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X-ray Investigation of Combustion Phenomena Occurring in Certain Pyrotechnic Elements Used in Military Ammunition

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Abstract: Investigation using Real-Time X-ray Radioscopy (RTR) of the combustion processes occurring in two different configurations of pyrotechnic items, currently used in ordnance in service with the Polish Armed Forces, are presented. In the first configuration, employed in the delay elements of the RGM type of impact artillery fuses, the end-burning delay pyrotechnic column in its narrower part ended with cavity, is situated in front of the inlet of the axial channel of the output tubular pyrotechnic augmenting charge. In the second configuration, utilized in tracers of anti-tank guided missiles, the end-burning pyrotechnic charge with an ignition cavity is inserted into the steel body and closed hermetically at both ends by plastic discs. In each configuration, ignition of the tested item was initiated by an electric fusehead system. The RTR sequence of images (30 fps) of the combustion of the tested items showed that the burning surface of their pyrotechnic charges were distinguished as a boundary between the unburnt part of the pyrotechnic charge and its distinctly less dense combustion products. For selected time points in the combustion process, the shape and position of such boundaries were captured. From these data, it was possible to discover more about the combustion phenomena occurring in these tested items, including the evolution and movement of the burning surface.
The combustion processes of the tested pyrotechnic delay elements and tracers, were occurring in accordance with the intended (expected) scenarios, *i.e.* all of the pyrotechnic charges were successively and totally consumed, and during their combustion there were no premature effects resulting in a shortening of their burning time.

Keywords: military ammunition, pyrotechnic charges, delay element, tracer, combustion, burning surface, Real-Time X-ray Radioscopy (RTR)

1 Introduction

Encouraged by the promising results from our investigations on the combustion phenomena of low-gas pyrotechnic charges employed in UZRGM hand-grenade delay elements, using Real-Time X-ray Radioscopy (RTR) [1], we decided to continue these experiments aiming to investigate the combustion of two other much more gaseous pyrotechnic configurations utilized in military munitions presently in service with the Polish Armed Forces, again using RTR. These configurations differed in the size, geometry and deployment of their pyrotechnic charges. One of these pyrotechnic configuration is employed in delay elements of impact artillery fuses, and the other is utilized in the tracers of anti-tank guided missiles. These configurations were tested under static firing conditions.

2 Experimental Part

2.1 Test samples and measuring arrangement

The test samples used for the investigation of the combustion processes, were the delay elements (Figure 1) used in the RGM type impact fuses of 122 and 152 mm artillery shells, and tracers (Figure 2) from anti-tank guided missiles, mounted onto the external cylindrical side surface of the missile, parallel to its longitudinal axis.

The delay element was designed to delay explosion of the above artillery shells. The delay element (Figure 1) consisted of an end-burning delay pyrotechnic column with its narrower part ending with a cavity, and an output tubular pyrotechnic augmenting charge. Both pyrotechnic charges were inserted into a steel body. The cavity of the end-burning charge was situated in front of the inlet of the axial channel of the tubular charge. The end-burning column and the tubular charge lay along the same axis, and were separated by a thin air gap. Such deployment of these pyrotechnic charges, especially the position of the cavity of the end-burning charge in relation to the axial channel of the tubular augmenting charge, was designed to obtain as much as possible of the effective directed transfer (flow) of the combustion products from the bottom part of the end-burning charge along the axial channel, resulting in avoidance of serious destruction of the tubular charge during this stage of the combustion process.

All of the pyrotechnic charges of the delay elements were composed of SC-1 pyrotechnic mixture, consisting of 74.5% of lead(II, IV) oxide (Pb_3O_4), 23.5% of zirconium powder and 2% of nitrocellulose.

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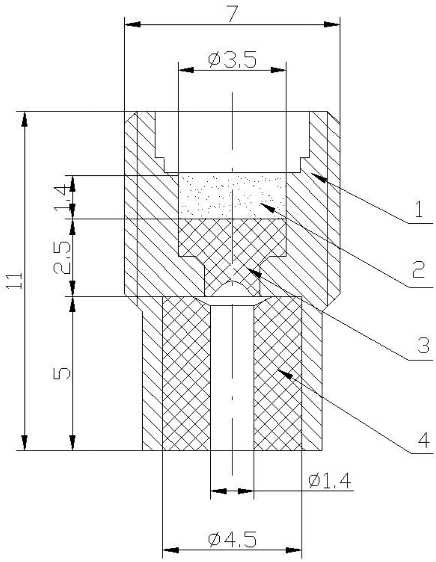

Figure 1. Axial cross-sectional view of the delay element used in the RGM type impact artillery fuse: 1) Steel body of the delay element; 2) Input-ignition pyrotechnic increment; 3) Main delay pyrotechnic increment with concave surface; 4) Tubular output ignition augmenting pyrotechnic increment. Dimensions are in mm.

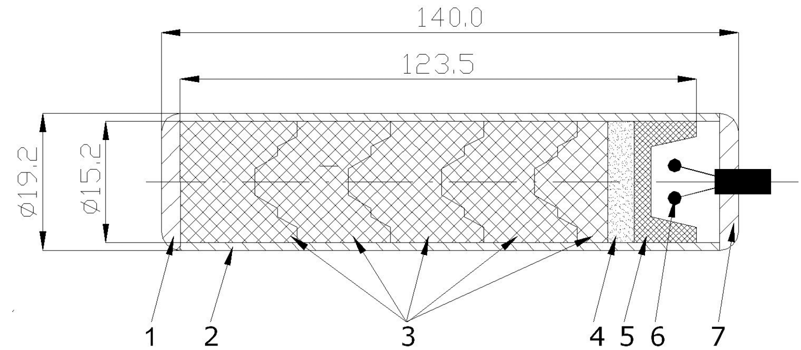

Figure 2. Axial cross-sectional view of the anti-tank guided missile tracer: 1) Forward plastic disc; 2) Steel body; 3) Main tracing pyrotechnic elements (segments); 4) Intermediate pyrotechnic segment; 5) Input ignition increment with cavity of trapezium-shaped cross-section; 6) Double electric fusehead system; 7) Rear plastic closure. Dimensions are in mm.

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The tracers were designed to give a visual (VIS) and thermal (IR) trail trace of the anti-tank missile for more than 33 s after firing [2]. The tracer (Figure 2) consisted of an elongated cylindrical steel body closed at both ends by plastic discs. The steel body contained end-burning pyrotechnic elements creating a tracing column whose ignition end had a cavity of trapezium-shaped cross-section accommodating a double fusehead electric ignition system.

The main part of the tracing column was composed of barium(II) nitrate(V) ($Ba(NO_3)_2$), barium(II) peroxide (BaO_2), zirconium and aluminum powder.

Each tested pyrotechnic item (delay element or tracer) was inserted into the RTR detection chamber of an MU-17F-225-9 diagnostic system (YXLON International X-ray Corporation), and the tested item was then examined (Figures 3a and 4a).

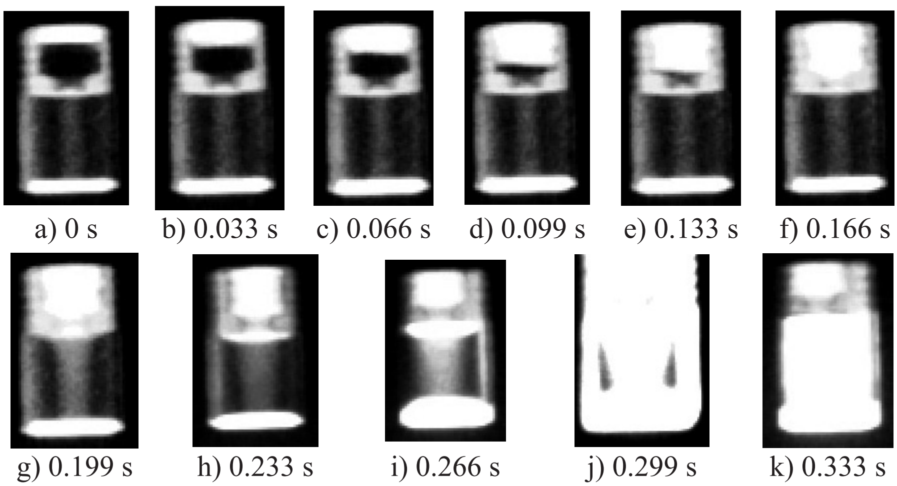

Figure 3. Sequence of RTR images of the tested delay element of the RGM type impact artillery fuse just before its ignition, and then during its combustion. Time points of each frame, are shown below each image.

The RTR images indicated that the tested delay element or tracer had no distinct structural defects such as voids or cracks. After X-ray examination, each tested pyrotechnic item was ignited in the RTR chamber by an electric fusehead system. The combustion of the pyrotechnic charges of each tested item, was detected and recorded by the RTR diagnostic system at 30 frames per second and resolution 1528×1052 pixels.

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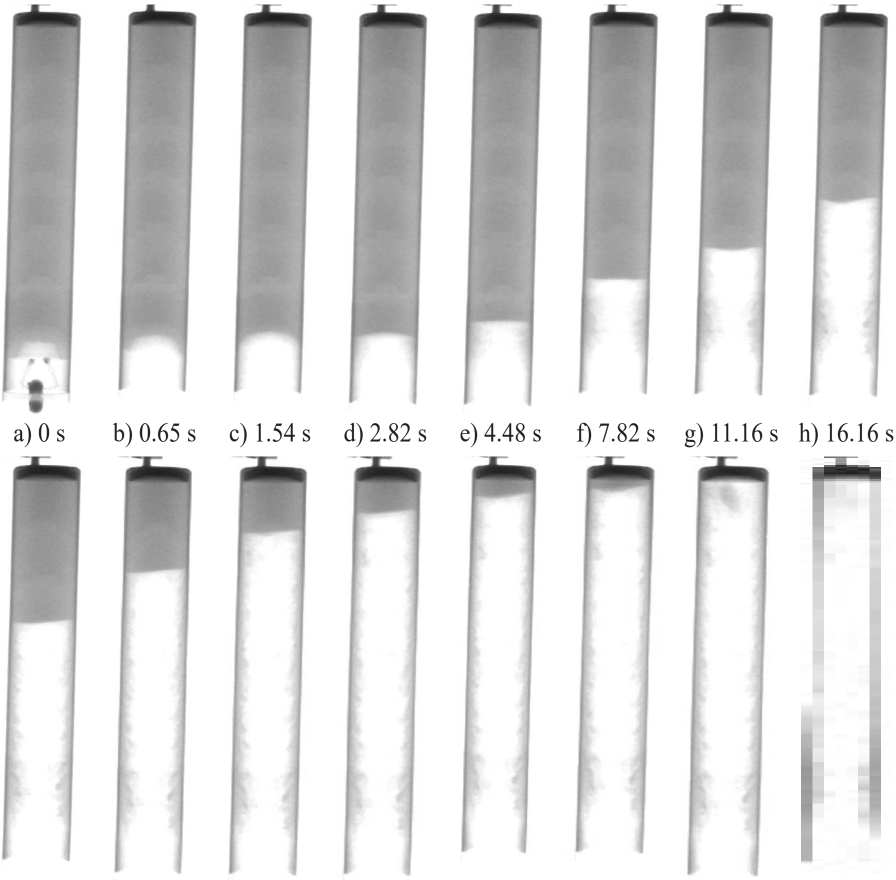
2.2 Test results and discussion

From the typical sequences of RTR frames for the delay element and the tracer, with the first frame showing the tested pyrotechnic item before its ignition (Figure 3a and Figure 4a for the delay element and tracer, respectively), and with the subsequent frames showing the combustion process of the delay element and the tracer (Figures 3b-k, Figures 4b-p, respectively), it is possible to observe the shape and position of the burning surface which is detectable as a boundary between areas of different density, *i.e.* between the unburnt part of the pyrotechnic charge and its combustion products of distinctly less density.



a) 0 s b) 0.65 s c) 1.54 s d) 2.82 s e) 4.48 s f) 7.82 s g) 11.16 s h) 16.16 s

i) 21.17 s j) 24.51 s k) 27.85 s l) 29.51 s m) 31.68 s n) 32.35 s o) 33.77 s p) 34.85 s

Figure 4. Sequence of RTR images of the tested anti-tank missile tracer just before its ignition and then during its combustion. Time points of each frame, are shown below each image.

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During the combustion of the end-burning pyrotechnic charge of the tested delay element, the observed burning surface was basically planar and occasionally slightly slanted (Figures 3b-3e). The consumption (burning up) of the final narrower part of the end-burning pyrotechnic charge with a cavity (Figure 3f) did not cause any visible mechanical damage to the tubular pyrotechnic charge. The relay of the ignition impulse from the concave part of the end-burning charge then caused combustion of the tubular augmenting pyrotechnic charge, resulting in the progressive broadening of its axial channel along its full length (Figures 3g-3j). During combustion of the tubular pyrotechnic charge, the shape of its axial channel evolved to form a trapezium-shaped cross-section with the larger side uppermost. In addition, in the course of the burning of the tubular pyrotechnic charge, erosion of its output (bottom) end was also observed (Figures 3i and 3j).

The total burning time of the delay element and the combustion time of its component pyrotechnic charges could be determined from the sequence of frames of the RTR images. The burning time of the end-burning part of the delay element was estimated to be *ca*. 166 ms (Figures 3a-3f). The burning time of the tubular augmenting charge was estimated to be between 133 ms and 166 ms (Figures 3g-3j), so the total burning time of the delay element, was estimated to be between 299 ms and 333 ms. The flow of the combustion products from the concave (bottom) part of the end-burning delay charge along the channel of the tubular charge did not cause any mechanical damage. Consequently, this means that the ignition impulse from the concave part of the end-burning charge should reach first the next high-energy charge of the firing/explosion chain of the artillery (fuse) shell. This also means that the construction (design) of the delay element ensures its proper sequence of action (combustion) under the static firing conditions of the test.

During ignition of the pyrotechnic charge of the tracer, its rear plastic closure with the dual electric fusehead system was separated (expelled) from the steel body due to the action of the pressure of the combustion products (compare Figure 4a with Figure 4b). So, the further burning of the tracer pyrotechnic charge was occurring in a combustion chamber (body) open from its rear (ignition) end (Figures 4b-4p). In the course of combustion, it was observed that the shape of the burning surface of the pyrotechnic tracer charge evolved. Initially the burning surface had the shape of the ignition cavity (trapezium-shaped cross-section) (Figure 4b) and then gradually became hemispherical (Figure 4c), increasingly more flattened (Figures 4d and 4e) and finally planar (Figure 4f). The planar shape of the burning surface evolved further reaching a slightly convex shape (Figures 4g-4n). The change of curvature of the burning surface, from planar to convex, was probably caused by the hot steel body of the tracer, heated for

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a relatively long time by the combustion products. The observed evolution in shape of the burning surface of the pyrotechnic tracer was in good agreement with theoretical predictions for burning surface evolution of end-burning, solid rocket propellant charges with an ignition cavity, presented in [3, 4].

For each tracer tested, the total burning time was greater than 33 s. The total combustion times of these tracers obtained by RTR, were in good accordance with the appropriate requirements given for such a type of tracer [2].

3 Conclusions

On the basis of the experimental measurements and observations presented above, it was possible to come to the following conclusions:

Using the RTR technique, it is possible to continuously (more precisely quasi continuously) detect and record combustion phenomena occurring not only in relatively large pyrotechnic charges, as presented for anti-tank missile tracers, but also in the relatively small pyrotechnic configuration used in the delay element of RGM type of impact artillery fuses (shells).

The basic characteristics and phenomena of the burning process of the tested delay elements and tracers, detected and recorded by RTR, were the temporary shape of the burning surface and its position at given time points. So, it was possible to discover more about the combustion phenomena occurring during the operation of the tested items under static firing conditions, including evolution of the burning surface, its movement, and also the burning time of the overall pyrotechnic charges or their components.

The combustion processes of the tested pyrotechnic delay elements and tracers, were occurring in accordance with the intended (expected) scenarios, *i.e.* all of the pyrotechnic charges were successively and totally consumed, and during their combustion there were no premature effects resulting in a shortening of their operation time.

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