speed movie camera records have shown that the time from switch actuation to ignition was 30.6 ms. The flame from the chamber in the igniter tube reached the end of the tube within 45 ms, and the average speed of the flame flashing from the tube was 3.05 $m \cdot s^{-1}$. These times will be subsequently utilised for adjusting the process for dust dispersal.

Subsequent studies dealing with the application of nitrocellulose as an igniter will focus on the suitability of its application from the viewpoint of different types of dust clouds. We will also study the effect of the properties of the dust clouds on the probability of their ignition by a nitrocellulose igniter. The next research paper will presents the results of a comparative study between a 5 kJ nitrocellulose igniter and commercially available igniters, *e.g.* from Sobbe or Simex.

Acknowledgements

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