Testing of the Failure of the Solid Rocket Propellant with Tomography Methods

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Abstract *– Paper presents a proposition of Non Destructive Testing (NDT) of the rocket engine powder rod. It presents actual state of the research and perspectives of its continuation. It suggests new method of differential tomography.*

Keywords: non-destructive testing, capacitance tomography, two – modal tomography, differential tomography

1. INTRODUCTION

Dynamically developing rocket technology is gaining bigger and bigger position in the modern world, having apart of the military ones a number of the civil application (e.g. cosmic research, meteorology). For the certitude of the fulfilment of the mission and people security, diagnosis of the rocket technical state, including engine is essential [9].

1.1 Powder rod diagnosis

Because of the easier maintenance the solid rocket propellant is currently more often applied. Conditions of the work of the rocket engine, from which stable propulsive thrust and stable pressure is required, depend not only on the construction but on the propellant used as well. Specifically – on the charge geometry and on the quality of the propellant mass internal structure; what means on the kind and intensity of defects occurring in the propellant. Even the most accurately established and controlled technical process can not assure the 100% defect free production of the powder charges. Not all the defects have the influence on the combustion course. It depends on its dimensions, kind and location. From this results the necessity of the control of the production process [5, 6] and of the postproduction testing of the ready product and control checking during maintenance period as well.

1.2 Powder rod technological defects

Technology of the powder charges has many similarities with the plastic technology. The main methods of the propellant charge production are pressing and casting. The main factor rendering technological process of the propellant charge difficult is the inadmissibility of the high temperature, and in the consequence incomplete fluidity of the mass moulded. In consequence we have form short shot and residual air bubbles.

In the pressed rods defects like delamination of the propellant mass parallel to the axe of the charge, and inclusions of the foreign matters mainly metallic occur.

It is necessary to detect:

- Delamination of the mass propellant of total surface from 250 mm^2;
- Delamination of the length over 30 mm;
- Delamination of the width from 3 mm;
- Inclusions with surface over 60 mm^2;
- All cracking of the propellant mass.

In the case of the complex propellant casting the end product as the combustible factor is usually monomer (fluid) with the oxidising substance (solid powdered crystalline mass), which mixed together is poured into the moulds in which polymerisation occurs. Solids added to the fluid are non-uniform in respect to the crystal dimensions and specific gravity, so during the polymerisation process following undesirable phenomenon occurs:

- Separation of the thick crystals on the bottom from the fine on the top of the mould;
- Separation of the higher density substance from the lower density;
- Bigger concentration on the bottom of the mould and smaller on the top.

In the casted rod should be detected:

- Single bubbles or their cluster with total surface from 200 mm^2;
- Foreign matter inclusions with dimension higher than 5 mm^2;
- All cracking of the propellant mass.

1.3 Powder rod maintenance defect

Powder rod maintenance is limited to their storage. The defects due to the storage conditions can be divided into two categories: mechanical or chemical.

The most common mechanical defects due to ageing are:

- Propellant mass cracking and spalling;
- Propellant mass delamination;
- Inhibitor layer deglutination.

Chemical defects that arise during the storage period are due to the reactions proceeding in the propellant mass. These reactions are accelerated by incorrect storage conditions. The most common defect of this kind is:

- Increase of the water and volatile mater content (over 0.7%);
- Decrease of the chemical durability;
- Decrease of the constancy;
- Decrease of the caloric value (combustion heat);
- Combustion velocity decreases.

Influence of the kind of the propellant (homogeneous or heterogeneous) on the defect formation should be underlined.

2. POWDER ROD DIAGNOSTIC STATE OF ART

Powder rod testing can be divided into destructive and non-destructive. Destructive methods are applied periodically to the randomly chosen rods most often from the lots, which guarantee time of maintenance, is over. Non destructive methods are usually used to post production control, which decide about usefulness of given lot for maintenance.

2.1 Destructive tests

There are time consuming and requiring specialised equipment test so they are very expensive. Usually they include:

- Visual survey;
- Water and volatile matters contents determination;
- Density determination;
- Calorific value determination;
- Chemical durability determination;
- Stability determination using mass decrement method;
- Linear combustion velocity determination.

2.2 Non destructive tests

X radiation ($= 10^{-4}$ m $\div$ 10 m) or radiation ($< 10^{-4}$ m), are used in these methods so they too are expensive and time consuming. They permit to detect the majority of the mechanical defects, which presents the majority of the post productive stage. It is possible to distinguish radiographic and radiometric methods.

To detect and determine the defect with radiographic method [1] in the tested rod it is necessary to perform a number of the time consuming operations (Figure 1):

- Preparation of the rod to exposition;
- Exposition execution;
- Irradiated film photochemical processing;
- Radiogram interpretation.

Defect detectability is much better then technical requirements. This test requires very careful rod location against the film. Crashes are detected in the range of the 8° angle and minimal detectable crash is in the range of the 1×3 mm.

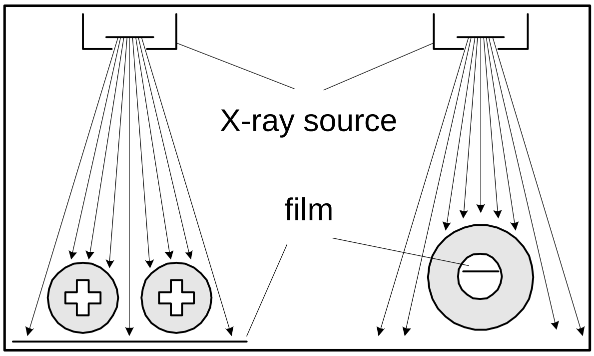


Figure 1: Radiographic test of the powder rod through one and two walls

Radiometric method [2] of the industrial product control consists in the measurement of the density of the radiation stream transmission through the product tested (Figure 2). Application of this method to the solid racket propellant tests is known from the long time, for example in the Allis Chalmers Company [7]. It results from the experience that with radiometric method is possible to detect the crash 0.3 – 0.4 wide and 15 – 20 mm deep.

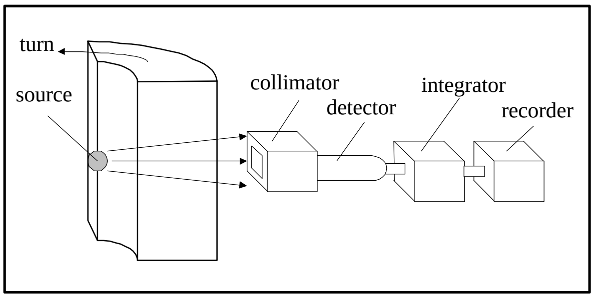


Figure 2: Principle of radiometer function

Tomography opens the new perspectives in the powder rod testing [4]. This method consists in the gaining of the slide images in the different planes or instants on the base of the measurements in the perpendicular planes. These measurements are non-invasive and often done without contact with the product.

3. SENSORS CONSTRUCTION

In the laboratories of the Department of the Maintenance and Technical Diagnostics of the Military University of Technology and in Industrial Institute of the Organic Chemistry in Warsaw series of the experiments to conform usefulness of the process tomography in diagnosis of the rocket engines powder rods were done. Tomograph type PTL300 – TP-G developed in the University of Manchester Institute of Science and Technology produced by Process Tomography LTD was used in these tests. Two kind of electrodes to testing of the rods of the different diameters were designed and made in Warsaw (Figure 3)

3.1 Brass sensors

These sensors are composed of the 12 electrodes, ring side screens and inter electrodes screens (Figure 4). Electrodes and screens are made of the brass sheet 1 mm thick, which assures the proper construction rigidity and electrical conductivity. Connection with the measurement unit was done by concentric load RG174A type, 1300 mm length and connectors SMB. Electrodes were connected with the mass through the 1M resistance to discharge the electrodes between the measurement cycles. Sensors were designed for the rod of 123 mm diameter made of the heterogeneous (composed) propellant testing, and were made in three lengths (long – 80 mm, medium – 50 mm and short – 30 mm).

Figure 3: Sensors used in the measurement

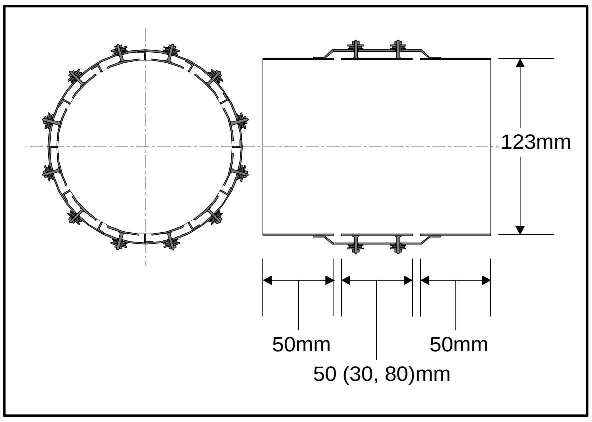


Figure 4: Brass sensors

3.2 Copper sensors

Copper sensors are composed of the 12 electrodes, ring side screens and inter-electrodes screens. All these elements were fabricated from a flexible copper-clad laminate (0.15 mm thick, covered by the 0.05 mm thick copper layer) using standard photolithographic and etching techniques (Figure 5). The whole after coiling and soldering was encircled by antistatic insulating foam and brass screen that ensure proper stiffness of the sensor. Connection with the measurement unit was done by concentric load RG174A type 1300 mm length and connectors SMB. Electrodes were connected with the mass through the 1M resistance to discharge the electrodes between the measurement cycles. Sensors were designed for the rod of 67 mm diameter made of the homogenous propellant with inhibitor testing and were made in 50 mm length.

4. EXPERIMENTS

Process tomography [3] opens new perspectives for plastics mass products and particularly for powder rod diagnosis [8]. The preliminary experiments confirm rightness of this application.

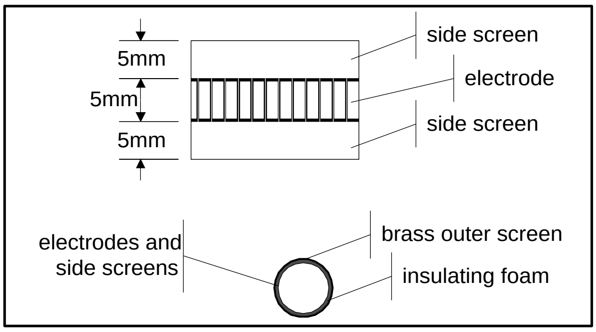


Figure 5: Copper sensors

4.1 Model rod testing

The subject to test in the first stage was the rod made from the composed propellant which basic components were:

- ammonium perchlorate;
- aluminium dust (about 10%);
- polymer binder.

Calibration necessary to the test was made on the model rod made of the same propellant (A mass), moulded without contamination and inclusions. Usefulness of the rod was confirmed by the radiographic method.

Tested rod (Figure 6) contained several intentionally put in contamination located in definite places. There were balls and plates made of steel, lead, glass and teflon. Moreover part of the rod was made of the material of the different composition (B mass).

Images in two planes crossing through the different masses were registered (Figure 7). In the plane 1 measurements were done using short (30 mm) and long (80 mm) electrodes.

Areas of the permittivity of the lower and higher values than the powder mass constant are sharply outlined on the images.

4.2 Heterogeneous rods testing

The powder rods with ring cross-section made of the heterogeneous mass were tested in the second stage. The measurement results are shown on the Figure 8. They were done on the one plane with the electrodes of the different length.

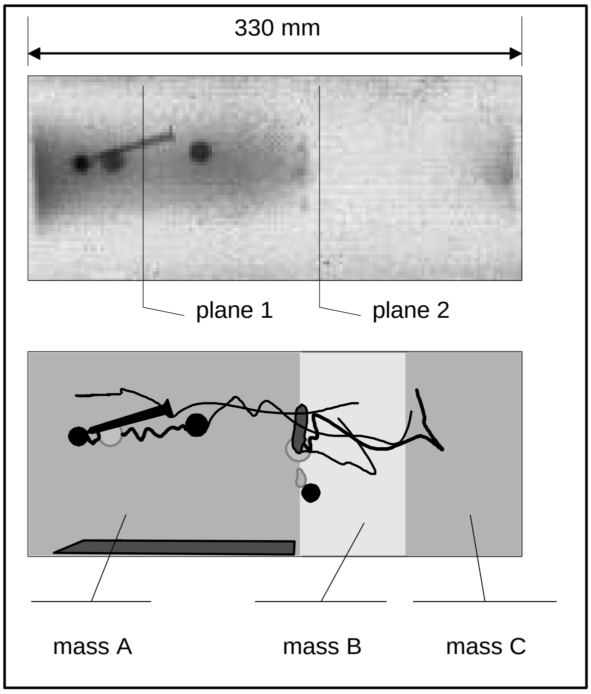


Figure 6: X-ray picture and cross-section of the tested rod

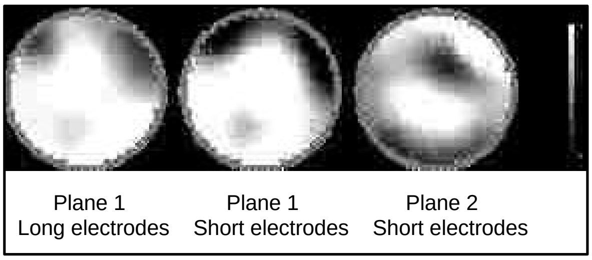


Figure 7: Model rod tomograms

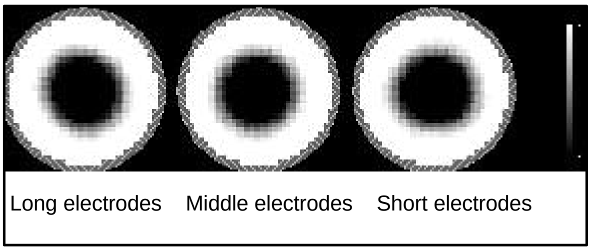


Figure 8: Heterogeneous rod tomograms

Measurements done with the long electrodes are not accurate, because the capacitance values are averaging along the electrodes. However the short electrodes are the cause of the difficulties in the results interpretation because the fields are strongly non-linear. The length of the electrodes depends on the tested rod diameters. Possibility of the use of central electrode (Figure 9) connected to the mass or divided electrode was considered. It could increase accuracy but it requires specialised reconstruction algorithm.

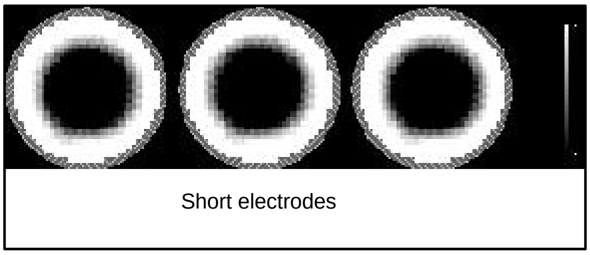


Figure 9: Rod with central electrode (connected to the mass) tomograms

4.3 Homogeneous rod testing

Copper electrodes were used to the next testing. The rods 67 mm diameter made of the homogeneous propellant with inhibitor were tested (Figure 10 and 11). Tomograms allow to affirm the chemical changes of the material and especially the moisture increase. However localisation of the inhibitor deglutination is difficult. The big difficulties are caused by the variable diameter of the tested rod.

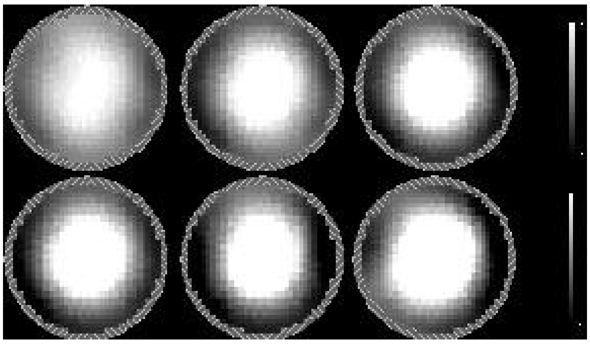


Figure 10: Homogeneous model rod tomograms

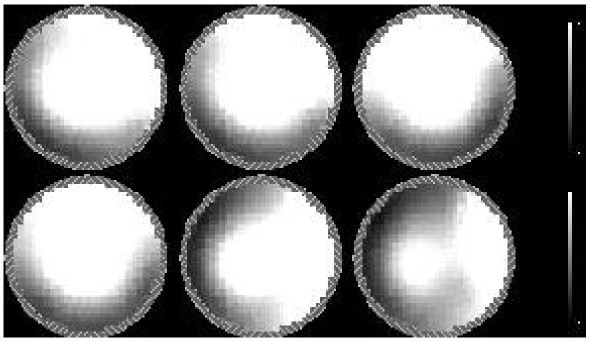


Figure 11: Homogeneous rod with deglutinated inhibitor tomograms

5. IMAGE RECONSTRUCTION AND VISUALISATION

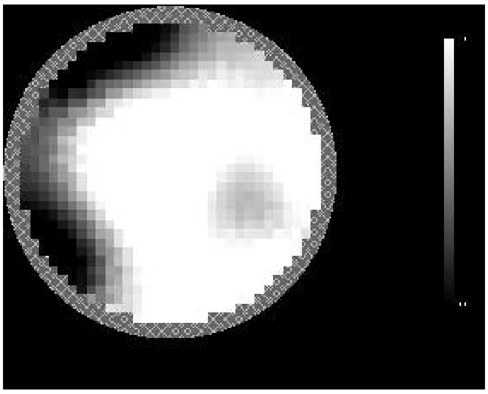
Modified back projection algorithm [10] was applied to image reconstruction and the images obtained were presented in two colours linear scale. To increase the tomograms readability multicolour step scale and visualisation in the Microsoft Excel program was proposed (Figure 12). Assuming only chemical changes it is possible to assign to particular kind of changes adequate contrast colours.

To make possible the assumption of the one kind of changes solely we propose to apply duo-modal tomograph: capacitance – X-ray. X-ray tests permit to distinguish the changes of the kind such as foreign matter inclusion, cracking or delamination. It does not make possible registration of the chemical changes, observed by capacitance tomography method well enough.

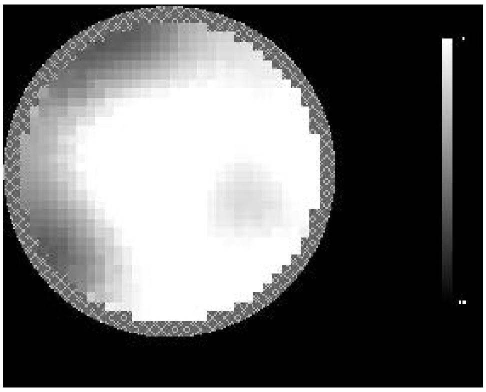
Next step is the vectorial presentation of the bit-maps images. It allows transmitting the images received in the test to quantity processing systems. The sequence of the successive tomographic images allows the secondary space reconstruction (3D). This reconstruction makes possible the evaluation of the adverse chemical or mechanical changes that took place in the volume.

Applying rough set methods the operator can get information that the changes took place in the volume bigger as A mm^3 and smaller than B mm^3.

Visualisation in the **Imgcon** program:

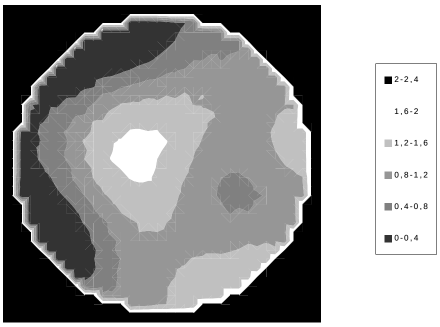


Unipolar



Bipolar

Visualisation in the **Microsoft Excel** program:



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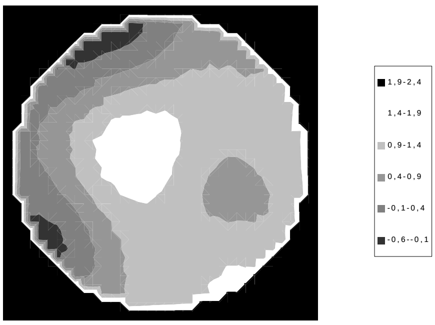

Bipolar

Figure 12: Comparison of the visualisation manners

6. FURTHER RESEARCH PERSPECTIVES

In summary the research done and experience acquired allow to affirm that the tomographic methods are useful in the powder rod for rocket engines non-destructive testing. Further research will concentrate on:

- optimisation of the electrodes dimensions;
- working out and testing of the specialised reconstruction algorithms;
- applying of the neural network to the reconstruction;
- design of the capacitance – X-ray tomograph;
- applying of the software to vectorial presentation.

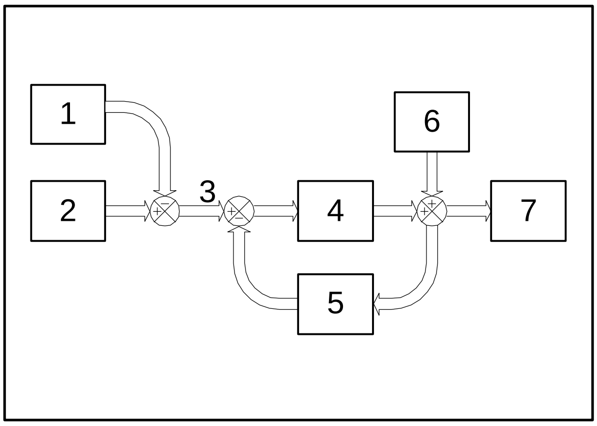

Figure 13: Differential tomography scheme

1 - STANDARD SPECIMEN 28 MEASUREMENTS*
2 - TEST OBJECT VECTOR OF 28 MEASUREMENTS*
3 - DIFFERENCE VECTOR (28)
4 - LINEAR BACK PROJECTION
5 - CALCULATE 28 NORMALISED DIFFERENCE VECTOR VALUES FROM IMAGE PIXELS
6 - PREVIOUS DIFFERENCE IMAGE
7 - LATEST DIFFERENCE IMAGE

*** NORMALISED USING SERIES MODEL**

At present the important direction of the research seems to be differential tomography (Figure 13) which allows to take the object standard specimen on-line into consideration. It will permit to reduce influence of such kind of factors as air moisture, temperature and external magnetic field on the testing results. It will thus make possible to conduct the research in the field and industrial conditions.

Authors hope, that defectoscopic tomography, which joints process tomography methods with medical tomography requirements will find its own place side by side with them in the scientific and applied research.

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