AUTOMATIC MEASUREMENT OF RESIDUAL STRESSES IN THE REPAIRED DETAILS OF farming machines BY THE COHERENT OPTICS METHOD

Andrey Apalkov[1], Teodor Akinfiev[1], Manuel Armada[1], Igor Odintsev[2]
[1] Technical University of Madrid, Center of Automatics and Robotics, Spain
[2] A.A.Blagonravov Mechanical Engineering Research Institute, Moscow, Russia
andrey.apalkov@iai.csic.es

Abstract. The problem to estimate the repair quality of farming machines details by the method of electronic digital speckle pattern interferometry (ESPI-method) is under consideration in this article. It is supposed to apply the drilling method (small-diameter hole) for the investigation of large-sized structures and details. The indentation of spherical probe is applied for qualitative evaluation of stressed state in the repaired details. The automatic inspection of repaired details will be performed by the walking robot which is intended for transportation of ESPI-interferometer to the point to be investigated and further fixing. The applying of the above mentioned approaches will allow to make the prompt conclusion on the repair quality of farming machines details.

Keywords: repaired details, ESPI-interferometer, speckle-pattern, walking robot.

Introduction

Recently the cost increasing for farming machines and corresponding spare parts is observed. For this reason the repair of worn out details is the most available way to provide the farming machines in the operation. The quality inspection of these details is of great importance for successful functioning of all the agriculture.

The important problem is to provide the required strength and guaranteed life-time while designing, creating, operating and repairs of the farming machines. One of the actual problems thereupon is the measurement of technological residual stresses (RS) in structural material especially near the welds. The adversely combination of operational and residual stresses (in particular their levels and directions) can cause the premature failure of structural elements with the necessity to provide the repair work. As a rule, the considerable number of failures in agricultural machinery is caused by rupture of load-bearing structure in the fixing places of engines, shock-absorbers etc. (points, which are exposed by the considerable cyclic loading).

In many cases the repair of farming machines occurs to the welding works. It is well known, that welding causes the residual stresses (yield stress level) in the welding zones. The repeated failure of these details could take place at the further operation. There are various techniques to indemnify from the welding-induced RS [1]. The method of residual stresses measurement in the repaired details is considered in this article. This approach will allow to diagnose promptly the reasons of farming machines failure and to estimate the repair works quality.

Materials and methods

The method of the electronic digital speckle pattern interferometry (ESPI-method) is proposed in order to measure the material deformation response on the mechanical influence (for stressed state estimation in the details). This method of response registration (measurement of displacement vector components) is a coherently optical, contact-less one with high sensitivity and does not require the preliminary preparation of surface [2].

It is reasonable to use the drilling method (small-diameter hole) as an influence on the material for diagnostics [3]. This method could be considered as non-destructive one when the probe hole dimensions do not exceed the allowable sizes of the defects for the large-sized structures and details. The material deformation response on the hole drilling is fixed by video camera of ESPI-interferometer, transferred to computer and saved as digital file. The mathematical data processing for the initial and deformed (after the hole drilling) conditions is the solution of the inverse problem for deformable solid body mechanics with application of the special computer programs by the finite element method (FEM) [4].

It is reasonable to estimate the repair works quality when the repair procedure (for example the welding of load-bearing elements with the consequent temperature annealing) is completed. In this

case it is proposed to use the indentation of spherical probe as the deformation influence on the surface of the repaired detail [5, 6]. This method is non-destructive one; it allows to estimate promptly the repair works quality. The mathematical processing is provided on the speckle pattern interferograms of the displacements in the plane (as they are the most informative). This approach could be used both for the indentation of spherical probe and for the hole drilling. In these cases the speckle-pattern interferograms of normal displacements and are used additionally for the assessment of stress values and signs in the investigation point only.

The scheme of the ESPI-interferometer for measurement of the material deformation response on the mechanical influence is shown on Figure 1. The interferometer basis is the rigid metal plate (load-bearing frame). All the interferometer's components (video camera, laser device, reflective mirrors) and the systems of hole drilling and spherical probe indentation are fixed on this frame. The interferometer should be rigidly fixed relatively to the point to be investigated.

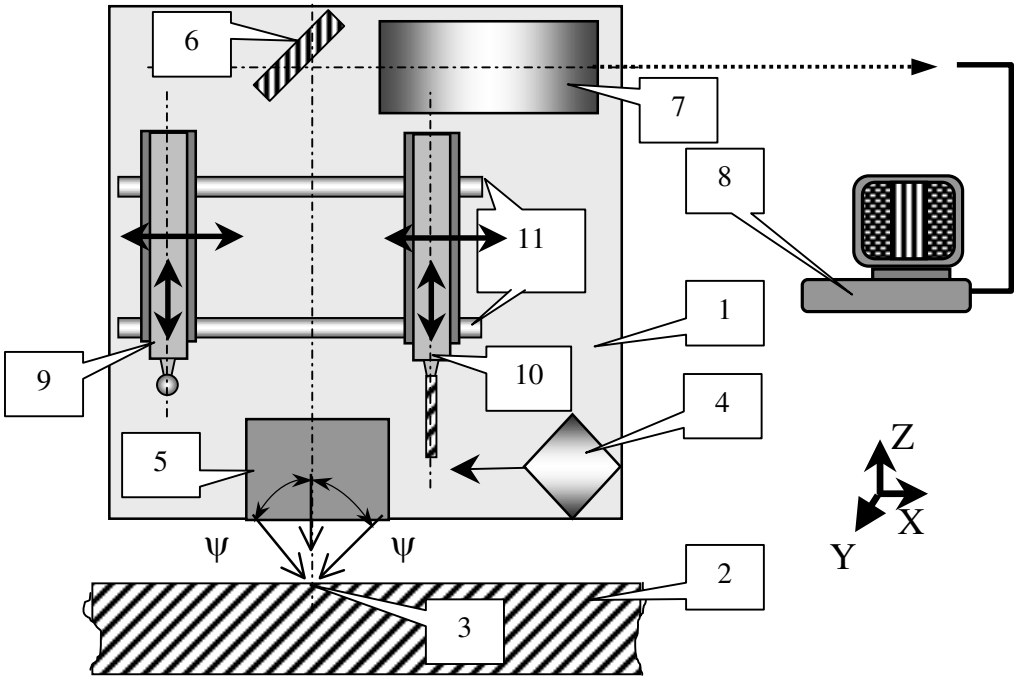


Fig. 1. **The arrangement scheme of the interferometer's functional elements on the load-bearing frame:** 1– load-bearing frame; 2 – object to be investigated; 3 – point to be investigated; 4 – laser source; 5 – angular reflector; 6 – revolving mirror; 7 – digital video camera; 8 – operator's computer; 9 – tooling for spherical probe indentation; 10 – tooling for hole drilling; 11 – guide-ways

The surface of investigated object in the interesting point should be illuminated by the coherent laser source. The laser beam extends and passing through the angular reflector illuminates the investigated surface under the specified angles. The various positions of mirrors allow to measure independently the spatial components (normal to the object surface or tangential ones) of the displacement vector. [2-6]. The procedure to register the material deformation response on the mechanical influence is as follows:

- The initial speckle-pattern interferograms for the normal and tangential components of displacement vector should be registered in the zone to be investigated;
- The hole drilling or spherical probe indentation should be performed;
- The speckle-pattern interferogramms should be registered after the deformation influence on the material.

The intensity difference for the two speckle-fields (registered in the initial and deformed conditions of the object) represents on the computer monitor the system of interference strips. These strips are the isolines of the respective displacements. After the described above procedures the

operator receives the information on the stressed state in the investigated point that allows to conclude on the reasons of elements failure or about the quality of the repair works on the farming machines.

Results and discussion

The series of experiments have been performed in the MERI RAS (Moscow, Russia) in order to evaluate the sensitivity of speckle-interferometer to the material deformation response on the hole drilling or spherical probe indentation in was carry out. The various stressed state of the plane and quasi-plane objects (with various thickness) have been investigated. The methodology of RS measurement by the hole drilling has been developed [7]. The diagnostics method of the materials stressed state is proposed (spherical probe indentation and registration of the deformation response by ESPI-method) [8, 9].

Figure 2 illustrates the typical speckle-pattern interferograms that are obtained after the hole drilling in the material being in the uniaxial tension. The similar types of speckle-pattern interferograms have been obtained for the various stressed states at the spherical probe indentation. This similarity (resemblance) allows to use the given method for the diagnostics of objects stressed state (qualitative comparison method of speckle-pattern interferograms).

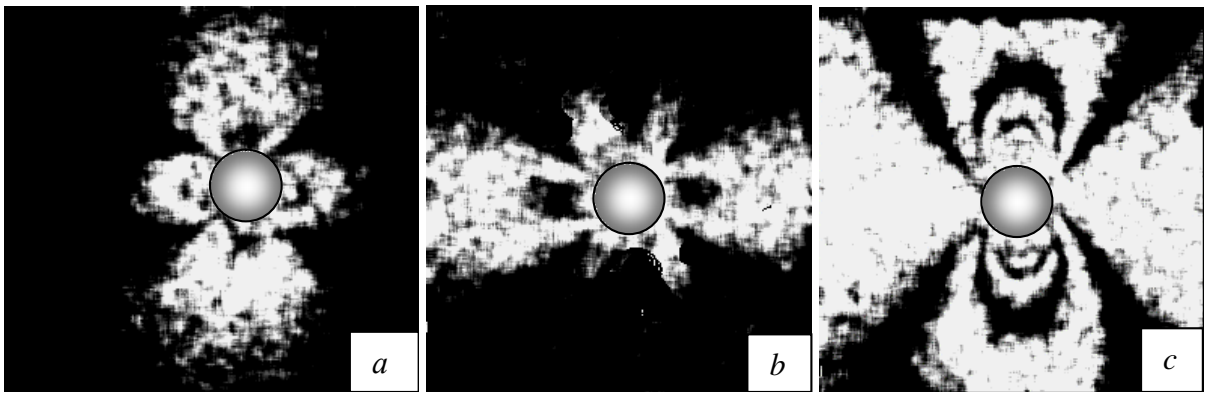
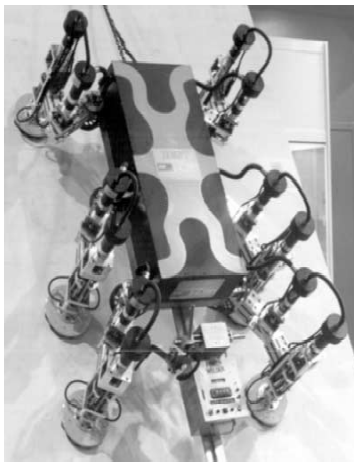
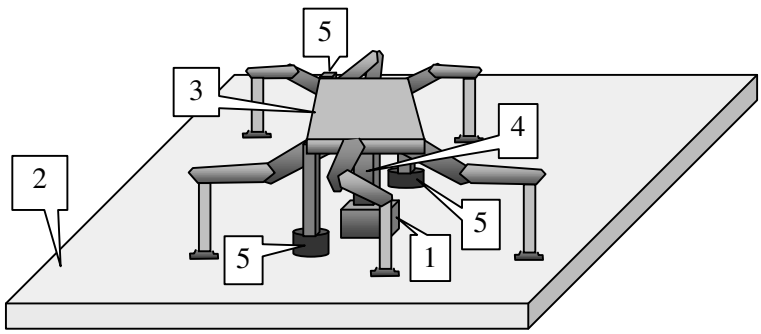


Fig. 2. **The typical speckle-pattern interferograms are obtained at the hole drilling at the uniaxial tension:** a – normal displacements, b and c – tangential displacements

It is reasonable to automate the measurement process in order to increase the efficiency of repair works It is proposed to use the walking robot (REST-1-type) that is designed and fabricated at the Institute of Industrial Automation (Madrid, Spain) for the welding of large-sized details of shipbuilding industry [10]. General view of the robot is shown on Figure 3. The measurement scheme of the material (repaired detail) deformation response on the hole drilling or spherical probe indentation is shown on the same figure.





1 – repaired detail; 2 – load-bearing frame; 3 – walking robot; 4 – ESPI-interferometer; 5 – rigid stoppers.

Fig. 3. **The general view of walking robot REST-1 and the measurement scheme:** leg number – 6; degrees of freedom – 18; leg distribution – frontal plane; leg disposition – reptile; body length – 1100 mm; body width – 600 mm: robot weight – 250 kg

It is necessary to install the load-bearing frame in order to realize the similar measurements in the repair workshop and to fix the detail. The measuring robot is equipped with the ESPI-interferometer that is fixed in its bottom part. According to the operator program the robot should install the interferometer in the investigated point and should be fixed by the stoppers. The large weight of the robot allows to exclude all the possible essential displacements at the hole drilling or spherical probe indentation.

All the operations are carried out in the automatic mode, such as: rigid fixing of interferometer relatively to the detail; recording of the initial and final speckle-pattern interferograms; hole drilling or spherical probe indentation; results transfer to the computer. Computer provides the mathematical processing of measured values and final result. In case of multiple measurements the robot moves on the frame according to the operator's program and carries out all the necessary operations. The concept of the universal robot facilitating the repair works is proposed in this article. This robot provides all the manual measurement manipulations in the automatic mode.

Conclusions

1. Basing upon the performed measurements of the residual stresses by the ESPI-method it is possible to give the conclusion on the quality of the repair works on the farming machine details.
2. The method of hole drilling is proposed for large-sized details while the spherical probe indentation is reasonable for qualitative estimation of stressed state in the repaired details.
3. The universal walking robot concept with the mobile platform for the stressed state investigation is developed.

References

1. Experimental mechanics/Edited by Kobajasi A., V.2. M: the World, 1990. 551 p.
2. Shchepinov V.P., Pisarev V.S., Novikov S.A., Balalov V.V., Odintsev I.N., Bondarenko M.M. Strain and Stress Analysis by Holographic and Speckle Interferometry.– Chichester.: John Wiley, 1996, 496 p.
3. Schajer G.S. Advances in Hole-Drilling Residual Stress Measurements. Experimental Mechanics, 2010, 50, pp. 159–168.
4. Apalkov A.A., Odintsev I.N. Razumovskiy I.A. The measurement method of residual stresses in the massive structural elements with the help of digital speckle pattern interferometry. Plant Laboratory, vol.69, №2, 2003, ISSN1028-6861, pp.45-49.
5. Apalkov A.A. The applying of digital speckle pattern interferometry for the measurement of residual stresses at the indenter forcing. Proceedings of 14th International scientific technical conference "Machine-building and technical sphere of XXI-th century", Sevastopol, 2007, vol. 1., Donetsk 2007, ISBN 966-7907-22-8, pp. 40-43.
6. Dolinko A.E., Kaufmann G.H. Measurement of the local displacement field generated by a microindentation using digital speckle pattern interferometry and its application to investigate coating adhesión. Optics and Lasers in Engineering, 2009, 47, pp. 527-531.
7. Apalkov A.A. The investigation of residual stresses in the NPP design elements by the hole drilling method and digital speckle-pattern interferometry. The dissertation abstract. MIPHI, Moscow, 2005, 24 p.
8. Mahutov N.A., Razumovskiy I.A., Odintsev I.N., Apalkov A.A. Methods and apparatus for the evaluation of residual stresses in the full-scale structural elements. Book of abstracts for 3-rd International scientific conference "Issues of actuators and machines dynamics and strength", Astrakhan 2007, ISBN 978-5-89154-230-3, pp. 153-154.
9. Apalkov A.A., Akinfiev T., Armada M.A. Concept of intellectual robot for the studies of stresses in tubes. Artificial Intelligence №3, Ukraine, 2009, ISSN 1561-5359, pp.285-292.
10. Grieco, J.-C., Prieto, M., Armada, M. Gonzalez de Santos P. A six-legged climbing robot for high payloads. Proceedings of "IEEE Internat. Conf. on Control Applications", vol. 1, 1998, pp. 446-450.