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The knowledge acquired by using of optical methods by strain fields investigation

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Abstract. These days are preferably used contactless optical methods for experimental investigation of strains and displacements, which give some information on whole investigated surface. In this contribution the optical systems working on electronic speckle pattern interferometry (ESPI) principle and digital image correlation (DIC) method are described. By using of ESPI and DIC methods the displacements and strains fields on chosen types of specimens are determined. Pros and cons of particular methods and influence of various factors on reached results accuracy are compared. There are also mentioned the possibilities of using of optical methods in application of devices on author's department.

Introduction

Speckle interferometry and digital image correlation are contactless experimental measuring techniques allowing the analysis of the displacements and also acquiring strain fields of whole investigated object surface. The high sensibility and enormous spatial resolution of speckle interferometry enables to investigate various kinds of homogeneous and heterogeneous materials. It is predominantly used for static investigation of in-plane deformations and bending [1, 2, 3]. On the one hand digital image correlation is method with lower sensibility but its pros predestine it for performing static and also dynamic measurements on various types of materials almost under all conditions [4, 5].

Basic principle of electronic speckle pattern interferometry and digital image correlation

The base of speckle interferometry is an interference of two monochromatic beams of light. Reference beam entering the CCD camera interfere with a beam reflected from a diffuse surface of a specimen and consequently create a characteristic pattern called speckle effect (Fig. 1).

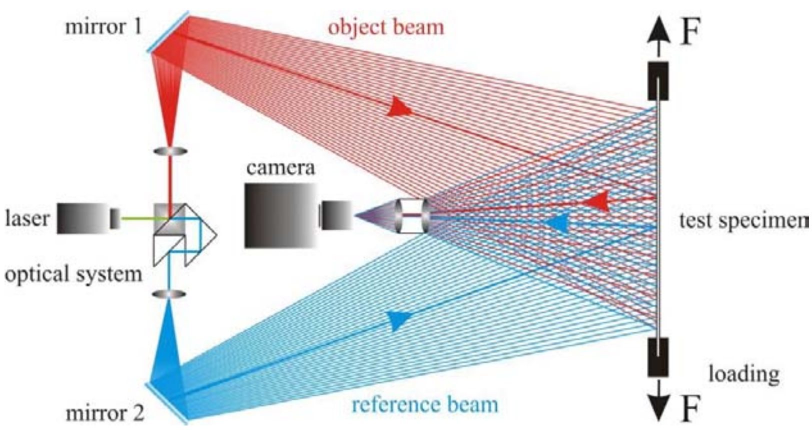
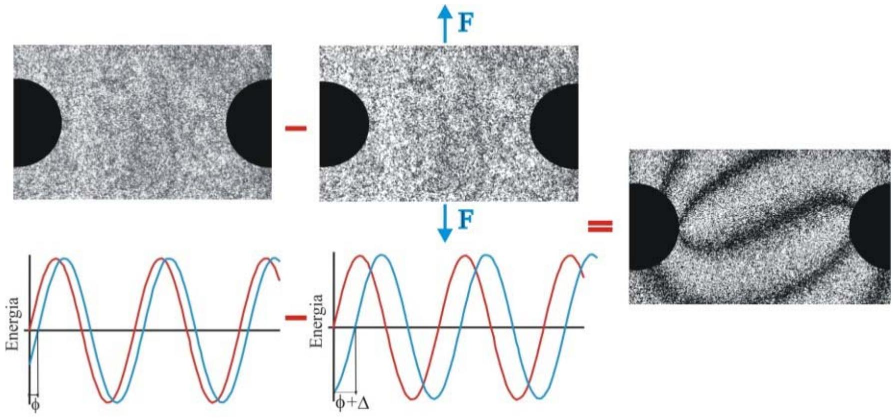


Fig. 1 Principle of ESPI

There is a distinct phase difference ϕ between both beams, which is changed after object deformation to $\phi + \Delta$. Their subtraction shows itself as a fringe pattern with various points intensity (Fig. 2).



a) b) c)

Fig. 2 a) Speckle image for unloaded specimen with energies of reference and object beam,
b) Speckle image for loaded specimen with energies of reference and object beam,
c) The result of mutual subtraction of images

The fringes represent the areas with equal displacement, but qualitative information about displacement can not be determined from this image. It is possible to obtain so-called 2π phase image by introduction of phase shift algorithm by which four images of intensity corresponding to changes of optical length of reference beam trajectory are acquired. Then the intensity of object points can be expressed as follows [1, 2, 5]:

$$I_i(x, y) = I_{0,i}(x, y) + I_{\mathrm{mod},i}(x, y)\cos(\phi(x, y) + \varphi_i), \tag{1}$$

where $I_0(x, y)$ is the environment intensity, $I_{\mathrm{mod}}(x, y)$ is modulation intensity, $\phi(x, y)$ is optical phase stochastic for every pixel of speckle field and $\varphi_i = \frac{\pi}{2}, \pi, \frac{3\pi}{2}, 2\pi$ present known phase shift of length of reference beam optical trajectory.

The essence of digital image correlation method is comparison of stochastic black and white pattern captured on digital snapshots of investigated object during its loading. In order to not taking a long time during the correlation it is performed on small image elements called facets (Fig.3). The size of these facets is determined by fineness of stochastic pattern because for correct correlation is necessary to contain white and also black part of the pattern for every facet [4, 5, 6].

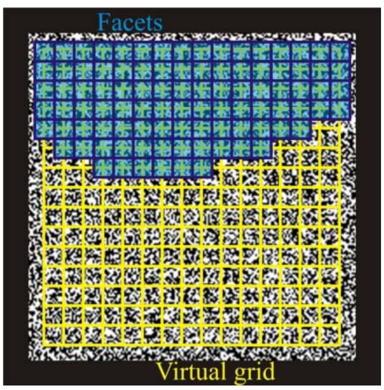


Fig. 3 The object with created stochastic pattern, facets and virtual grid

CCD cameras that enable spatial analysis are usually used for recording. By using of only one camera the investigation is limited only for planar deformations (Fig.4).

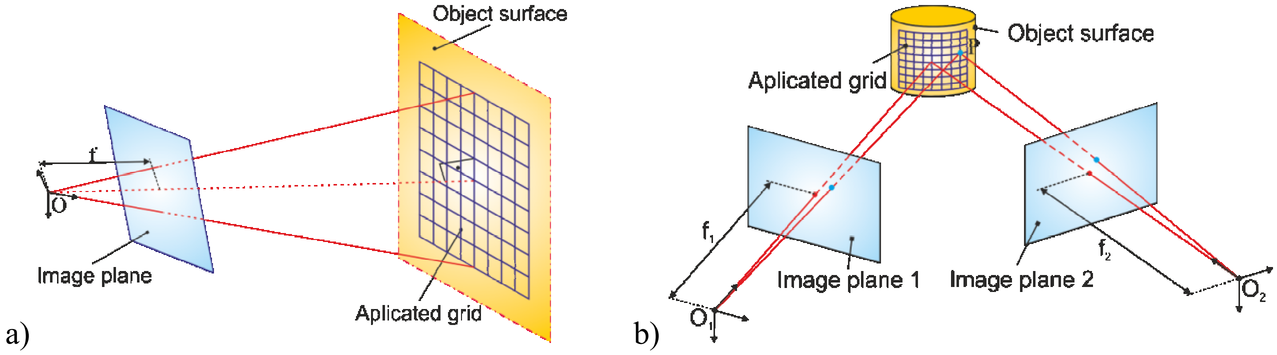


Fig. 4 Principle of: a) 2-dimensional DIC, b) 3-dimensional DIC

There is a shifting and a deformation of stochastic pattern which totally copy the specimen surface during its loading. By recording of pattern from two various directions it is possible, with knowing of mutual cameras position, magnitude of objectives and deflection of lenses, to determine absolute position of every object point and thus obtain its contour. Mentioned parameters are determined by cameras calibration – correlation systems Dantec Dynamics – by which the experiments were performed and which use Zhang algorithm for calibration parameters computation.

The use of ESPI and DIC in fullfield strain analysis

The possibilities of utilizing of Q-300 Dantec Dynamics that use electronic speckle pattern interferometry are presented on the example of uniaxial metal-sheet specimen loading (Fig.5a).

With respect to high method sensibility for mutual shifting of sensing head and investigated object the universal loading device Zwick Z020 (Fig.5b) was used, for which in software Zwick Roell the following parameters were set:

Initial loading	**Girder shifting**	**Waiting time before acquisition**	**Waiting time after acquisition**	**Maximal force**
50 N	0,01 mm / step	3 s	4 s	1500 N

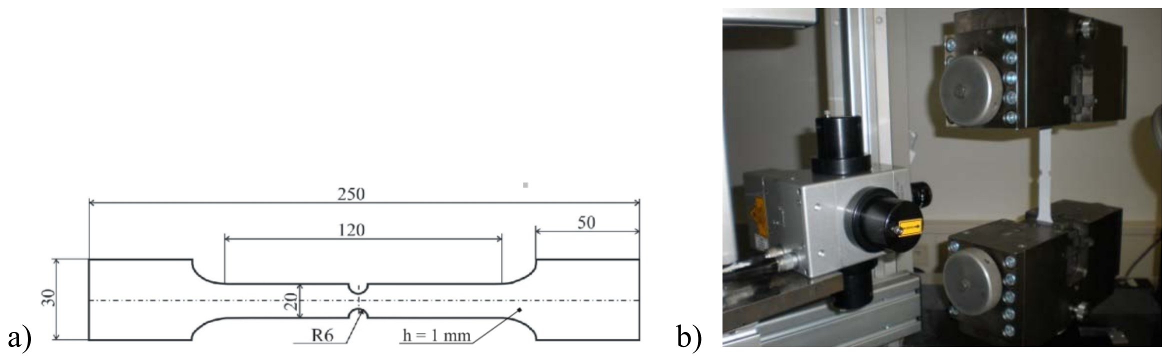


Fig. 5 a) Investigated specimen b) Optical device Q-300 Dantec Dynamics with short iluminating arms, the specimen clamped by universal testing device Zwick Z020

The distance of CCD camera from investigated specimen was 292 mm what caused by using of objective with 25 mm focal length and lenses placed in four short illuminating arms that by this setting the field of view displayed by CCD camera was of size 60x50 mm.

There are illustrated strain fields ε_y and particular normal stress fields σ_y on the Fig. 6a and Fig. 6b, acquired by program ISTRA which is operative part of ESPI devices.

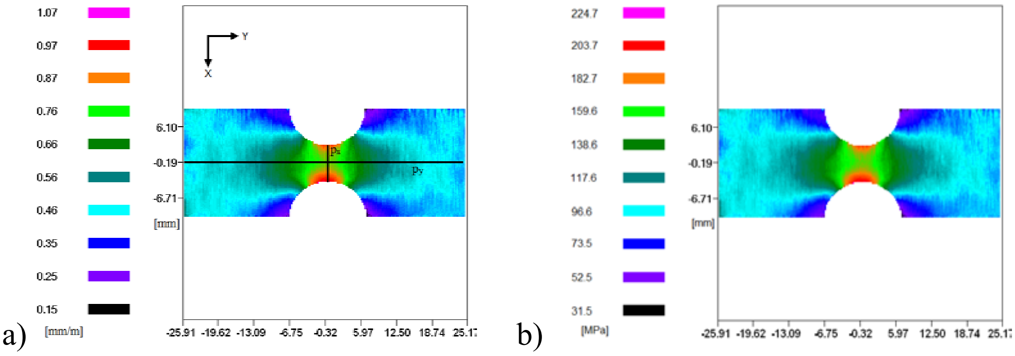


Fig. 6 a) Strain field ε_y (30th loading step)

b) Normal stress field σ_y (30th loading step)

The time variation of strain ε_y in sections defined by lines p_x and p_y (depicted on Fig.6a) related to four various loading states is depicted on Fig. 7.

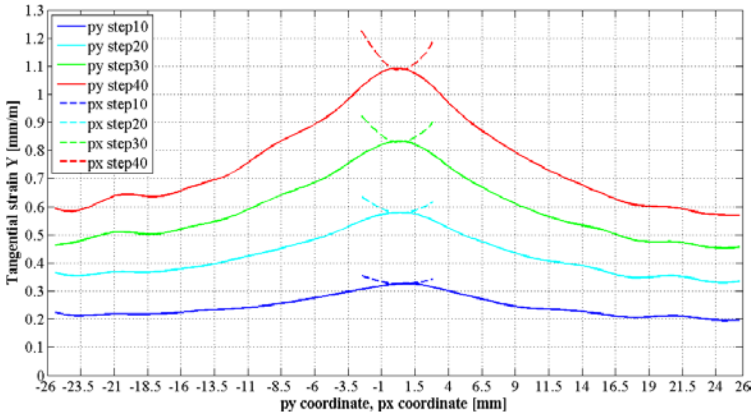


Fig. 7 The time variation of strains ε_y in sections defined by lines p_x and p_y

Optical system ESPI was also used for realisation of shear test. Simple specimen with so-called butterfly-shape was used for shear deformation (Fig. 8a). Own clamping appliance was designated owing to assurance of required stress state (Fig. 8b). The advantage of designed clamping appliance is possibility of its partial modification and loading of testing specimen not only by shear but also by tensile or creation of planar deformation. There are fields of shear deformation and shear stress determined by system ESPI with respect to mentioned proceeding on Fig. 9.

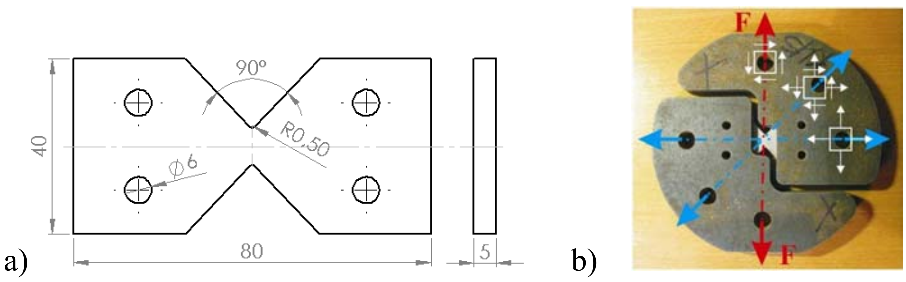


Fig. 8 a) Testing specimen, b) Clamping appliance for shear test

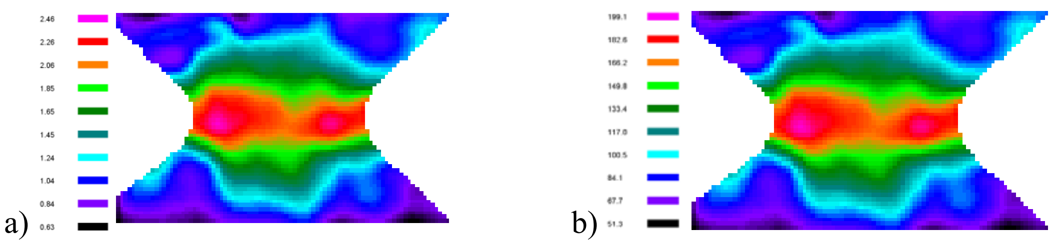


Fig. 9 Full-field distribution of: a) shear deformation b) shear stress

Digital image correlation gives possibility to measure not only in laboratory conditions but also in solving problems of technical practice. According to kind of used system it is possible to perform either static or dynamic measurements.

In next section is presented analysis of thermal elasticity of electric hot-plate with using of low-speed correlation system Q-400 Dantec Dynamics.

On the electric hot-plate's surface was created fine black and white pattern in order to utilize full resolution of 5Mpx CCD cameras. During warming-up of hot-plate the vapours which unpleasant influence allowed evaluating only first 53 seconds of measurement were released. With respect to that warming-up of the hot-plate should be equable only a part of the stove was used to evaluation.

On the Fig. 10 can be seen displacement and strain fields in last evaluating step acquired by software Istra4D which is operating and controlling member of correlation systems Dantec Dynamics.

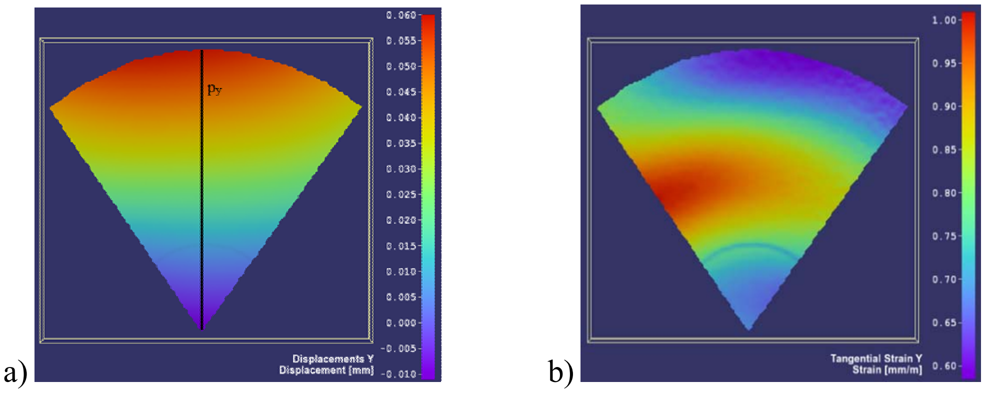


Fig. 10 Field of: a) displacements in Y direction, b) strains in Y direction on evaluated part of hot-plate

Software Istra4D provides utilizing of virtual meters in similar way as upper mentioned program ISTRA. The charts on Fig. 11 give better information about time variations of displacements and strains on line p_y depicted on Fig. 10.

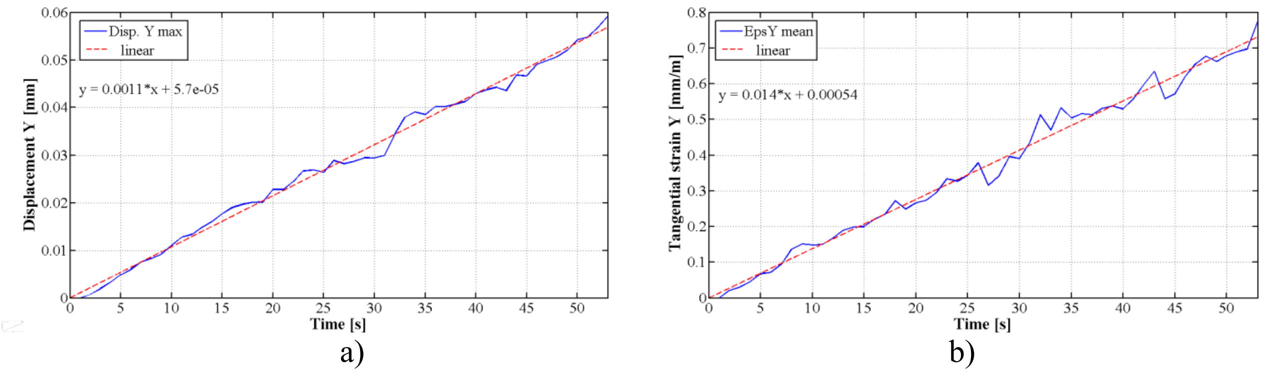
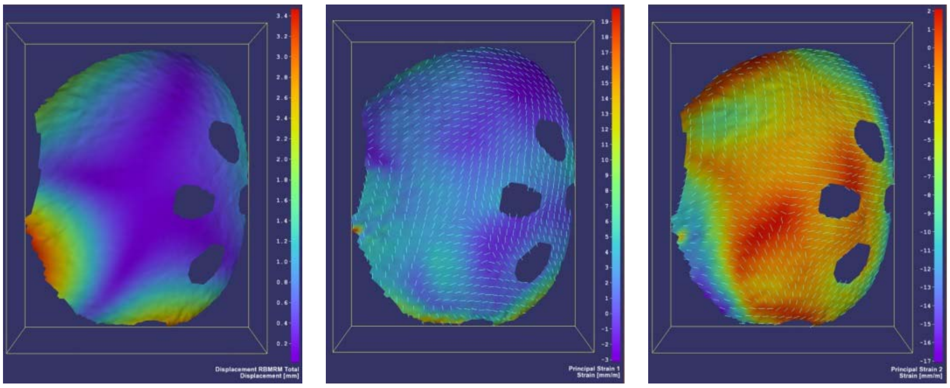


Fig. 11 Time variation of: a) displacements of line p_y in Y direction, b) strains in Y direction

By the measurement was found out that the temperature of electric hot-plate warmed about 38°C. This ascertaining leads to determination of thermal expansion coefficient of hot-plate material which fit to value of $16{,}8.10^{-6}$ K^{-1}.

By a drop test a cycling helmet was analysed with using of high-speed Q-450 Dantec Dynamics system. With respect to fact that impact of helmet takes very short time the measurement had to be realized with maximal possible frequency of sampling which was in our instance 6000 fps.

There is depicted total deformation field and main strain fields on the Fig. 12 in time which relates to stopping of the helmet on barrier.



a) b) c)

Fig. 12 Fields of: a) total deformation, b) principal strain in direction 1, c) principal strain in direction 2

Comparison of basic properties of both optical devices is presented in next table:

	ESPI (Q-300)	DIC (Q-400)
Sample surface preparation	optically rough surface	random black and white pattern
Measurement area	1x1.5 [mm²] - cca. 100x150 [mm²]	1x1 [mm²] - several m²
Measurement accuracy	disp.: 0.03-0.1μm, strain: 10-20μm/m	disp.: 10μm, strain: 1000μm/m
Sampling frequency	1 fps	max. 2 fps
Using conditions	laboratory testing	operating environment
Export possibilities	ASCII	ASCII, STL, HDF5

Summary

In this contribution are described two optical methods serving for experimental investigation of displacement and strain fields – electronic speckle pattern interferometry and digital image correlation. There are presented properties on two solved problems which these optical devices are disposing. Among biggest pros of ESPI we can put the possibility of automatic gain of stress fields and high sensibility which on the other hand constrain the using of given method only for laboratory conditions. The biggest pros of DIC is its application in operating conditions, possibility of measuring big-size specimens and better alternatives of data export.

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