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Q-STRESS v.1.0 – a Tool for Determination of Stress Fields using Digital Image Correlation Systems

Martin Hagara^{a,*}, Róbert Huňady^a^a*Technical University of Košice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice, Slovakia*

Abstract

The contribution deals with a description of noncommercial program, created for digital image correlation systems Dantec Dynamics. Described version of this product called Q-STRESS v.1.0 processes data exported from the software delivered together with correlation systems and allows fast and simply visualize displacement or strain fields and calculate the further to the stress fields. Moreover in chosen points the program allows depict the courses of displacements, strains as well as stresses during the loading process. In this contribution the description of the program is supplemented by its practical application in investigation of stress fields in the surroundings of small hole. Version 1.0 is created only for the analyses in elastic domain.

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1. Introduction

Digital image correlation is a modern non-contact method serving for analysis of displacements or strains. The heart of the digital image correlation system is a digital CCD camera, which captures the random black and white pattern created on the investigated object during its loading and the acquired images compares together with the reference one. By using of single camera system only 2D measurements can be realized, but by stereoscopic arrangement of multi cameras system also 3D measurement can be done. An undisputed advantage of this method is a fact that the correlation system does not perform measurement in a single point like in case of conventional gauges, but it provides information about the whole scanned surface.

* Corresponding author. Tel.: +421-55-602-2469.

E-mail address: martin.hagara@tuke.sk

According to maximal sampling frequency correlation systems are divided into low-speed and high-speed ones. As the low-speed systems are characterized by higher spatial resolution, they are used for deformation analysis. On the other hand the high-speed systems contain CCD cameras with lower resolution however their sampling frequency achieves several thousands, 10-thousands or even 100-thousands frames per second. For that reason they can be used for various dynamic analyses encompassing motion analysis, vibration analysis [1-5], drop tests [6] or crash tests [7].

The stress fields analysis performed by digital image correlation systems using virtual fields' method were described in 2008 by Dr. Avril and Prof. Pierron. Pursuant to their created software, called CamFit, several experiments were realized, described e.g. in the following publications [8-10]. This software allows identify the mechanical properties of materials due to the results reached from full-field deformation measurements [11]. It is needed to obtain the input data from software VIC 3D.

Nomenclature

σ_x	normal stress in x-direction computed in Q-STRESS
σ_y	normal stress in y-direction computed in Q-STRESS
τ_{xy}	shear stress in xy-plane computed in Q-STRESS
σ_1	principal stress 1 computed in Q-STRESS
σ_2	principal stress 2 computed in Q-STRESS
σ_{SV}	Saint-Venant's equivalent stress computed in Q-STRESS
σ_{HMH}	Huber-Mises-Hencky's equivalent stress computed in Q-STRESS
ϵ_x	normal strain in x-direction obtained from Istra4D
ϵ_y	normal strain in y-direction obtained from Istra4D
γ_{xy}	shear strain in xy-plane obtained from Istra4D
ϵ_1	principal strain 1 obtained from Istra4D
ϵ_2	principal strain 2 obtained from Istra4D

2. Q-STRESS – basic principle and application

Devices Q-400 and Q-450 Dantec Dynamics are correlation systems with high quality and wide range of applications, however they allow determine only the displacement and strain fields. Our goal was to create the software with user-friendly interface allowing read and process the measured data in such a way that it would be possible to visualize not just the displacement or strain fields, but also the stress fields.

Exported data from the software Istra4D, delivered with correlation systems Dantec Dynamics, are in a form of HDF5 files with a structure depicted in Fig. 1.

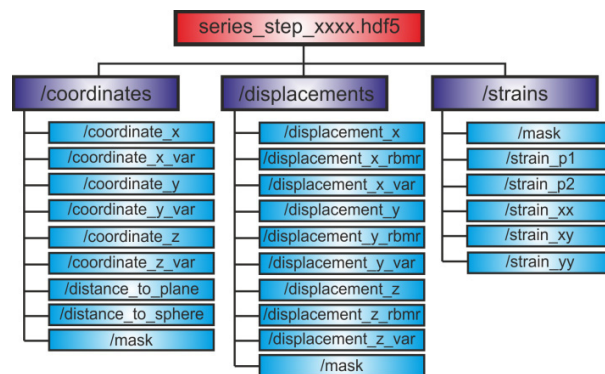


Fig. 1. Structure of HDF5 file exported from Istra4D.

HDF5 files contain three main groups (coordinates, displacements and strains), whereby each of them consists of several datasets with the amounts of the quantities measured in so-called mask points. The mask points with the value of 1 represent the correlated locations. If the value is 0, it concerns either unfilled places or the parts of investigated objects, which from some reason could not be correlated. The total size of mask is then expressed as a product of maximal quantum of mesh rows and columns.

The HDF5 files can be simply processed in the program Matlab. This is the main reason, why also Q-STRESS v.1.0 was created in this program.

2.1. Q-STRESS interface

The interface of software Q-STRESS v.1.0 comprises of three parts:

- processing part (Fig. 2a),
- computing part (Fig. 2b),
- visualization part (Fig. 2c).

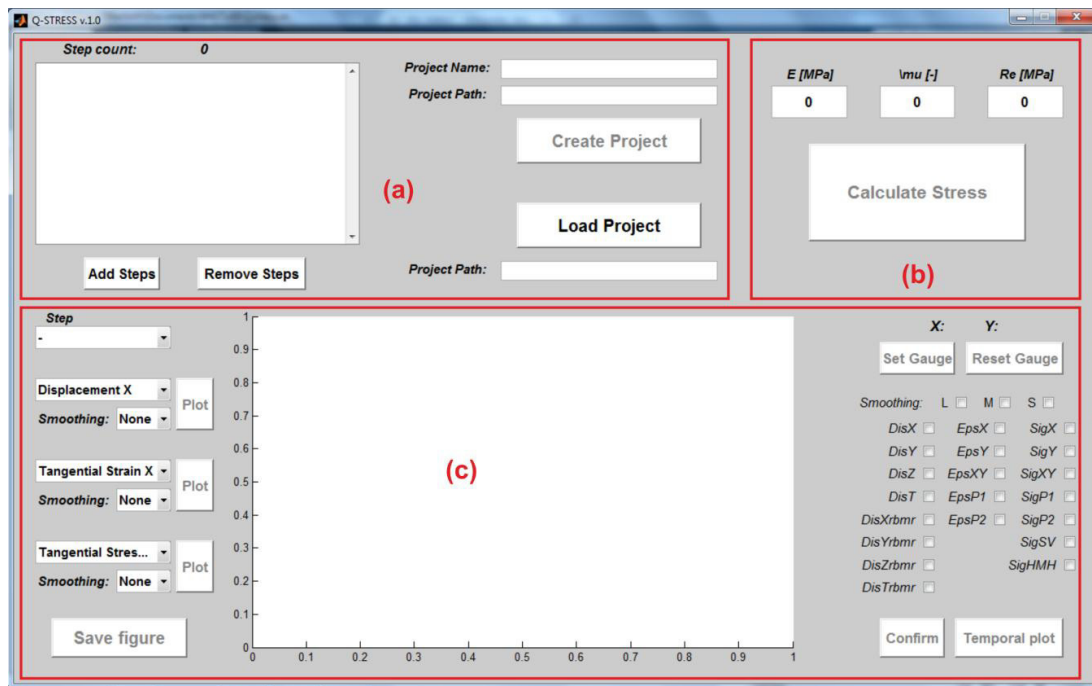


Fig. 2. Q-STRESS interface: (a) pre-processing part; (b) computing part; (c) visualization part.

In the processing phase the user has to read HDF5 files (clicking on the pushbutton “Add Steps”) exported from Istra4D for the purpose of creation of matrices needed for calculation of the stresses. If it is needed to remove one or more steps from the analysis, it can be done by clicking on the pushbutton “Remove Steps”. After reading of the files the program automatically shows the number of steps entering into the calculation (“Step Count”). When the denomination of the project is entered into the field denoted as “Project Name” the program generates the path, where the project will be saved and shows it in the field with a name “Project Path”. The pushbutton “Create Project” is activated only in case if:

- the number depicted in the field “Step Count” is minimally equal to 2,
- the user correctly entered the name of the project.

Consequently the project has to be read. For this scope the pushbutton “*Load Project*” is used. This button was created with such a purpose, that it must not be necessary to create a new project on each occasion. In this way the project can be read immediately after the Q-STRESS initialization.

The computing part of the program contains three editable fields, into which the parameters, needed for calculation of stresses, are entered. It deals about the following parameters:

- Young modulus E [MPa],
- Poisson ratio μ (denoted as μ) [-],
- yield stress R_e [MPa].

While the first two are necessary for the calculation of stresses according formulas (1)-(7) mentioned below, the last serves for identification, whether does not occur the plastic deformation during the loading of the object. After entering of these three values the pushbutton “*Calculate Stress*” is automatically activated. When this button is clicked on the program calculates the values of stresses for each mask point with the value of 1 by using following formulas:

$$\sigma_x = \frac{E}{1-\mu^2} \cdot (\varepsilon_x + \mu \cdot \varepsilon_y) \quad (1)$$

$$\sigma_y = \frac{E}{1-\mu^2} \cdot (\varepsilon_y + \mu \cdot \varepsilon_x) \quad (2)$$

$$\tau_{xy} = \frac{E}{2+2\mu} \cdot \gamma_{xy} \quad (3)$$

$$\sigma_1 = \frac{E}{1-\mu^2} \cdot (\varepsilon_1 + \mu \cdot \varepsilon_2) \quad (4)$$

$$\sigma_2 = \frac{E}{1-\mu^2} \cdot (\varepsilon_2 + \mu \cdot \varepsilon_1) \quad (5)$$

$$\sigma_{SV} = \sigma_1 - \mu \cdot \sigma_2 \quad (6)$$

$$\sigma_{HMH} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2} \quad (7)$$

If the program determines that any calculated value of equivalent stress overpasses the amount of “*Yield Stress*”, it displays the announcement “*Calculated stress is higher than entered amount of yield stress*” and shows the step number, by which this event happened. As Q-STRESS v.1.0 is limited for the stress investigation in elastic domain, for the next analysis only the steps with lower consecutive number can be used.

In the visualization phase, which is activated immediately when all the stresses are calculated, the user can choose the number of step, which will be investigated. He can change between the visualization of displacement fields, strain fields or stress fields, whereby he can decide, whether the results without smoothing or with low/medium/strong smoothing will be depicted. Software Istra4D contains ACSP filters working on adaptive spline polynomial algorithm with levels of filtering from 3x3 to 31x31. Smoothing set to 31x31 gives the most smoothed results. The smoothing levels in Q-STRESS v.1.0 are created as a combination of filters “*Lowess*” and “*Loess*” in

such a way to correspond the levels of ACSP filters: 11x11, 21x21 and 31x31. Depicted field can be saved in Matlab format *.fig clicking on the pushbutton “Save Figure”.

Virtual gauge is a tool allowing depiction of temporal change of chosen quantity. It can be activated by pushing the pushbutton “Set Gauge”. Thereafter one point on the visualized field has to be chosen, in which a temporal change of selected quantity will be determined. After selection one of the offered quantities and level of smoothing it is necessary to confirm the choice by clicking on the pushbutton “Confirm”. Consequently the pushbutton “Temporal Plot” serving for depiction of new figure with temporal plot of chosen quantity is activated.

2.2. Q-STRESS application

For the verification of program utility and credibility an analysis was performed on a specimen (Fig. 1) with stress concentrator (hole with diameter of 2.5 mm) loaded by a tension loading.

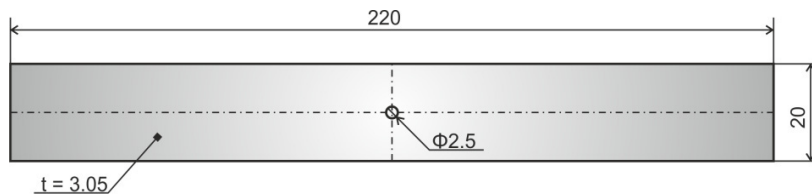


Fig. 3. Dimensions of investigated specimen.

Experiment was realized in laboratory conditions, where the loading was performed with mechanical loading system working on lever mechanism, to which the force transducer HBM RSCC/200kg was attached (Fig. 2a). Due to relatively small forces caused by used loading system the specimen was made from material PS-1 used in PhotoStress method, with the thickness of 3.05 mm and following mechanical properties $E = 2500 \text{ MPa}$, $\mu = 0.38$, $R_{p0.2} = 81 \text{ MPa}$, $\rho = 1280 \text{ kg.m}^{-3}$.

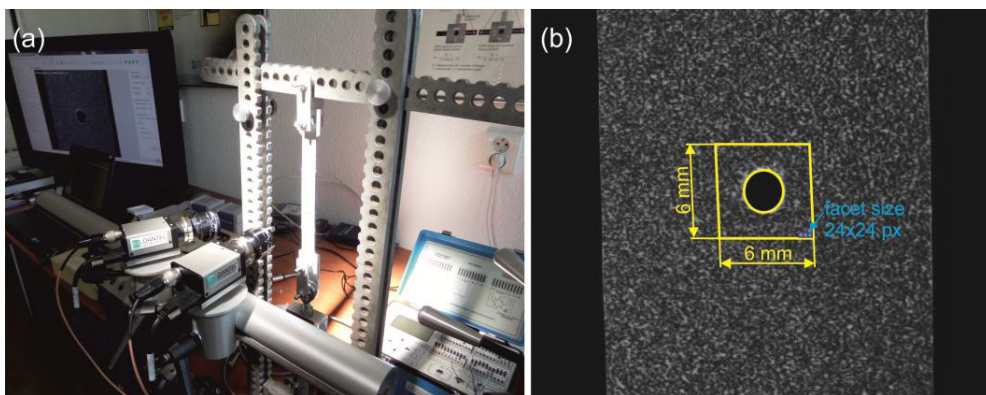


Fig. 4. (a) configuration of the measuring apparatus; (b) size of the evaluated surface with depicted facet size used for evaluation.

For the investigation of small areas it is needed to create a random black and white pattern with very fine structure on the specimen surface. For that reason the pattern was printed on a vinyl foil, which was subsequently attached to the specimen surface. In Fig. 2b it is possible to see the image captured by one of the correlation system cameras, expressing the size of evaluated specimen surface (ca. $6 \times 6 \text{ mm}^2$).

The specimen was loaded in vertical direction by a tension force varying from 0N to maximal value 700N with constant increment of 50N, by which the snapshots were captured. Correlation system thus besides the reference

image (without loading) captured next fourteen loading states of the specimen. All these states were exported into Q-STRESS v.1.0 and processed. Fig. 5 illustrates how the visualized results can look like.

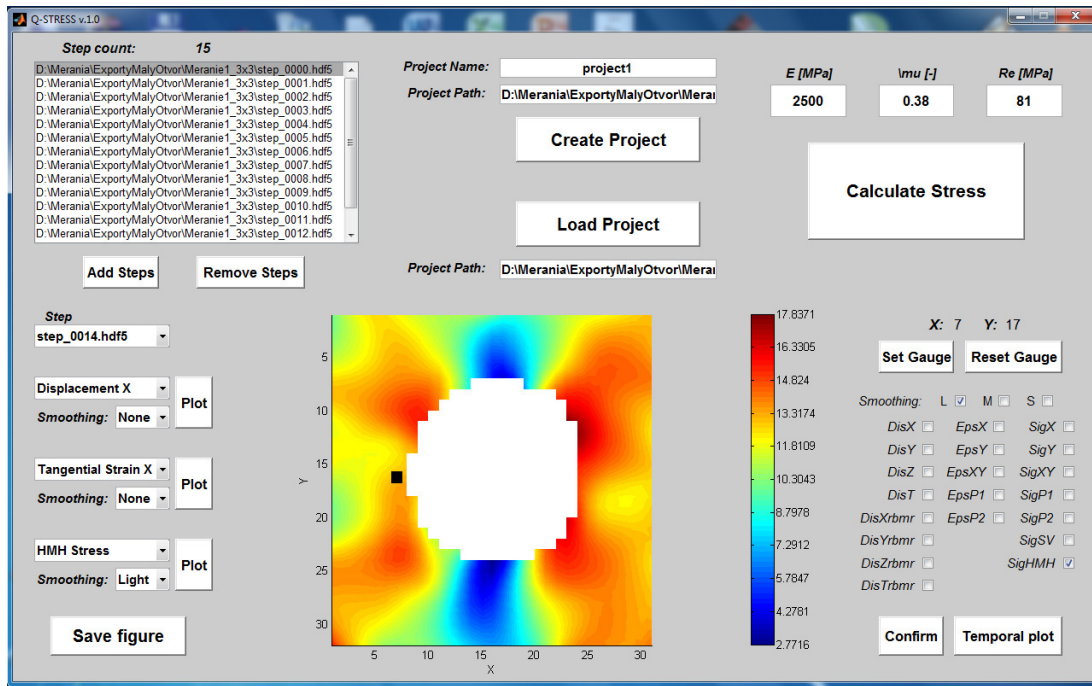


Fig. 5. Visualized results in a form of Huber-Mises-Hencky's stress with a virtual gauge denoted by black dot.

A virtual gauge was chosen in a point with coordinates of X = 7 and Y = 17 to verify the credibility of the obtained results. The temporal plot depicted in this point was compared to the temporal plot obtained by the numerical analysis performed for the same point SolidWorks. The comparison can be seen in Fig. 6. Depicted results reach the correspondence adequate to the comparison of the results obtained experimentally and numerically.

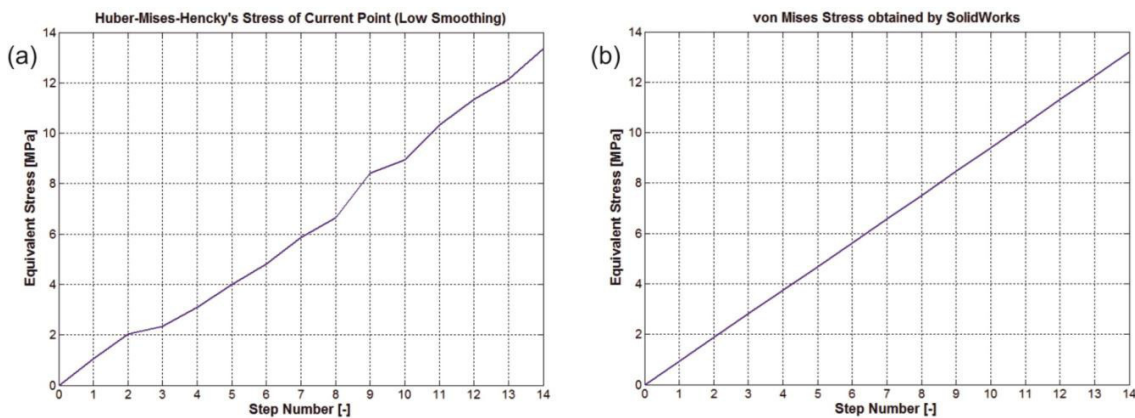


Fig. 6. Comparison of temporal plot of: (a) HMH's Stress obtained by Q-STRESS v.1.0; (b) von Mises Stress obtained by SolidWorks.

Conclusion

Digital image correlation is a technique serving for full-field deformation analysis. Its main advantages are non-contactless and application on all objects, on which the random black and white pattern can be created. Correlation systems Dantec Dynamics allow just determine and visualize the displacement and strain fields. Program Q-STRESS v.1.0 is a tool serving for calculation and visualization of stress fields from the data exported from Istra4D. The results obtained by this program by stress analysis of the locations with stress concentrators allocate an adequate correspondence between results obtained experimentally and numerically. Therefore Q-STRESS becomes a convenient tool for investigation of stress fields in elastic domain by using digital image correlation method.

Acknowledgements

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