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New measurement possibilities of deformation anomalies and complete stress field distributions by portable digital-holographic gauge camera

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Abstract

Holographic interferometric deformation measurements have more than half century behind them. However, up to last decade they have been restricted mostly to laboratory measurements. The turning-point was the advent of three technical novelties: small solid state lasers, high resolution digital image sensors and fast enough computers. This started the long awaited transfer process from the closed laboratory rooms toward the real industrial environment. The Laser-FALCONEYE (L-FE) digital-holographic gauge camera is one of the forerunners in this transfer process which is still far from end. The dozen examples of applications to be outlined here intend to support this process further more. The examples can be divided in two main areas: deformation distribution measurements and stress distribution measurements based on stress-relief deformation measurement at diagnostic blind-hole drilling. The measured materials are mainly metals - but plastics, glasses, ceramics and rocks, too, have been measured with success.

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Keywords: NDT; Digital holgraphy; Interferometry; Deformation measurement; Stress measurement; Blind hole drilling; FEA

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1. Introduction

Holography itself and its interferometric measuring descendant, as well, have already more than half century behind them. However, their digital versions are not much older than a decade, at least not in real practical applicability. The turning-point was the advent of three technical novelties: small solid state lasers, high resolution digital image sensors and fast enough computers. This started the long awaited transfer process from the closed laboratory rooms toward the real industrial environment. The Laser-FALCONEYE (L-FE) digital-holographic gauge camera is one of the forerunners in this transfer process which is still far from end. The dozen successful examples of typical applications to be outlined here intend to support this process further. The examples cover two areas: deformation distribution measurements and stress distribution measurements based on stress-relief deformation measurement at diagnostic blind-hole drilling. The measured materials are mainly metals - but plastics, glasses, ceramics and rocks, too, have been measured with success.

The Laser-FALCONEYE (L-FE) gauge camera is a portable measuring device which can operate on a wide range of industrial fields. It works on digital holographic principle and it is equipped with extension capabilities up to half-magnitude at resolution and field of view - by a special "scanning&magnification" method (Gyimesi et al, 2009). The application examples to be presented here are from the last five years of measurements (Füzessy et al, 2012; Dobránszky et al, 2015; Gyímesi et al, 2016; and see also "Websites", 2016)

2. General application possibilities

As for structural integrity purposes, holographic interferometry can measure surface deformation accompanying structural integrity changes in complete 3D vector form. It "sees" the deformations quite directly: in the form of contour lines (interferometric fringes) overlapping the measured surface. It is a non-contact and full-field method. It works with high sensitivity of about 0.1 μm, and in measuring range of upper limit about 10 μm. The limits of the field of view are basically around 50-100 mm in diameter and the spatial resolution is about 0.05 mm. All these limits are only basic values and can be overcome significantly with some extra efforts, if needed. The L-FE holographic gauge camera has these basic parameters in its present basic form – but it is similarly capable for further development.

Holographic deformation measurement can be useful in structural integrity evaluation even along two different lines. First, the actual deformation measurement of structures (or structure elements) can find the most deformed and therefore most critical parts – and surface stress level distribution can be calculated from it, as well, On the other hand, preferred or required homogeneity of deformation can be controlled (and then adjusted properly if needed) at load transfer measurements – or, for example, to get more precise mechanical material property data in their measurements. The more precise data may serve best, perhaps, increasing the accuracy of the lengthy simulation calculations. Even beyond this, the simulation results themselves can be made more reliable by validating them with real world deformation measurements.

The other application line for structural integrity is, where intentionally applied measurement loading, so called diagnostic load is used to reveal some structural weakness information. Inner pressure increase in pressure vessels can cause minor bulging at local wall weaknesses, for example at corrosion faults – which can be detected from the outside. Similarly, welds on pressure vessels can be monitored the same way. Their possible deformation anomalies compared to their surroundings could be the most direct control possibility of their actual mechanical achievement: the real way of joining two parts under loading.

A special diagnostic load can be the well-known blind hole drilling, as well, used for stress measurements regularly with strain gauges. Here the holographic deformation measurement can make the stress-relief deformation measurable in its direct visual completeness. It does this much easily and faster and last but not least much reliably than the strain gauge method. It provides even the real practical possibility of detailed scanning of complete stress field distributions. Besides it works in much smaller corners and on rough surfaces, as well. These stress data (residual or combined) can be useful not only for direct structural integrity evaluations, but once again, in the case of simulations, too - providing validation possibility, in this case on stress level

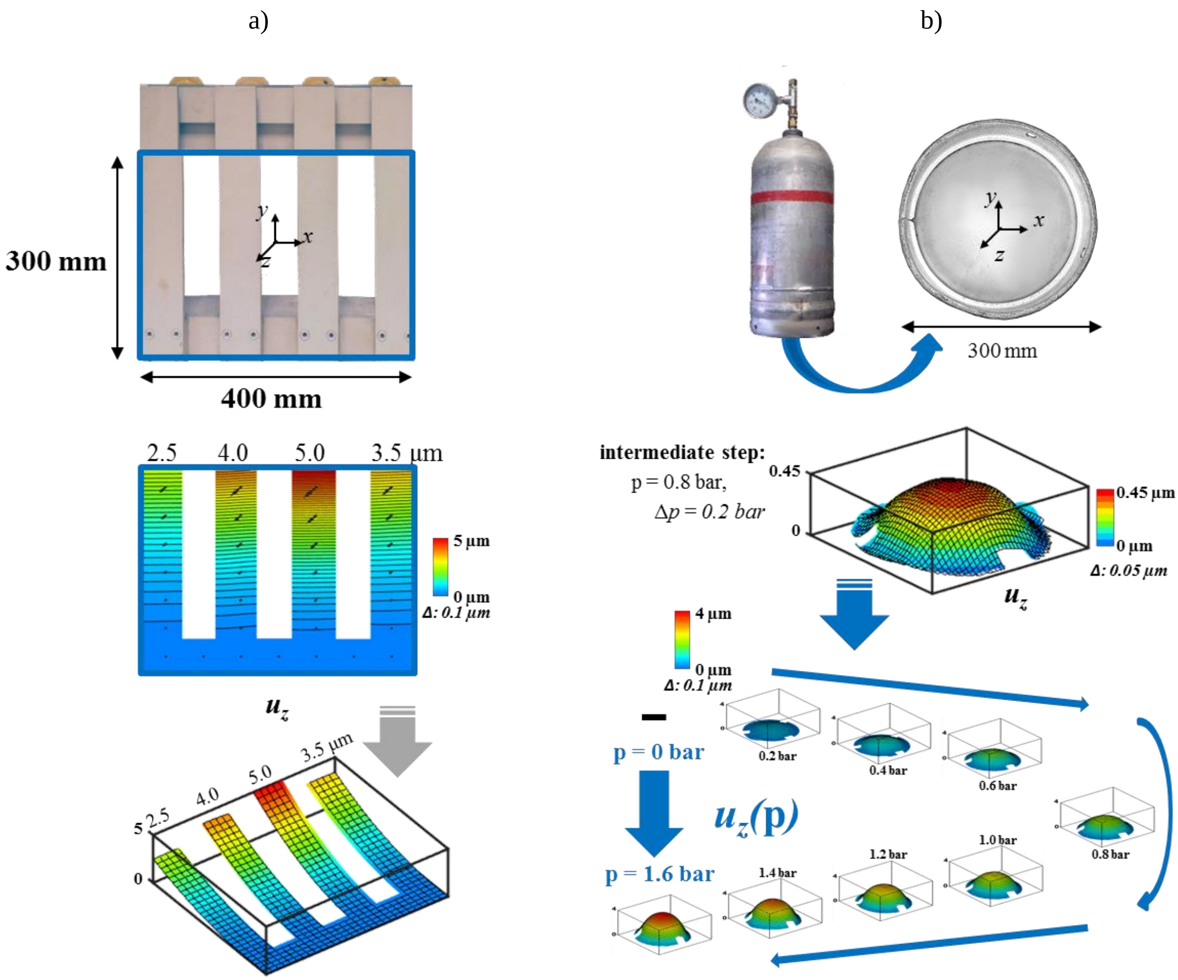

Fig. 1. (a) *Large field of view*: deformation of cantilever beams at micrometer screw controlled loading at the top; (b) *Large field of view*: The complete deformation process of bulging of a pressure vessel bottom

3. Specific application examples

3.1. Deformation distribution measurements

Fig. 1. shows the deformation of objects with a large field of view - which size is not common in digital holographic measurements. In Fig. 1. (a), the deformation of a model object is displayed: a set of cantilever beams where the beams are loaded with precision micrometer screws at their tops. This way their bending measured by L-FE holo-camera at their top, too, could be validated mechanically with the micrometer screw values there. Fig. 1. (b), shows the deformation of pressure vessel bottom as a function of the applied inner pressure. The bulging phases of the bottom are monitored with the perpendicular u_z component distribution. The u_x and u_y in-plane components are not shown for the sake of brevity, as before.

Fig. 2. (a) shows the deformation occurring during a manufacturing process where an aluminum sleeve and a steel pin are pressed into each other. The process is measured in 50 steps to remain within the basic measuring range of digital holographic interferometry at each step – and the required extension of the upper limit is reached by extreme accurate evaluation of the interferometric fringe systems. This way they could be added without much increase of the basic error. Here the u_{xy} combined in-plane component is displayed.

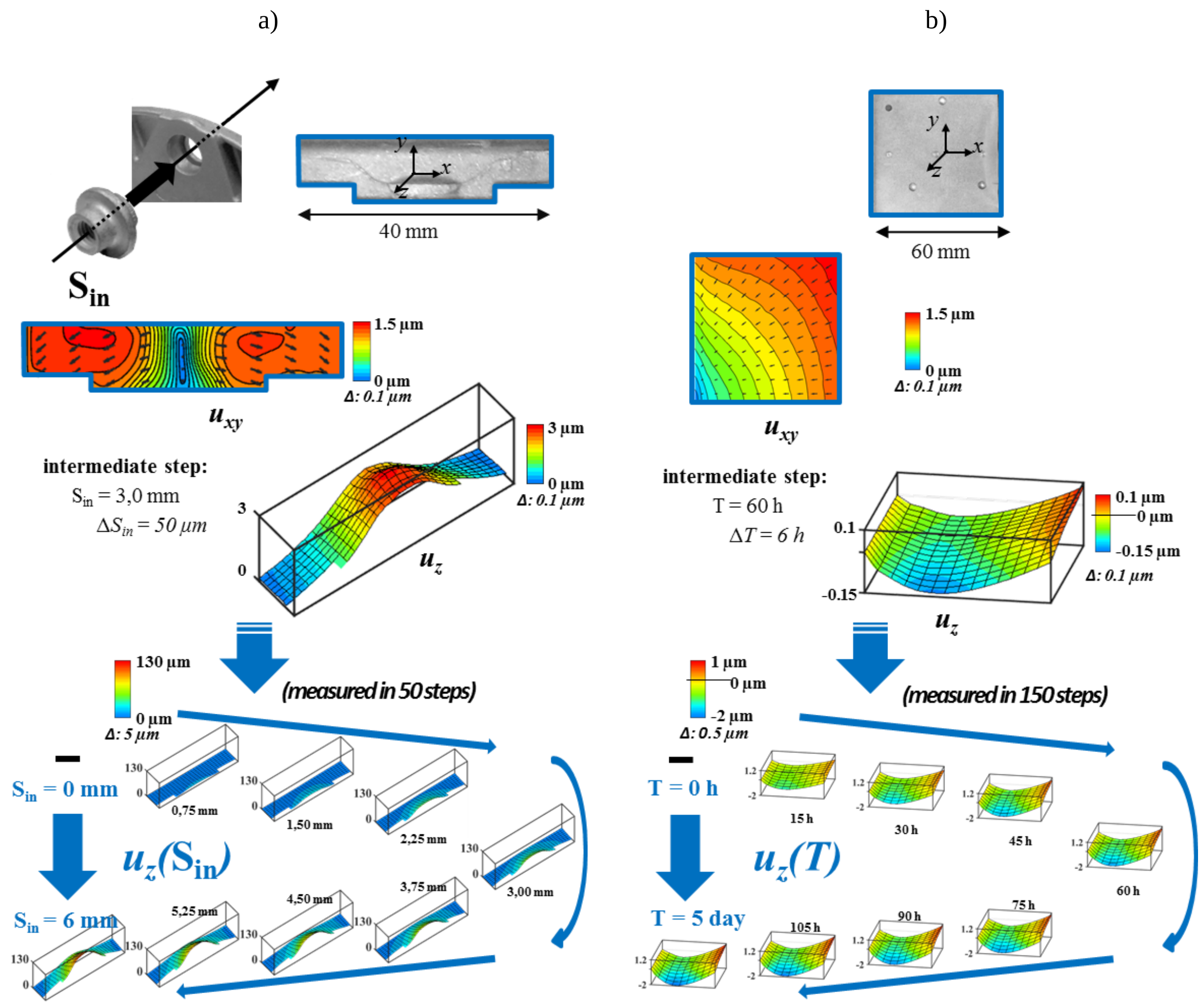

Fig. 2. (a) The complete deformation process of pressing of aluminum sleeve and a steel pin into each other: *up to extended measuring range*; (b) The complete deformation process of self-shrinkage of injection molded plastic plate: *long term monitoring)*

Fig. 2. (b) shows the deformation occurring during the self-shrinkage of an injection molded plastic plate after production. Here the final deformation of the plate is well within the basic measurement range – the special difficulty was to provide long term stability for the 5 day long measurement.

Fig. 3. shows the deformation of objects directly for inspection of their structural integrity status. In Fig. 3. (a) the extra-large pressure deformation (bulging) and its tiny local deformation extrema (depressions) are shown at increasing pressure in the case of a corroded pressure vessel bottom. Simulated and real corrosion blind holes are on the inside of the bottom which can be localized this way from the outside, too. In Fig. 3. (b), the deformations of different quality welds are compared at a given inner pressure in a pipe. All the three components of deformation are displayed on the weld surface and in their surroundings. The lower weld deforms quite differently as its surroundings because it stretches less in both on-surface directions: it notches like a short belt. The upper weld, however, deforms quite similarly as it surroundings – it cannot be recognized on the deformation map. This is undoubtedly a more adequate joining type and deformation transfer monitoring could be a new quality control mean for welds.

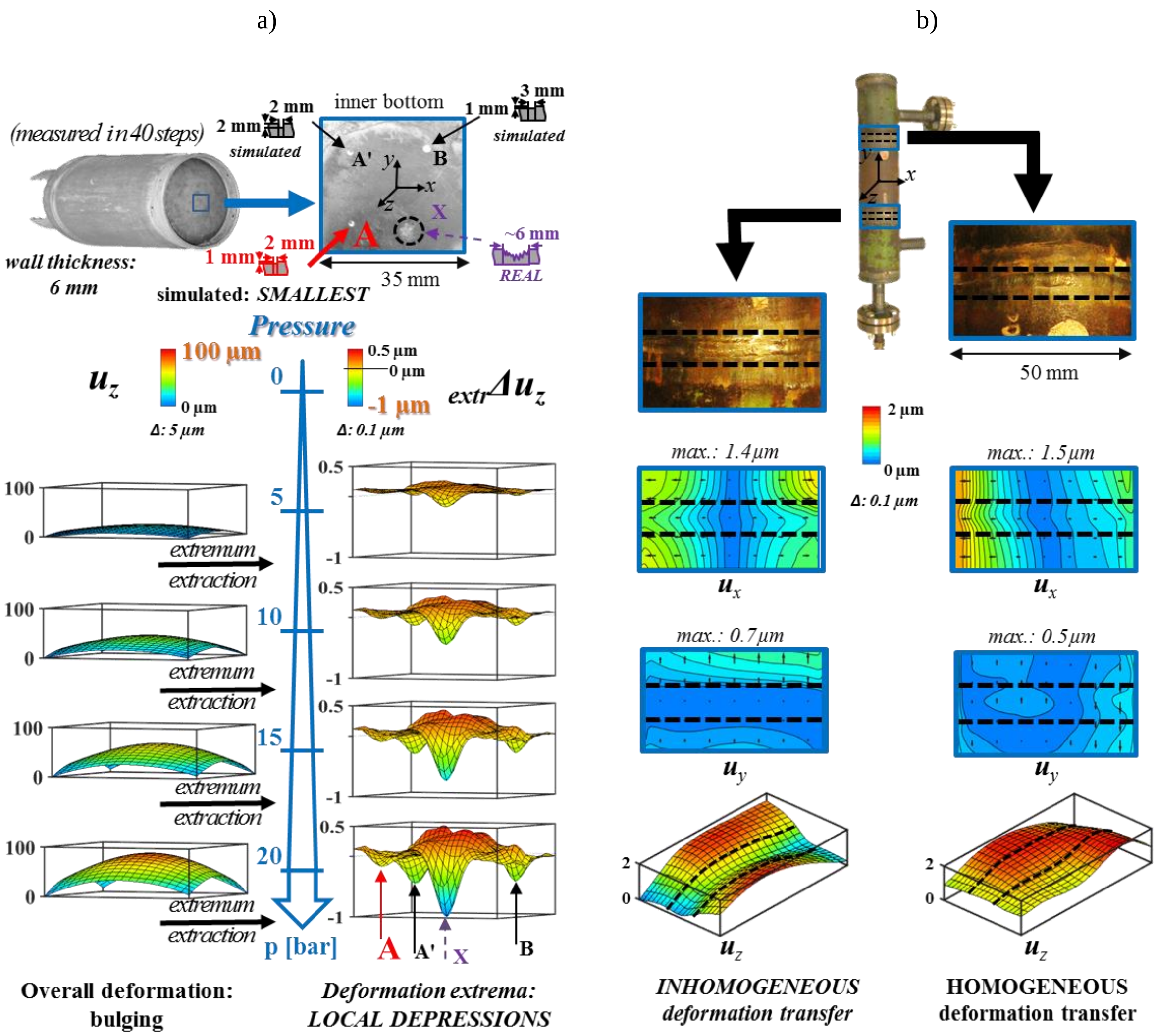

Fig. 3. (a) Monitoring of extra-large pressure deformation and extraction of tiny deformation extrema on it: at corroded pressure vessel bottom; (b) 3D deformation of different welds for comparison with surroundings: to control their deformation transfer property

3.2. Stress distribution measurements

Fig. 4. shows the residual stress distribution displayed with principal directions and magnitudes - as elliptical deformation of a stress-relieved gauge circle around the diagnostically drilled blind hole. Fig. 4. (a) shows the residual stress distribution in the single wires of a twisted multicore aluminum cable. The diameter of the wires is small thus the diagnostic blind-hole-drilling has to be extreme small: almost invisible. It can be used to predict self-bending tendency when cut in two. Fig. 4. (b) shows the residual stress in a pressure vessel after long term use. It is measured with "controlled and minimized incremental blind-hole-drilling" method. This starts with the smallest hole diameter and depth available for measurement and then the hole is increased gradually in both dimension under synchronous strict surveillance of the deformation answer. At the first evaluable deformation answer the hole drilling is terminated. This way the possibility of causing harm by the diagnostic hole drilling can be minimized. In our example the negligible 30-45 MPa stress required a 5 mm diameter hole but a dangerous 300 MPa residual stress could have been detected by a 0.5 mm diameter hole already.

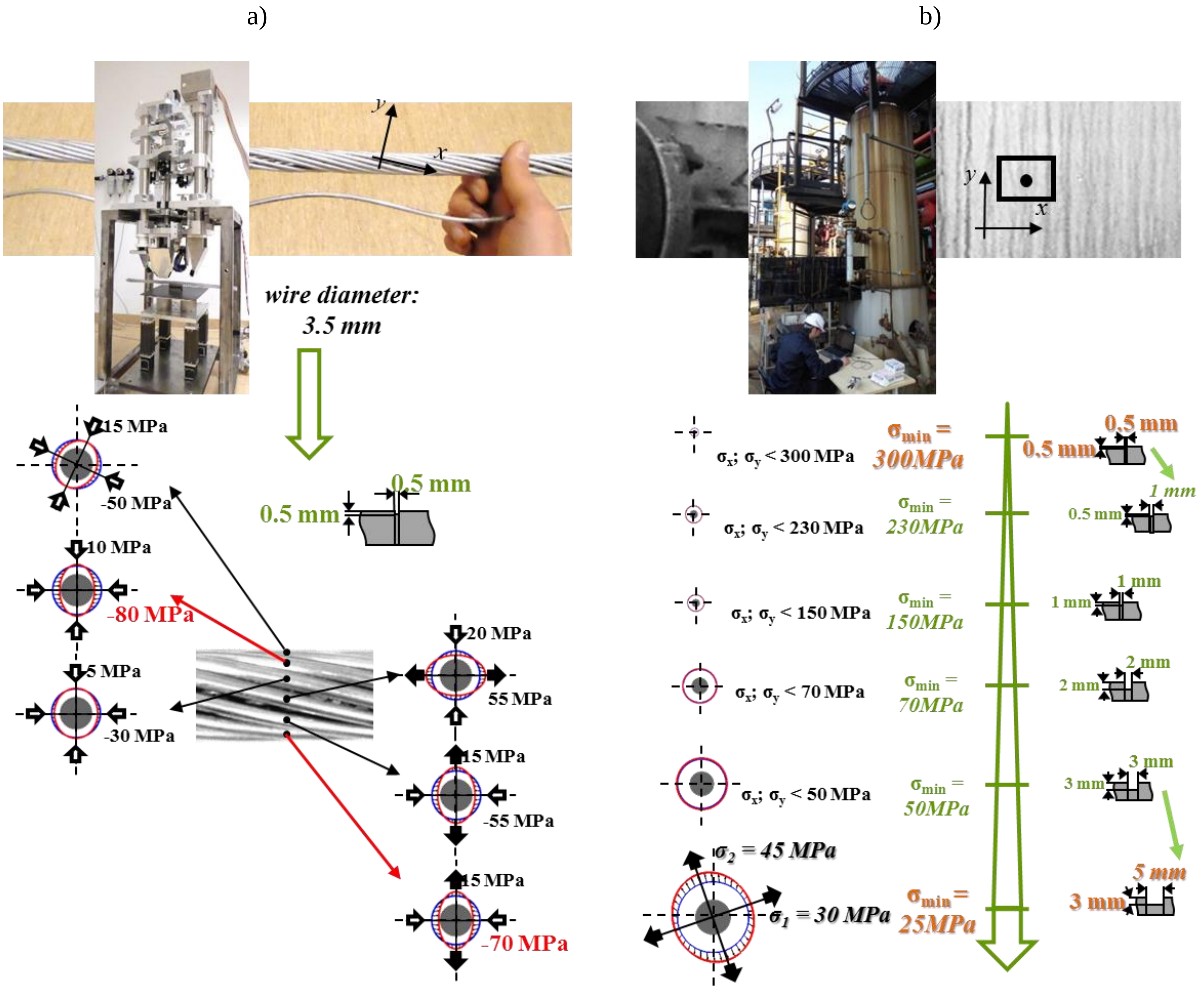

Fig. 4. (a) Residual stress in wires of twisted multicore aluminum cable: measured with extremely small blind-hole-drilling; (b) Residual stress in pressure vessel (after long term use): measured with controlled and minimized incremental blind-hole-drilling

Fig. 5. shows the residual stress distribution occurring in or around welds. Fig. 5. (a) shows the residual stress distribution in the case of a welded stainless steel plate The stress is measured on both the front and back surfaces: along the weld and along a perpendicular line. The principal surface stresses happened to be quite aligned with the weld direction and the direction perpendicular to it, on both surfaces, too –therefore they could be displayed in a single joint graph. Fig. 5. (b) shows the residual stress distribution in the case of a welded hollow section along a contour-line on the surface and through full depth, too. In the latter case, the blind-hole drilling was performed incrementally: with a step-by-step deepening of the same hole. This had a detectable deformation answer down to about 5 mm depth in steel. Thus the displayed depth distribution was measured by drilling from both sides, up to half depth from above and from below.

3.3. Two-way connections to finite element analysis simulations

Fig. 6. illustrates the possibility of fruitful cooperation between deformation and stress measurements and FEA simulation. As seen in Fig. 6. (a), the measured deformation of the model object, a compressed block with a centered hole in it, coincides well with the FEA simulated version. It does it in the derived strain and stress distributions, too. This way it could be used for real validation of FEA results.

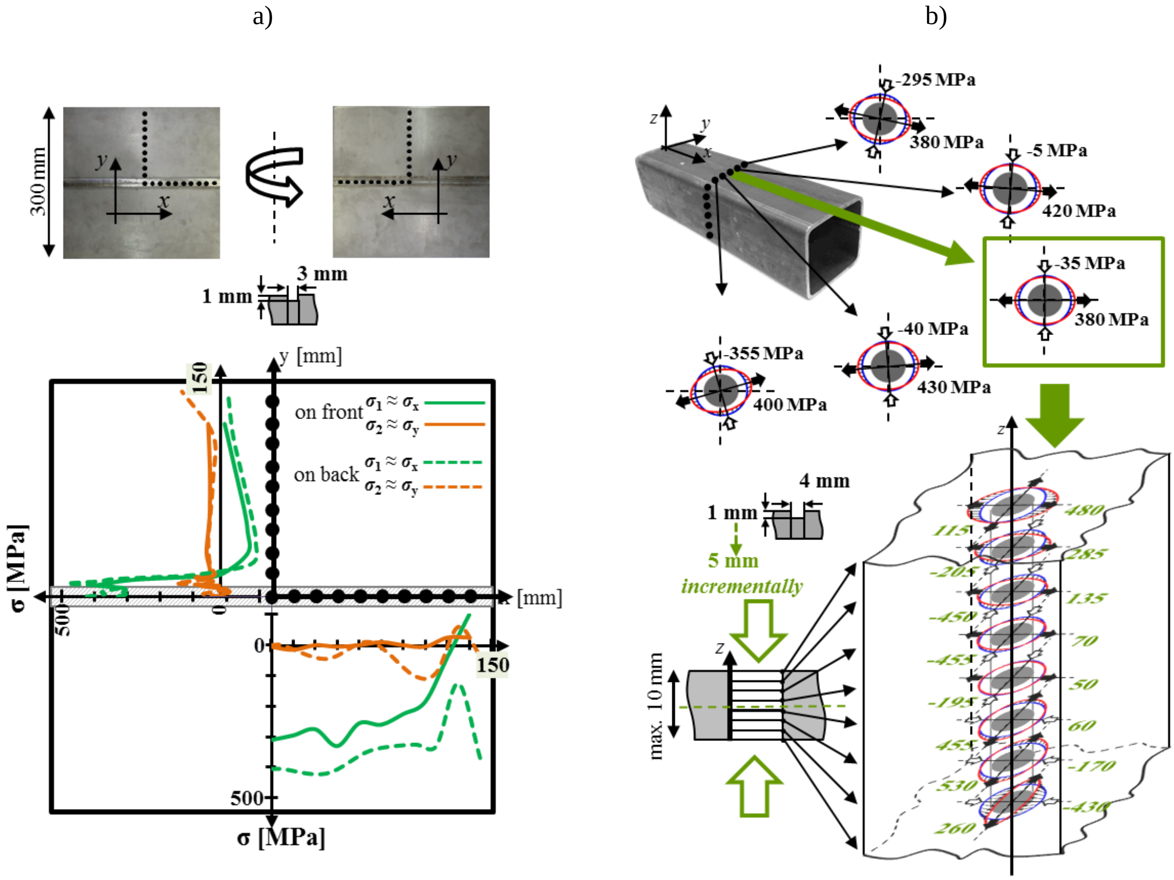

Fig. 5. (a) Residual stress distribution along the weld and along a perpendicular line;
(b) Residual stress distribution in welded hollow section along a contour-line and through full depth.

As seen in Fig. 6. (a), FEA simulation can predict the deformation of the gauge circle around the blind hole at stress-relief measurements – and provide a simulated scale (or at least anticipatory pre-scale) for the evaluation of stress form gauge circle deformations. This way, it can replace, for instance, the tedious recording of an empirical scale by measurements on a tensile machine (left column in the comparison). In some more complex cases this may remain even the only possibility.

4. Perspectives

For digital-holographic interferometric deformation and stress measurements, the transition from laboratory to the real world of industry has started and it is on its way in our days. It provides extreme high sensitivity together with synchronous full-field feature. It is non-contact in deformation measurement (and deformational stress measurement) - and semi-nondestructive in residual stress measurement with blind-hole-drilling. In the latter case, its extreme high sensitivity makes the application of the smallest holes possible – among all.

Nevertheless, its transition is not without difficulties to be solved and not without rivals either. However, its extreme basic sensitivity (it starts with where the other methods usually end up) and its extreme overall quality in full-field nature will certainly guarantee real successful applications in the high-tech industry of our days.

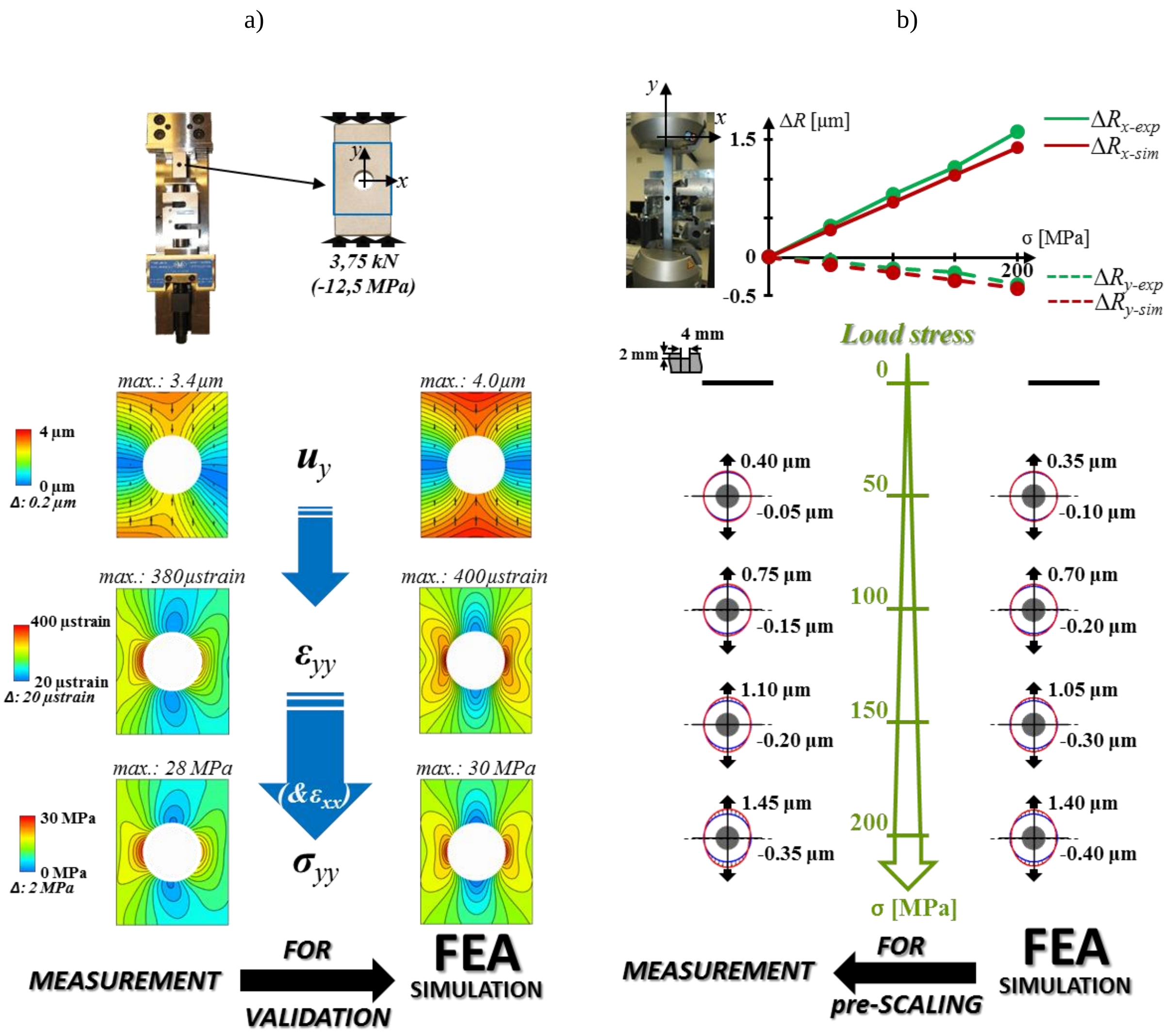

Fig. 6. (a) Deformation measurement for validation of simulation;
(b) Hole-drilling stress-relief deformation in simulation for pre-scaling of stress measurement.

References

Gyimesi, F., Fuzessy, Z., Borbely, V., Raczkevi, B., Molnar, G., Czitrovszky, A., Nagy, A. T., Molnarka, G., Lotfi, A., Nagy, A., Harmati, I., Szigethy, D., 2009. Half-magnitude extensions of resolution and field of view in digital holography by scanning and magnification. Applied Optics 48(31), 6026-6034.

Füzessy, Z., Gyímesi F., Borbély, V., 2012. Upgrading Holographic Interferometry for Industrial Application by Digital Holography, in: “Optical Imaging and Metrology: Advanced Technologies”, In: Osten, W., Reingand, N. (Eds.). Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, pp. 413-437.

Dobránszky, J., Lőrinc, Zs., Gyímesi, F., Szigethy, A., Bitay, E., 2015. Laser welding of lean duplex stainless steels and their dissimilar joints, 8th European Stainless Steel and Duplex Stainless Steel Conference, Graz, Austria, pp. 138-147.

Gyímesi, F., Szigethy, A., Borbély V., Kiss, R. T., 2016. Structural integrity measurement possibilities by L-FE digital-holographic gauge camera, International Conference on Combined Digital Optical & Imaging Methods applied to Mechanical Engineering, Monte Verita, Ascona, Switzerland, to be published.

"Websites", 2016: www.technoorg.hu, www.dr-gyimesi.hu