Experimentální Analýza Napětí 2010
Experimental Stress Analysis

Abilities of new software for PhotoStress® method

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Abstract: PhotoStress® method allows separation of principal strains and stresses on loaded photoelastically coated real structural members. At present time beside of quantitative values of differences of principal strains (stresses) and their directions allows gaining their visual mapping on whole coated surface. Process of stress measurement and evaluation is based on determination of magnitudes and directions of principal strains or stresses in a point to which is necessary to accomplish several measurements. In order to accelerate this proces of measurement in point, on line or on surface was, together with firm Kybernetika, s.r.o., created on the workplace of authors software application ***PhotoStress***. In the measurement chain can be used reflection polariscopes M030, M040 and LF/Z-2 by which can be determined directions and magnitudes of differences of principal strains or stresses on the base of photographs loaded photoelastically coated objects by using three methods of separation (Slitting method, method of oblique incidence and method of shear stress differences). The development of ***PhotoStress*** application, description of which is a base of a paper, continues and a program product is under further evolution.

Keywords: PhotoStress®method, software ***PhotoStress***, reflection polariscopes

1. Introduction

PhotoStress® method is widely used method appropriate for visual and quantitative determination of directions and magnitudes of principal strains or stresses on photoelastically coated objects. The workplace of authors is equiped by three mesurement units that are determined for measurement of parameters of direction and differences of principal strains or stresses by this method. The polariscopes M030, M040 and LF/Z-2 allowed determination of parameters of direction and differences of principal stresses and consequently every equipment allowed on the base of experimentally determined further parameter to separate principal stresses or principal strainsthat is lengthy process especially if it is applied in several points of

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coated surface. In order to accelerate this process was created new software application ***PhotoStress*** that simply on the base of photography of color isochromatic fringes of loaded objects allows to determine directions and magnitudes of separated values of principal strains or stresses in point, line or curve. For determination of third parameter that is necessary for assessing of separated values of principal stresses are at present in the application built three methods - Slitting method, method of oblique incidence and method of shear stress differences. In following parts of a paper is given base principle ***PhotoStress*** application and example of determination of direction and magnitude of principal normal stresses in partite ring by using Slitting method of separation.

2. Charakteristics of software application PhotoStress

Software application ***PhotoStress*** (Fig.1) is based on recognizing of colors of individual pixels of color isochromatic fringes that are created during loading and lightening of coated objects with polarized light by reflection polariscope. From the color of individual pixels of a photograps is determined order of isochromatic fringes and subsequently are determined values of differences of principal strains and principal normal stresses. On the base of bundles of isocline lines the application allows to determine direction in individual pixels of analyzed surface. In ***PhotoStress*** application the analyzed field of isochromatic fringes is divided into two areas (Fig.2):

- area of isochromatic fringe order N in range from *0* to *0,35*,
- area of isochromatic fringe order N in range from *0,36* to *3,00*.

Fig. 1. Software application *PhotoStress*.

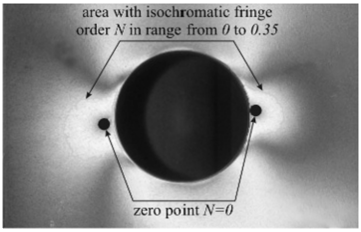

Fig. 2. Specification of area of isochromatic fringe orders N in range from 0 to 0,35.

In areas where the isochromatic fringe orders are smaller than *0,35* are the colors very inconspicuous. For determination of fringe order in this area is primarily marked area of null point (with fringe order $N=O$). Consequently the application bounds the area with isochromatic fringe order N in range from *0* to *0,35.* In this area are searched by gradient method the shortests trajectories between area of null point and isochrom line with fringe order 0.35. To the every point in this area is given fringe order on the base of ratio of its distance from null point to isochrom line of order 0.35 in the frame of given trajectory. Algorithm for determination of isochromatic fringe order in area of fringe orders in range from 0.35 to 3.00 is based on determination of color of given pixel (in HSV color space, where Hue determines prevailing spectral color, *Saturation* determines to how extent is the color clear and Value describes the measure of brightness) and its index that represents order of repeating of six color fotoelastic colors. To the every point of color fotoelastic pattern is given RGB value of color space. This value represents relative intensity of red, green, and blue color, which is not enough for PhotoStress® method. That is a reason why is in PhotoStress built algorithm for transformation of color components from RGB color space to HSV color space. During the recomputation of individual color pixels to value of fringe order is used value H (Hue). To this value is given value of fringe order *N* according to defined transformation function. This function is determined according to calibration measurements provided on polariscope LF/Z-2 with using camera Canon PowerShot A480. To the sequential indexing of analyzed area is used 8-directional algorithm FloodFill.

3. Example of determination of principal normal stresses by *PhotoStress* application

In example of direction and differences of principal normal stresses determination by application ***PhotoStress*** was used excentrically loaded specimen of partite ring whose shape, dimensions and character of loading is given in Fig.3. Partite ring with thickness *3 mm* was covered by photoelastic coating PS-1 with thickness *3,125 mm*. It is loaded by force *F=1000 N* in loading frame according to Fig.4.

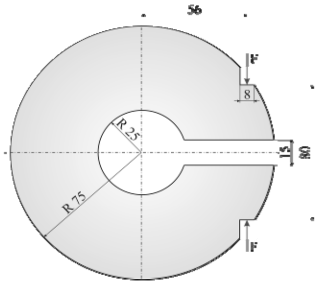

Fig. 3. Shape, dimensions and character of loading of partite ring.

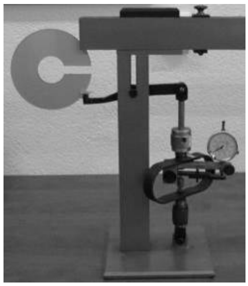

Fig. 4. Loading of partite ring.

Measurement and evaluation chain for determination of magnitudes and directions principal strains and stresses by application ***PhotoStress*** (Fig.5) consists of loaded photoelastically coated object, notebook with installed application ***PhotoStress*** and output, e.g. printer.

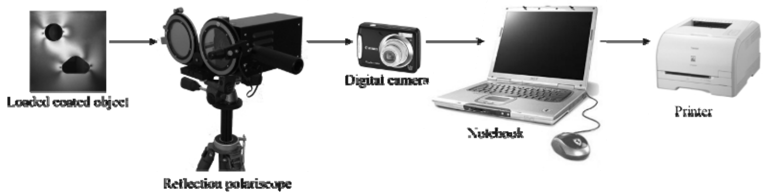

Fig. 5. Measurement and evaluation chain for determination of stresses by *PhotoStress* application.

After sensing of isocline line bundles during small loading (Fig.6) and izochromatic fringes during succesive loading (Fig.7) were the pictures imported into application ***PhotoStress***.

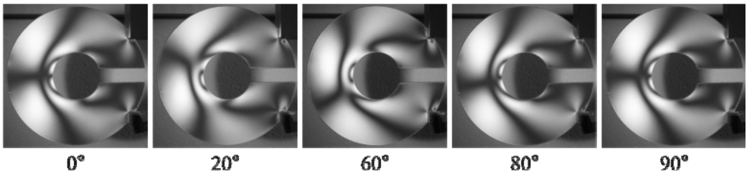

Fig. 6. Some pictures of isoclines.

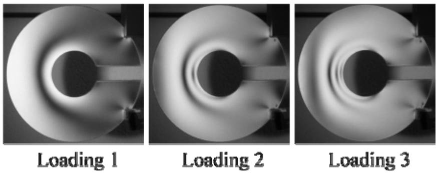

Fig. 7. Some pictures of isoclines.

Necessary condition for computation of principal strains or stresses is creation of mask in application ***PhotoStress***, or separation of object from background. In Fig.8 is shown creation of mask of partite ring. Red boundary represents automatic selection on the base of edge detection and violet boundary represents manual selection of edges. By the red cross are marked areas that are not important for our investigation. Developed mask is given in Fig.9.

Fig. 8. Creation of mask.

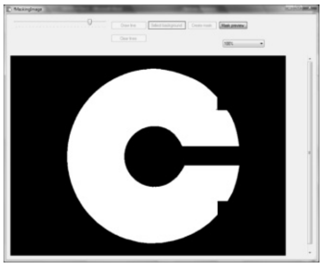

Fig. 9. Masko of partite ring.

In application ***PhotoStress*** is the process of creation of isocline lines simple and very quick (Fig.10). Isocline lines are drawn manually by quadratic Bézier curve that is determined by three control points for every picture of isocline lines with increment of 10 from 0° to 90°.

After processing of individual pictures of isoclines is whole analyzed field recomputed by algorithm for approximation of directions oof principal strains or stresses for every point of mask. Created file of isoclines with increment 10 on excenrically loaded partite ring is shown in Fig.11.

After creation of isocline line bundles and their successive recomputation for individual pixels of mask is possible to show isostatic lines of I. and II. kind (Fig.12). Blue curves represent isostatic lines of I. kind and red curves isostatic lines of II. kind.

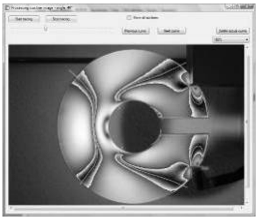

Fig. 10. Process of creation of isocline bundles.

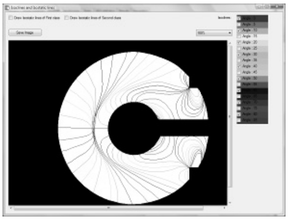

Fig. 11. Isocline bundles on partite ring.

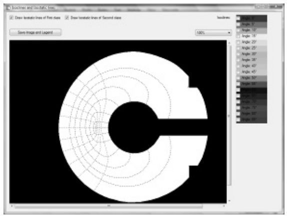

Fig. 12. Izostat lines of I. and II. type on partite ring.

Process of indexing of color isochromatic fringes is provided in folder ***Isochromes***. The null points, or start points are marked (Fig.13) for algorithms of color determination in individual pixels of picture and then starts recomputation of isochromatic fringe order in given pixels. After marking of null points and recomputation are highlighted colors in whole analyzed region of investigated object (Fig.14).

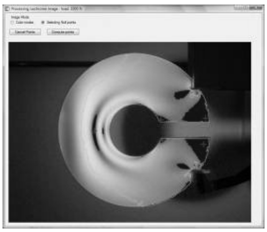

Fig. 13. Chosing of null points on loaded partite ring.

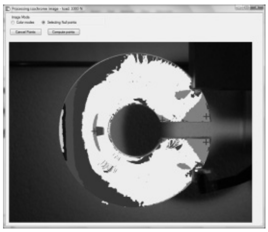

Fig. 14. Analyzed area after counting of isochromatic fringe orders.

After processing of osoclines and isochromes are defined in a folder ***Test*** necessary parameters for photoelastic coating and material of analyzed object. Application contains predefirned material characteristics for material of object (steel, aluminium, copper, titanium and brass) and material of photoelastic coating (PS-1, PS-2, PS-3, PS-4, PS-6, PS-8, PL-1, PL-2, PL-3, PL-6, PL-8).

In application ***PhotoStress*** is included a term region. It is geometrical entity in which is provided measurement of directions and magnitudes of principal strains and stresses. Application offers three types of regions: point, abscissa (line segment), and curve. Region is defined in a folder **ROI definition**.

For determination of principal normal stresses in partite ring was used line segment (Fig.15).

Determination of directions of principal normal stresses, magnitudes of fringe orders and differences of principal normal stresses in defined regions is provided in folder **Results.** In this folder is also possible, in case of abscissa or curve region, to prescribe number of parts on which the region should be divided. Consequently we determine in these boundary points values of principal stresses. Numbering of points beginns with zero. In our case we have used 6 equivalent parts (Fig.15). After this operation of dividing we generate resulting values and directions of principal normal stresses in defined region.

Magnitudes of directions of principal normal stressesare determined by application ***PhotoStress*** in individual point of line segments (Fig.15) as is shown in Table 1.

Table 1. Directions of principal stresses in points of chosen region

	Region	*Points of measurement*						
		0	1	2	3	4	5	6
***Principal direction of stress* [°]**	Segment	90	90	90	90	90	0	0

In Fig.15 is shown dividing of line segment between points *0* to *6* to individual parts and graphical representation of directions of principal normal stresses in these points.

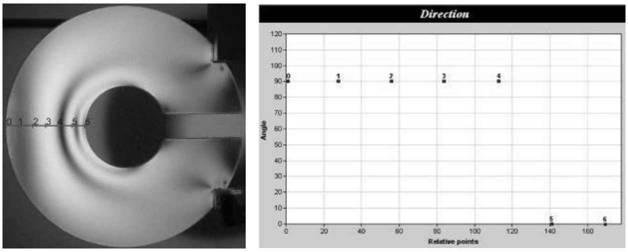

Fig. 15. Directions of principal normal stresses in points of defined area.

The points 1, 2, 3, 4 and 5 lie inside area of coating. Stress state in these points is plane and consequently by first measurement in these points we determine only difference between principal normal stresses σ_1-σ_3. Individual components of principal normal stresses σ_1 and σ_3 are determined by further measurement using method of separation. Values of fringe orders *N* and differences of principal normal stresses σ_1-σ_3 in individual points of region are given in Table 2.

Table 2. Differences between principal normal stresses in individual points of area

Point of region	0	1	2	3	4	5	6
N [-]	0,63	0,45	0,37	0,27	0	0,89	1,44
σ_1 - σ_3 [MPa]	63,43	45,26	37,92	27,03	0	89,57	144,23

Graphical representation of charts of differences of principal normal stresses σ_1-σ_3 in individual point of line segments is given in Fig.16.

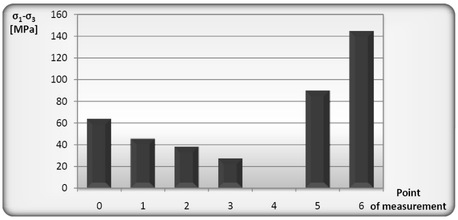

Fig. 16. Chart of differences between principal normal stresses σ_1-σ_3 in individual points of line region.

For determination of individual values of principal normal stresses in points of line segment region that lie outside free boundary of coating was used Slitting method. In this method is created a slit throught photoelastic coating in direction of principal stresses σ_1 and σ_3. On the analyzed line region of partite ring was the slit created along isostatic line of II. kind (outer boundary - neutral axis) and isostatic line of I. kind (neutral axis – inner boundary) that lie on axis of symmety of partite ring, along line segment region (Figs.17, 18).

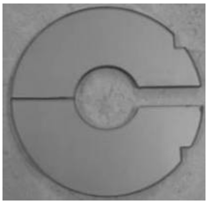

Fig. 17. Unloaded partite ring with a slit.

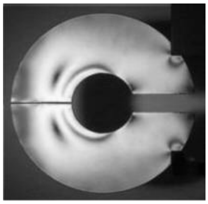

Fig. 17. Loaded partite ring with a slit.

Values of separated principal normal stresses σ_1 and σ_3 determined by application ***PhotoStress*** are given in Table 3.

Table 3. Separated values of principal normal stresses σ_1 and σ_3

Principal normal stress [MPa]	***Points of measuremnet in line region***						
	0	1	2	3	4	5	6
σ_1	63,43	43,89	36,91	25,78	9,63	2,47	0
σ_3	0	-1,37	-1,01	-1,25	0	-87,1	-144,23

In Fig.18 is given chart of separated values of principal normal stresses σ_1 and σ_3 in individual points of region by Slitting method.

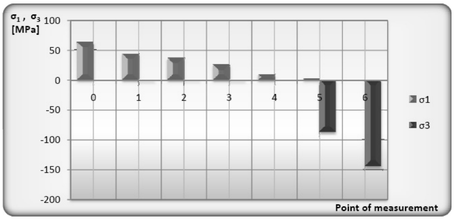

Fig. 18. Chart of separated values of principal normal stresses σ_1 and σ_3 in individual points of region.

4. Conclusion

As is obvious from example of determination of directions and magnitudes of principal normal stresses in partite ring, application ***PhotoStress*** provides quick quantitative analysis that gives opportunity to use it not only in laboratories, but also in technical practice. Application will be improved in order to provide not only statical, but also dynamical analyses with usig stroboscopic light and quick cameras. Application is also modified in order to accomplish analysis of residual stresses by PhotoStress® method and the hole drilling method. For separation of individual values of principal strains and stresses are developing further mathematical methods of separation.

Further improvements will be published on future scientific conferences and in journals.

Acknowledgement

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