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INFORMATIONAL METHOD OF SRM INTERNAL THERMAL PROTECTION COATING INSPECTION

State control method of visual inaccessible surfaces of technical objects was examined by rescarch of digital images which contains information about their state and quality. Received data lets classity compare and mark out the classes of "normal" and "abnormal" digital images. Results and conclusions of visual analysis were confirmed by statistical treatment of matrix measurements of digital images. [dx.doi.org/10.29010/085.6]

Keywords: *thermal protective covering; solid propellant rocket engine; rubber compound; visual analysis; digital images.*

Carbon fiber polymer composites find application in various space technologies such as solid rocket motors, or SRM (Figure 1). An SRM is a critical part of a rocket. It is responsible for a successful flight mission, which is why strict quality requirements are imposed on the development of solid rocket motors. An internal thermal protective coating is one of the SRM's key components [1-2]. An informational and measuring method is developed to check the condition and quality of an internal thermal protection coating which is unavailable for visual inspection and cannot be checked by standard methods.

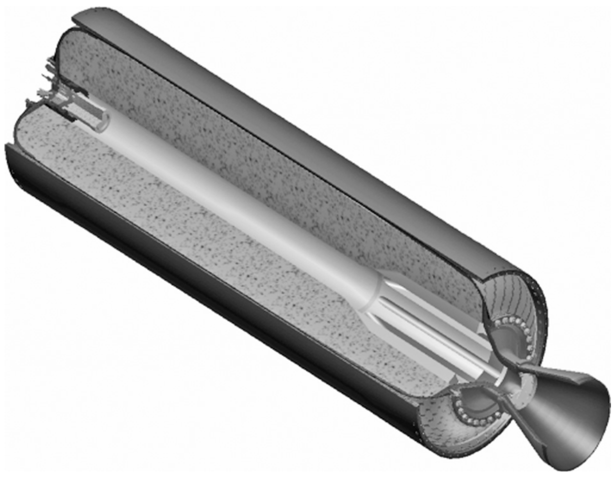


Fig. 1. Internal thermal protection coating assembled with a pressure shell and solid propellant

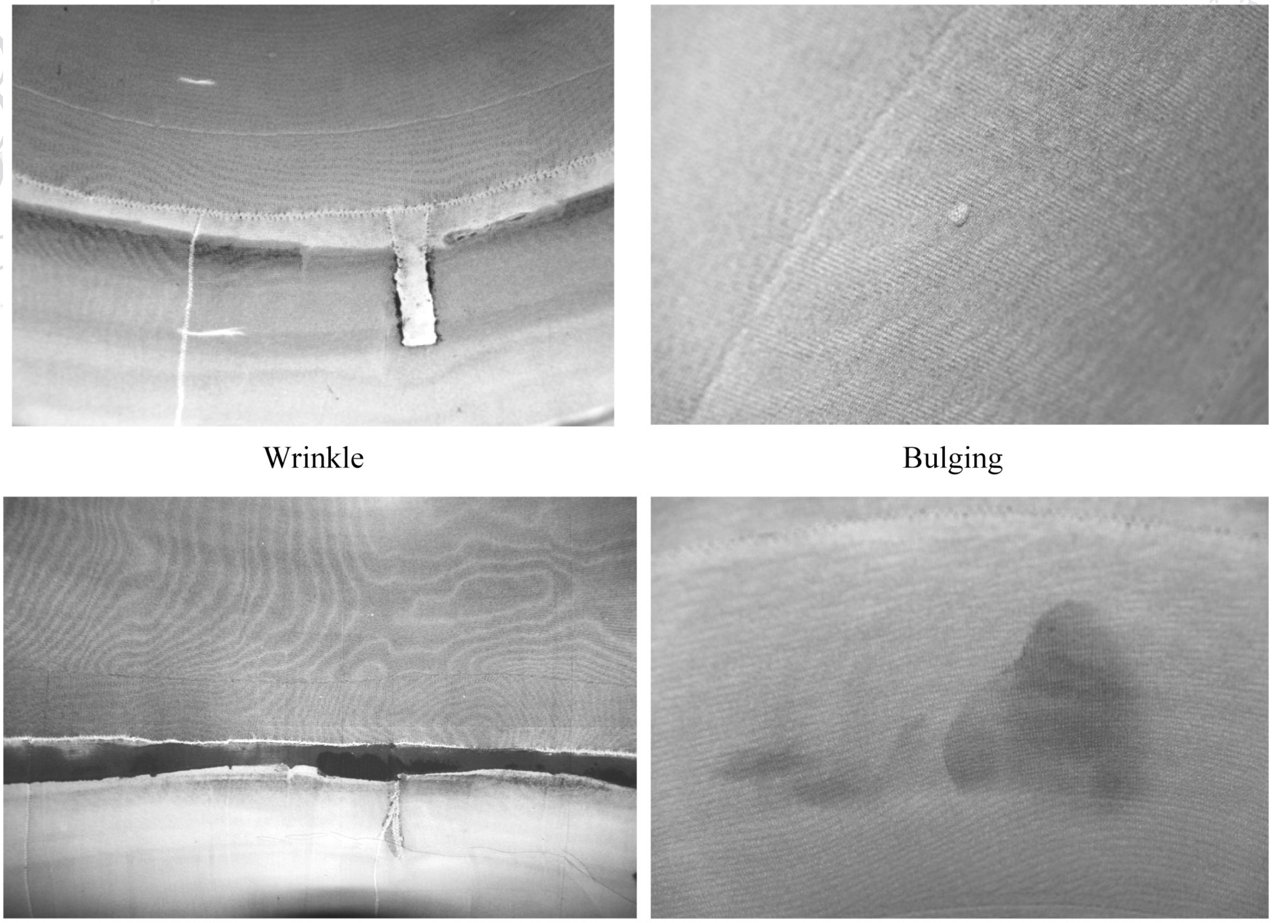
The analytical visual inspection of an internal thermal protection coating was done. The surface was photographed and the digital images were analyzed to detect unacceptable defects (flaws) such as wrinkles, bulging, spots of different nature, cloth punched severely by rubber, mechanical damage, if any (Figure 2).

The measurements of digital images of the internal thermal protection coating are the matrices of numerical brightness values and provide information on the condition and quality of the coating. A digital image consists of a finite number of elements. Each of the elements is located in a particular point of the inspected surface. The center of each element has rectangular coordinates denoted with two figures, *i* and *j*.

If the brightness in this point (center) is S, then $S(i, j)$, with $i = 1, 2, 3 \dots n_1$ and $j = 1, 2, 3 \dots n_2$, is the measurement matrix of image brightness (intensity of surface's grey colour varying from white to black), or the matrix of intensity of an electromagnetic signal reflected from the surface in this point (i, j) [3].

The analysis of the images starts with *understanding* or *interpreting* them as the visual patterns of the thermal protection coating being inspected. Although these patterns are subjective, they make it possible to distinguish low, medium, or high brightness intensity and its domains of various shapes, to outline boundaries and draw contour lines. An entire set of thermal protection coating images can be grouped thereby into the images which are similar or differ from each other. This is what an inspection procedure starts with – visual identification and grouping of images of the inspected item's thermal protection coating.

Visual inspection of digital images is an initial source of information on the objects which are unavailable for direct visual inspection and analysis and are tested therefore by non-destructive methods. The weakness of visual inspection is a low probability of detection of small defects on the surface as well as the relation between the ability to find defects and the subjective factors (acuity of vision, tiredness, experience and skills of a specialist who is analyzing the image) and inspection conditions (light, optical contrast). Nevertheless, the simplicity of the visual and measurement inspection, its low labor intensity and



Wrinkle — Bulging — Cloth punching — Spots

Fig. 2. Digital images of thermal protection coating defects

good informativeness make this inspection procedure to be carried out obligatory prior to the statistical processing of digital images of an SRM thermal protection coating's surface. A set of digital images of small surface segments provides the information on coating's condition.

The images of a good thermal protection coating shall be similar and alike. If the coating meets the standards, such images will prevail. Visual analysis of digital images implies the detection of defects and identification of how they differ from the prevailing images which are similar and correspond to the standard. The informativeness of original digital images is related to the subjective and objective factors which generally depend on visual perception of information. Visual analysis is a multistage process of information transformation, collection and display, comparison of digital images to each other within the set by various informational characteristics. It is a result of experience and skills in visual inspection of digital images.

An important feature of the process of detecting, distinguishing and identifying the objects in an image is that this image differs from the initial one by a number of characteristics. First of them are brightness, colours, and three-dimensional characteristics of the inspected inner surface of an SRM casing.

As for the informational characteristics of digital images, it should be noted that they can show up in a number of classes of objects, with every single class of objects having its own number of objects with dimensional and other features. The basic informational characteristics which can be used for coating's visual analysis and inspection with help of digital images are:

1) brightness (number of shades within the brightness range from $X_{\min}$ to $X_{\max}$)

2) colour

3) three-dimensional characteristics (shape, linear dimensions, configuration of detected flaws)

The conclusions of a digital image analysis should be confirmed and updated through the statistical processing of experimental matrices of digital image measurements and by comparing their parameters. These are mathematical expectations, variances and probability distribution laws which provide information of thermal protection coating's condition. Their estimations can be found through the processing of measurement matrices $\overline{X_k}(i, j)$, where k is the number of a digital image, using the following formulas:

1) Estimation of expectation can be found as a mean value of measurements of each matrix

$$\overline{X^*}(k_1) = \frac{1}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} X_k(i,j)$$

where n_1, n_2 are the orders of matrices, $k = 1, 2, \ldots N$ is the quantity of processed digital images.

2) Estimation of sampling variance can be found as a mean value of deviation of a measurement $\overline{X_k}(i,j)$ from its mean value $X^*(k)$

$$\overline{D^*}(k) = \frac{1}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \left(X_k(i,j) - \overline{S^*}(k) \right)^2,$$

Statistical regularities of random values $X_k(i, j)$ are a graphic representation of the measured coating reflectivity of each thermal protection coating's image being analyzed.

Such a graphic representation is called histogram in mathematical statistics. In this research, brightness was estimated between the totally black (0 units of brightness) to the totally white (255 units of brightness). In other words, brightness measurements were limited within the range $0 \le X(i,j) \le 255$. The range was divided in 100 segments with a length of $\Delta X = 2.55$ each. The segments were numbered from 1 to 100 ($1 \le m \le 100$). A brightness value is denoted as $X(i, j) = q$, where $q = 0, 1, 2 \ldots 255$ (whole numbers).

The boundaries of the segments are $X(m) = X(m-1) + \Delta X = 2.55m$, where m is the number of a segment $\Delta X(m) = X(m) - X(m-1)$.

For a matrix with the order of n_1 by n_2 ($i = 1, 2 \ldots n_1$ and $j = 1, 2 \ldots n_2$), the total number of measurements is $n = n_1 \cdot n_2$. The number of measurements $X(i,j) = q$ which fall within a range from $X(m-1)$ to $X(m)$ can be found if the following inequality holds:

$$X(m-1) < X(i,j) \le X(m),\ X(0) = 0$$

The number of measurements $n(m)$ which fall within an interval $X(m) - X(m-1) = \Delta X(m)$ can be found from the formula

$$n(m) = \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \Big[\big(\operatorname{sgn}\big(X(i,j) - X(m)\big) - \\ - \operatorname{sgn}\big(X(m-1) - X(i,j)\big) \big) \Big].$$

By assuming that $m = 1, 2 \ldots 100$, a sampling of measurements $X(i,j)$ which fall within the intervals $\Delta X(1)$, $\Delta X(2) \ldots \Delta X(100)$ can be found. A histogram number is a deviation $n(m)/(n_1 n_2) = n(m)/n$, an accuracy of $X(i, j)$ measurements falling within histogram intervals $\Delta X(m)$. A sampling $n(m)/n$ is taken as an estimation of an inspected surface's brightness probability distribution law.

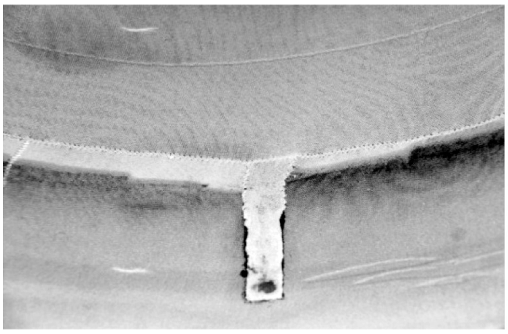
Being a digital image of reflectivity of the inspected surface, a histogram provides much more information on the thermal protection coating's condition than a mean value and a sampling do (Figure 3).

As a sequence of frequencies, a histogram $\frac{n(m)}{n}$, ($m = 1, 2 \ldots 100$) has the origin $\frac{n(m_1)}{n} > 0$ and the end $\frac{n(m_2)}{n}$. A minimum brightness value $X(m_1)$ is in a point m_1, an apparent maximum brightness $X(m_2)$ is in a point m_2. The difference of them – $\Delta X(m_1 m_2) = X(m_2) - X(m_1)$ – is an indicator of scatter, an analogue of sample variance. In visual analysis, it is an indistinct estimation of black, grey, and white domains. Histograms help also find a domain $\Delta X(m_3)$ where a frequency $\frac{n(m_3)}{n}$ has its maximum. There can be several of such domains: $\Delta X(m_4)$ and so on.

So the results of the analytical and computing processing of a digital image can be presented as

1) Sampling of histogram numbers $\frac{n(m)}{n}$, $m = 1, 2 \ldots 100$

2) Table of numerical characteristics of a digital image: a mean value, sampling variance, parameters of the histogram



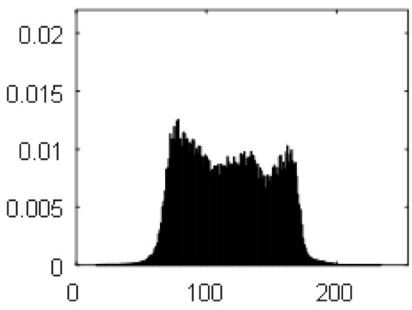


Fig. 3. A digital image and its histogram

Table 1

Numerical characteristics of a digital image

№ of measurement	Estimate of measurement		Estimates of histograms			
	$\overline{X}$	$\sqrt{D^*}$	$X(m_1)$	$X(m_2)$	$\frac{X_1+X_2}{2}$	X_2-X_1
1	106	28	23	173	98	150

The integral estimation of thermal protection coating's condition is done by synthesizing the results of visual analysis done for normal digital images and those revealing the flaws or any deviations from the standards. The first integral indicator is a mean value of all particular mean values $\overline{X(r)}$ and their sampling variance $D^*(r)$, where r is the number of a normal digital image:

$$\overline{\overline{X}}_1=\frac{1}{R}\sum_{r=1}^{R}X(r),\ \overline{\overline{D}}_1^*=\frac{1}{R}\sum_{r=1}^{R}\left(\overline{X}_1-\overline{X(r)}\right)^2,$$

where R is the quantity of normal digital images.

These characteristics indicate the reflectivity of the thermal protection coating being inspected and can be applied for comparing with other samples of thermal protection coatings. They can also be used for detection of off-normal images. With a probability $R = 0.95$, any random value, the distribution law of which is similar to the Gaussian distribution (or large sums of random values related to them), corresponds with the following: it is higher than the difference between its expectation and two roots of the variance, and it is lower than a sum of them, which corresponds with the following inequality:

$$\overline{\overline{X}}_1-2\sqrt{\overline{\overline{D_1^*}}}\le\overline{X(r)}\le\overline{\overline{X}}_1+2\sqrt{\overline{\overline{D_1^*}}}$$

The images for which the inequality does not hold are excluded from the group of normal images and undergo one more analysis [4-6].

Conclusions

An informational and measurement method has been developed to make the analysis of internal thermal protection coating's condition. It was found that visual analysis is a primary source of information on the quality of an internal thermal protection coating. Visual analysis was done for every digital image, the images corresponding to the standard and those revealing flaws were identified. The subjectivity of such identification is obvious, so the statistical processing of measurement matrices as the random values with unknown statistical regularities is required to confirm the results of visual analysis through estimating numerical parameters which are provided by digital images and characterize the condition of a surface.

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ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ КОНТРОЛЯ ВНУТРЕННИХ ТЕПЛОЗАЩИТНЫХ ПОКРЫТИЙ РАКЕТНЫХ ТВЕРДОТОПЛИВНЫХ ДВИГАТЕЛЕЙ

Рассмотрен метод контроля состояния визуально недоступных поверхностей технических объектов, путем исследования цифровых изображений, которые содержат информацию об их состоянии и качестве. Полученные данные позволили классифицировать, сравнивать и выделять классы цифровых изображений. Результаты и выводы визуального анализа подтверждены путем статистической обработки матриц измерений цифровых изображений. [dx.doi.org/10.29010/085.6]

Ключевые слова: *внутренее теплозащитное покрытий; ракетный двигатель; резиновая смесь; визуальный анализ; цифровые изображения.*

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