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Technical note

THE USE THE OF DIGITAL IMAGE CORRELATION IN A STRAIN ANALYSIS

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This paper provides a description of the basic principles and procedures that can be found in strain measurements by means of an experimental method known as the digital image correlation (DIC) while using the correlation system Q-400 and the evaluation software Istra4D. The second part of the paper includes the application of DIC method in strain measurements on a sample made of a PS-1A photoelastic material while using the correlation system Q-400.

Key words: digital image correlation (DIC), correlation system Q-400, software Istra4D, strains.

1. Introduction

The method of digital image correlation (DIC) is an optical experimental method which is used in measurements of a two- or three-dimensional displacements and strains. Its principle lies in a digital image registration. For the first time it was studied at the University in South Carolina at the beginning of the 1980s (Bruck *et al*., 1989; Chu *et al*., 1985), though it reached its biggest boom not earlier than in the recent years following considerable progress in IT technology and digital photography. Like in other optical experimental methods nowadays, advanced equipment, hardware and software are used in the DIC method too (Dantec Dynamics. Digital Imagine Correlation System (Q-400). www.dantecdynamics.com; Kostka, 2012; Trebuňa and Šimčák, 2007). The method has found its place not only in experimental mechanics, but also in biomechanics, fracture mechanics, in the research into the composition materials, determination of the residual stress etc. (Dantec Dynamics. Digital Imagine Correlation System (Q-400). www.dantecdynamics.com; Trebuňa *et al*., 2011a; 2011b). Correlation systems with the DIC method enable us to analyze deformation phenomena on components of various shapes and materials. As a result of such measurements, it is now possible to uncover the surface shapes, displacements and deformations of statically or, possibly, dynamically loaded objects. The DIC method further enables us to perform direct measurements while there is no need for neither additional analytical nor numerical processing of the results. A considerable advantage of the method is the possibility of contactless measurements. Detailed explanations of the basic principles and procedures in measurements of two- and three-dimensional displacements and strains by means of the digital image correlation method can be found in the Handbook of Experimental Mechanics by Trebuňa and Šimčák (2007).

2. The principle of measurement in the DIC method

The DIC method is based on camera recording of the surface of an object under analysis. The surface consists of the black stochastic coating on the white background. A particular part of the object to be scanned is divided into smaller virtual subareas, the so called facets, which have a characteristic and unique pattern (Fig.1).

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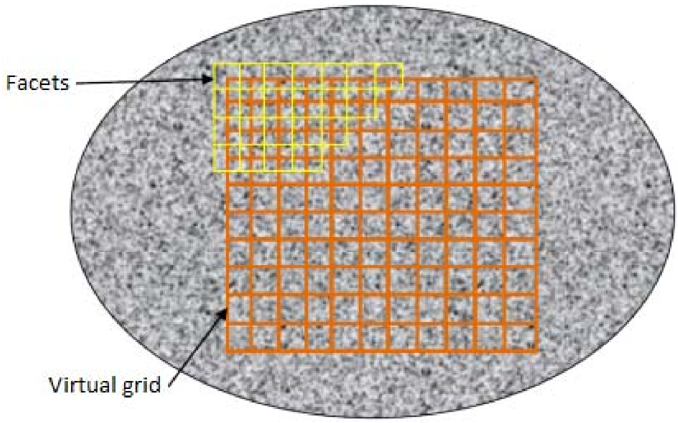

Fig.1 Division of the analysed surface into virtual subareas.

After cameras had recorded the particular area under analysis, the subarea before and after deformation is correlated to determine the strains and displacements of the particular points over the analysed surface. With one camera placed perpendicularly to the measured sample it is possible to determine displacements and strains in the plane area. In the 3D image correlation (Fig.2) at least two cameras are directed at the measured part of the sample. Each camera is placed in individual direction and is focused independently. After the cameras are calibrated and focused and image parameters are set, the measurement can be carried out. The digital images of the object, which were successively taken during loading, are then compared with the original image of the object which was taken while no load was applied.

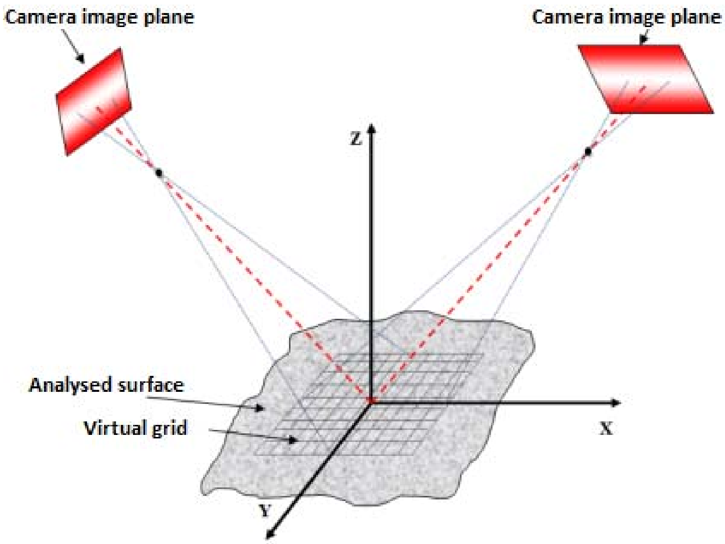

Fig.2 Principle of the 3D image correlation.

3. The correlation system Q-400

The correlation system Q-400 (Fig.3) is an optical measuring device which is based on the principle of the digital image correlation. It can be used in measurements of 2D displacements and strains in objects of any material. The system differs from the correlation system Q-450 through higher resolution of cameras, though it takes fewer images per second. The system Q-400 can be applied in fracture mechanics, measurements of strains and displacements in the event of tests carried out on objects under bending, tensile or torsional loads or under combined loads. Cameras within the correlation system Q-400 are set to resolution of 5 megapixels, however no more than 2 shots per second can be taken (Dantec Dynamics. Digital Imagine Correlation System (Q-400). www.dantecdynamics.com).

Fig.3 The 3D digital image correlation system Q-400.

The system can be applied for objects of various sizes through simple change of the optical lens. The illumination system, which is a part of this set, provides especially strong homogeneous light that ensures excellent measurement conditions. Table 1 includes the technical data of the system Q-400 (Dantec Dynamics. Digital Imagine Correlation System (Q-400). www.dantecdynamics.com; Trebuňa *et al.*, 2011a; 2011b).

Table 1. Technical data of the system Q-400.

Analysed surface	*20*x*15mm²* to *1000*x*750 mm²*
Results of the measurement	3D displacements and strains
Calibration boards	*105*x*148 mm²* to *420*x*594 mm²*
Measurement range	Up to hundreds percent of deformation
Electronic controls	Notebook; Windows 7, Vista or XP Professional; implemented analogue device for receiving and recording input-output data; 16-bit resolution; 8 independent freely adjustable analogue channels for data collection; ± *0.05V* up to ±*10V* synchronised for camera launch; 2 channels of analogue output, software Istra 4D
Illumination	Illumination system HILIS, stroboscopic cold LED light
Measurement sensitivity	Displacements up to 1/100000 of visual field based on measurement conditions (e.g., up to *1 μm* within visual field of *100 mm*)
Application	Measurements of displacements and strains on objects of various materials.

4. Calibration

External as well as internal calibration parameters must be known in order to transfer all points in the field into the 3D coordinates (Dantec Dynamics. Digital Imagine Correlation System (Q-400). www.dantecdynamics.com).

External calibration parameters are:

a) the focal length of lenses;
b) the radius of the lens distortion;
c) the tangent distortion of the lenses;
d) the focus parameters.

Internal calibration parameters are

a) the rotation vector;
b) the displacement vector.

All of the calibration parameters are determined according to identification of indicators while their common position is known in advance. For this purpose we use the so called the calibration targets (Fig.4) of various sizes.

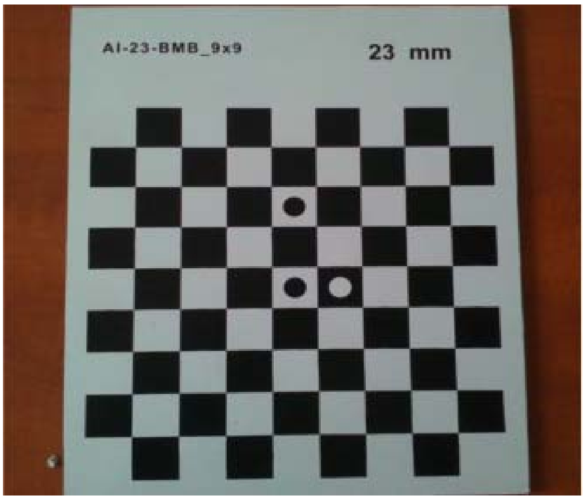

Fig.4 The calibration target AI-23-BMB_9×9.

The calibration targets exhibit a very precise geometry. The camera system is focused at the calibration target in its different positions and, then, identifies the specific indications. After some recordings of the calibration target in its different position the system calculates the internal and external calibration parameters. The Istra4D software enables us to set up cameras, calibration as well as the assessment of the measurement results.

5. Experimental strain analysis by means of the DIC method

In the experimental strain analysis by means of the DIC method as performed on the tested set (Fig.5) we used the correlation system Q-400. The set was made from the PS-1A photoelastic material where its thickness was *3.125 mm*. The shape and size of the set are depicted in Fig.5. PS-1A is commonly used in stress and strain analysis by means of the PhotoStress® method (Kostka, 2012).

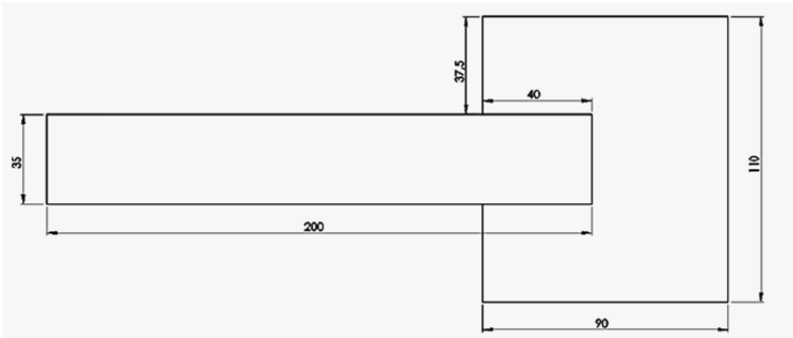

Fig.5 Shape and size of the tested set.

The entire tested set was sprayed white before measurements. When the white layer dried out, the stochastic shape (Fig.6) was sprayed onto the white background with a black blow-up pen. With the stochastic shape under gradual load we can ascertain the displacement of individual points on observed surface of the tested set (Kostka, 2012).

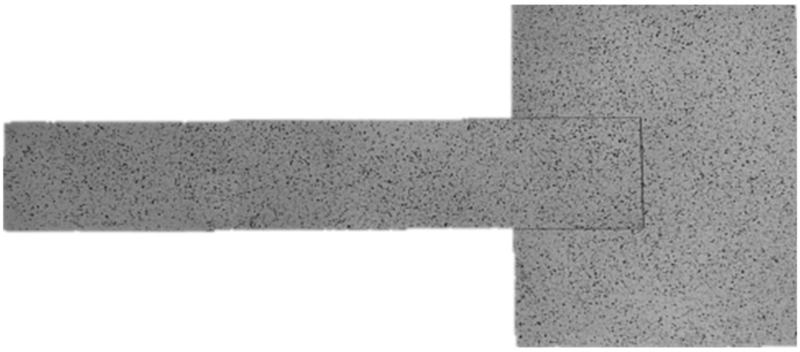

Fig.6 The stochastic layer on tested set.

Having sprayed the layer and positioned the tested set in the loading frame, we attached the cameras and light which illuminated the tested set. Then, the Istra4D software was activated. The cameras were positioned in *0.88 m* distance from the tested object (Fig.7). Each camera was focused manually, brightness of the cameras was set and the whole camera system was then adjusted through the software.

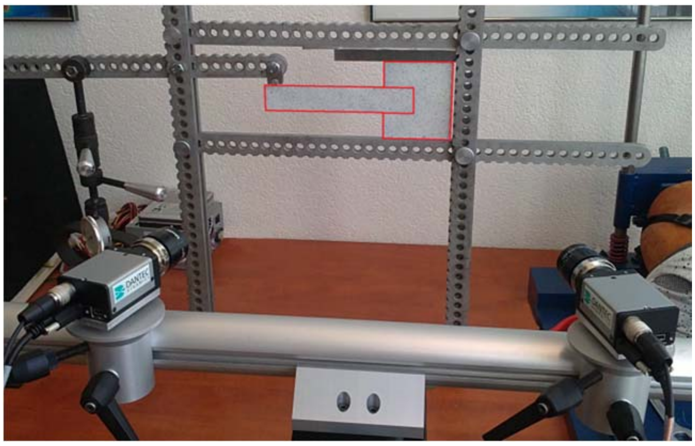

Fig.7. The camera system of Q-400 during recording the set under analysis.

The first shot was taken when no load was applied to the analysed set. Based on this shot, the following shots were compared, i.e., those taken at loads 5 N, 15 N, 25 N, 35 N and 45 N. A new digital image was taken after every single load.

Having taken all images, the cameras were calibrated again. Calibration target DANTEC DYNAMICS 11 mm (Fig.8) was placed into the place of the tested set. In the Istra4D we selected a relevant type of target calibration and launched calibration. The target was moved to sides and turned in various directions. When cameras registered its position, calibration parameters were saved. A presentation of calibration in the Istra4D is depicted in Fig.9.

Fig.8 Calibration target DANTEC DYNAMICS *11 mm.*

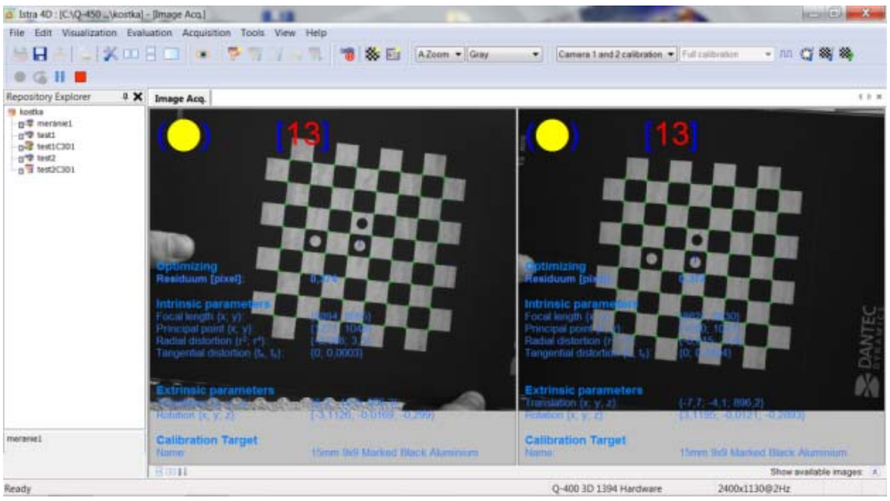

Fig.9. Illustration of the calibration in Istra4D.

After calibration of cameras, an initial image appears which depicts a mask, i.e., the area of our interest or, possibly, the analysed area of the tested set (Fig.10).

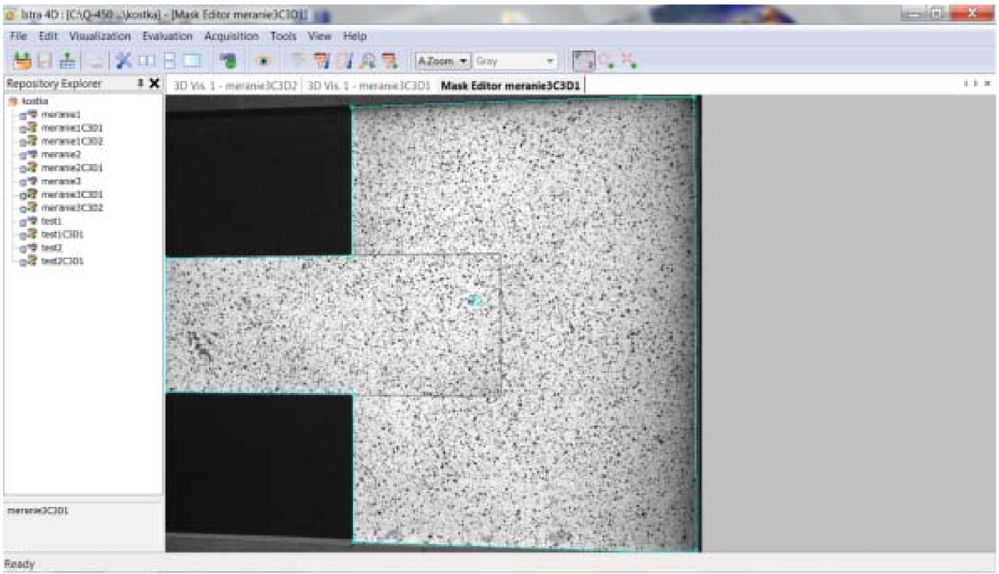

Fig.10. Representation of the mask.

Figure 11 depicts the evaluation of strains in Istra4D.

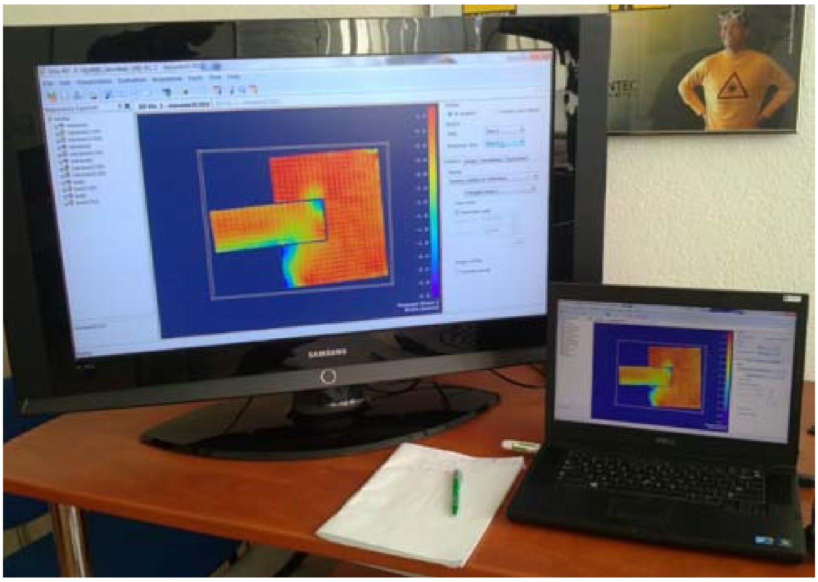

Fig.11. Evaluation of principal strains in Istra4D.

Figure 12 depicts strains, shearing strains and principal strains found in the tested set at individual stages of load (Kostka, 2012).

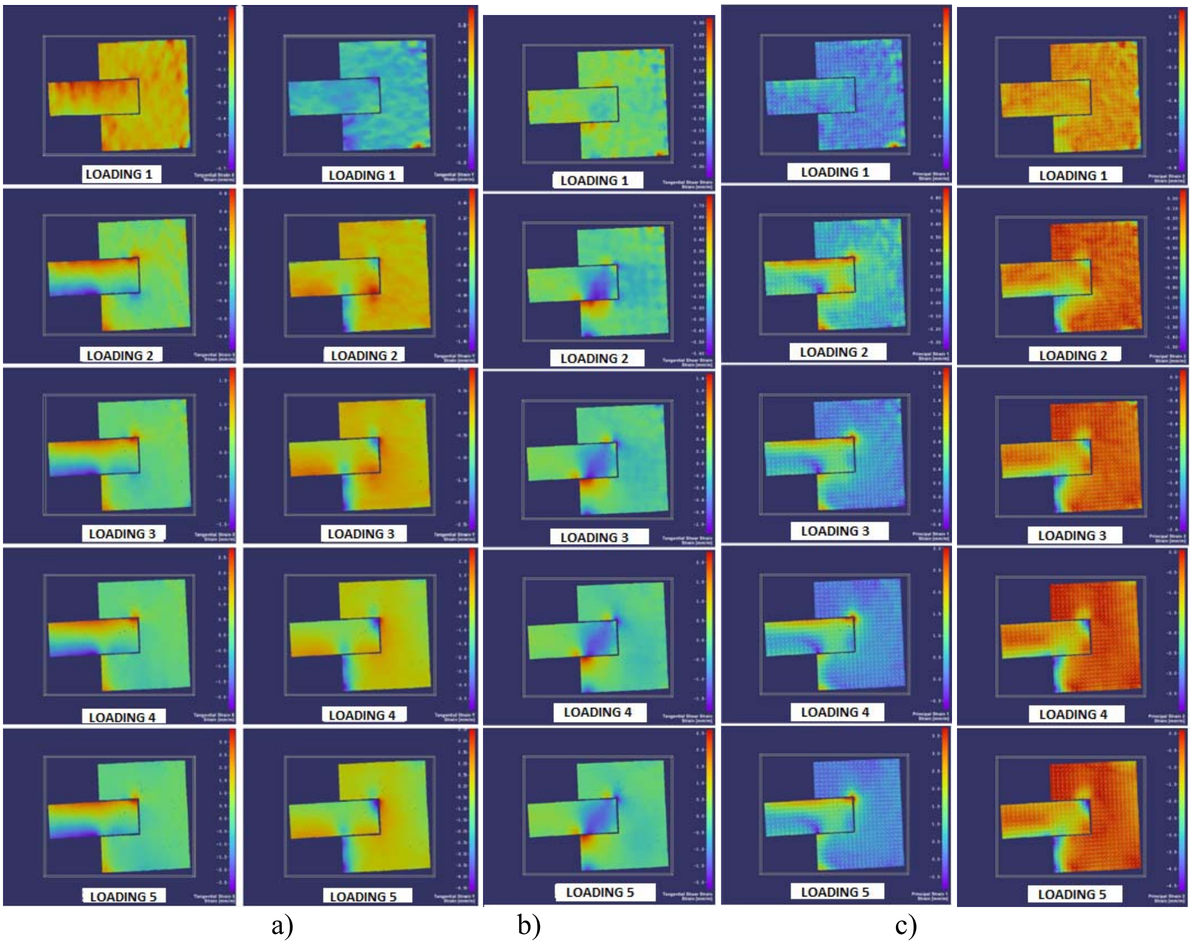

Fig.12 a) Strains ε_x, ε_y; b) Shearing strain; c) Principal strains ε_1, ε_2.

With the DIC method we can also determine principal strains ε_1, ε_2 at a particular point at different loads. The measurement at point A (Fig.13) was taken at five loads applied on the tested set with forces 5N, 15N, 25N, 35N and 45N.

Fig.13 The measurement point of principal strains

The measured values of principal strains at point A under particular loads are listed in Tab.2. A graphical illustration of their distribution is depicted in Fig.14, where the vertical axis represents the principal strain and the horizontal axis represents the load.

Table 2. Principal strains 1 and 2.

Load [*N*]	Principal strains ε_1 [-]	Principal strains ε_2 [-]
5	*0.096074*	*-0.065179*
15	*0.391648*	*-0.346052*
25	*0.708965*	*-0.65114*
35	*1.138007*	*-1.140211*
45	*1.385819*	*-1.418023*

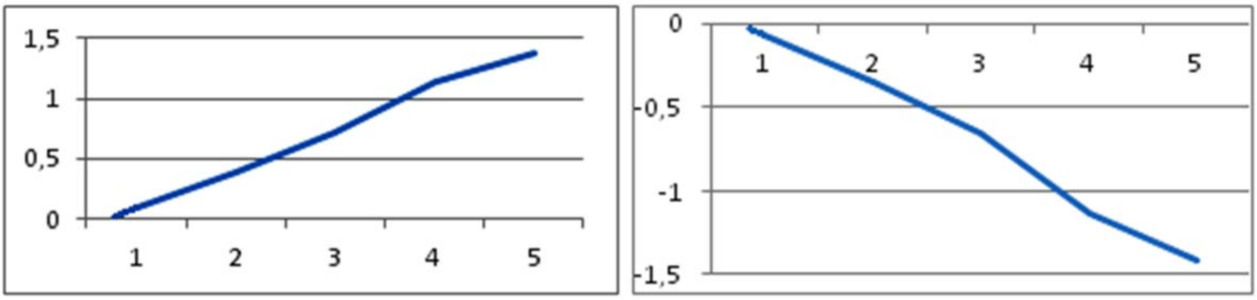

Fig.14. Distribution of principal strains ε_1, ε_2.

6. Conclusion

Being equipped with high-speed cameras, the method of digital image correlation (DIC) has found a wide field of application in experimental mechanics as well as in other industrial areas. It can be applied in tests of various materials, components, fracture mechanics, high-speed applications and measurements carried out on surfaces with restricted access. Characteristic for the method is high sensitivity of measurements. Systems which are used in the method enable us to observe different deformation phenomena. Thanks to its flexible structure, the correlation system Q-400 provides a wide range of applications from microscopic testing in microelectronics and biomedical materials to various measurements of aviation, automotive, mechanical, nautical or railway components (Kuryło, 2012; Papacz, 2012; Trebuňa and Šimčák, 2007).

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