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Procedia Structural Integrity 13 (2018) 1605–1608

Structural Integrity Procedia

www.elsevier.com/locate/procedia

ECF22 - Loading and Environmental effects on Structural Integrity

Strain measurement of pressure equipment components using 3D Digital Image Correlation method

Nenad Mitrovic*[a], Aleksandar Petrovic[a], Milos Milosevic[b]

[a]University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia
[b]University of Belgrade, Innovation Center of Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia

Abstract

Pressure equipment has widespread application in various industrial sectors. Due to this variety, pressure equipment can have complex structure and is subjected to different working loads (static, dynamic, thermal etc.) during the operation life that can cause failure. Strain measurement of complex structure has always been a huge challenge for researchers. Conventional experimental methods (e.g. strain gauges) give only limited data sets regarding measurement on critical areas with high geometrical discontinuities. 3D Digital Image Correlation method is an optical method that enables full-field strain measurement of critical areas on structural components. Sphere/cylinder junction is common geometrical discontinuity on pressure equipment and globe valve housing was chosen as representative example. In this paper, globe valve housing was subjected to external axial loading caused by pipeline dilatations. Highest measured von Mises strain values around 0.15 % were recorded on cylinder/sphere intersection. Determining strain state of critical areas enables better understanding of complex structures and provides an opportunity for further development and improvement for practical industrial application.

Peer-review under responsibility of the ECF22 organizers.

Keywords: Pressure equipment; 3D Digital Image Correlation Method; Geometrical discontinuity; Globe valve housing; Axial loading.

1. Introduction

Pressure equipment has widespread application in various industrial sectors. Due to this variety, pressure equipment can have complex structure and is subjected to different working loads (static, dynamic, thermal etc.) during the operation life that can cause failure. Valves are commonly used industrial fittings that come in variety of shapes and have a complex

* Corresponding author. Tel.: +381 11 3302 200; fax: +381 11 3370 364.
E-mail address: nmitrovic@mas.bg.ac.rs

Peer-review under responsibility of the ECF22 organizers.
10.1016/j.prostr.2018.12.338

geometry. Globe valves are typical example of complex geometry that can be approximated as sphere/cylinder junction. Strain measurement of complex structure has always been a huge challenge for researchers. Conventional experimental methods (e.g. strain gauges) give only limited data sets regarding measurement on critical areas with high geometrical discontinuities. Several authors, (Ascough et al., 1996; Attwater et al., 1994; Galić et al., 2011; Schindler and Zeman, 2003), analyzed sphere/cylinder junction in their papers. Junction was analyzed using finite element method, with experimental verification of numerical model. Experiments are usually conducted using strain gauge, LVDT, extensometer etc. Problem with this type of equipment is that it doesn't provide full displacement/strain field, only a result on selected point on the object. As mutual conclusion of all abovementioned papers is that there is not enough experimental results in present day literature, a modern experimental method is needed for better understanding of complex objects under loading (Mitrovic et al., 2014).

3D Digital Image Correlation (DIC) method is an optical method that enables full-field strain measurement of critical areas on structural components. 3D DIC method is applied in analyzing different problems – from simple specimens (Hagara and Huňady, 2014; Milošević et al., 2016)a to more complex structures (Hagara and Pástor, 2017; Mitrovic et al., 2012, 2011). Paper by (Mitrovic et al., 2012) presented that it is possible to analyze local strain field of geometrically complex globe valve housing subjected to internal pressure using 3D DIC method, so the method is used for analyzing local mechanical properties of valve housing subjected to axial loading.

The aim of this paper is to analyze strain field on globe valve housing, i.e., sphere/cylinder intersection subjected to axial loading using 3D DIC method.

2. Materials and Methods

Strain measurement on the globe valve DN32, PN6 was performed for the axial force of 30.1 kN. Axial force value represents the pipeline dilatation for the temperature difference of 90°C. Experimental setup includes stereo cameras, globe valve, tensile testing machine and lighting, as shown in Figure 1. 3D system Aramis 2M (GOM, Germany) based on DIC method was used for strain measurement. Aramis parameters were as follows: camera lenses: 50mm; measuring distance: 80 cm; calibration panel: CP 20/90/D07210; measuring volume: 105 x 80 x 55 mm; facet size: 25 x 20; calibration deviation: 0.038. Zwick/Roell Amsler HB250 tensile testing machine with maximal test load of 250 kN was used in the experiment. Parameters of the tensile testing machine were as follows: maximal experimental loading: 30.1 kN; movement control as a function of force; force increase 0.2 kN/s; total loading time 150s. Custom-made LED lamp was used for lighting. Specimen loading and image recording were performed automatically. Images were recorded immediately before, every 5s during the loading and immediately after loading. First recorded image was used as reference image for data processing. Number of recorded images was 34. Detailed experimental procedure was defined by (Mitrovic et al., 2017).

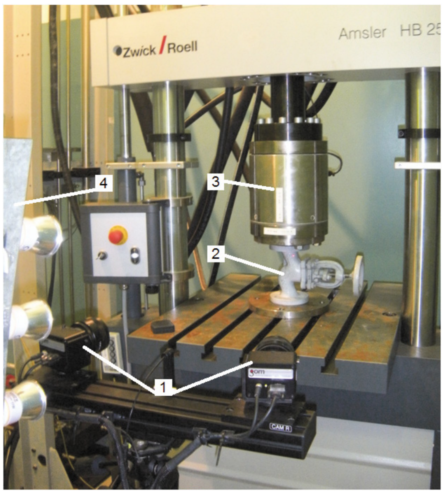

Fig. 1. Experimental setup: 1 – Stereo cameras; 2 – Globe valve; 3 – Travel measurement system; 4 – Lighting.

3. Results and Discussion

Cylinder/sphere intersection on globe valve housing was the area of interest and von Mises strain results are presented in this paper. Strain field was analyzed using three sections (Sections 1, 2 and 3) and one stage point (Stage point 1). Sections 1 and 3 are positioned near the edges and Section 2 is positioned in the middle of the strain field. Section length is similar and around 80 mm. Stage point 1 is positioned on cylinder/sphere intersection.

Von Mises train field is presented in Figure 2 for the maximum force of 30.1 kN. The highest measured strain values between 0.12 and 0.15 % were measured on the cylinder/sphere intersection. Strain values decrease on the intersection when moving from Section 1 towards Section 3 as the geometrical discontinuity is decreasing. Strain values on the cylindrical part of the valve house are significantly lower.

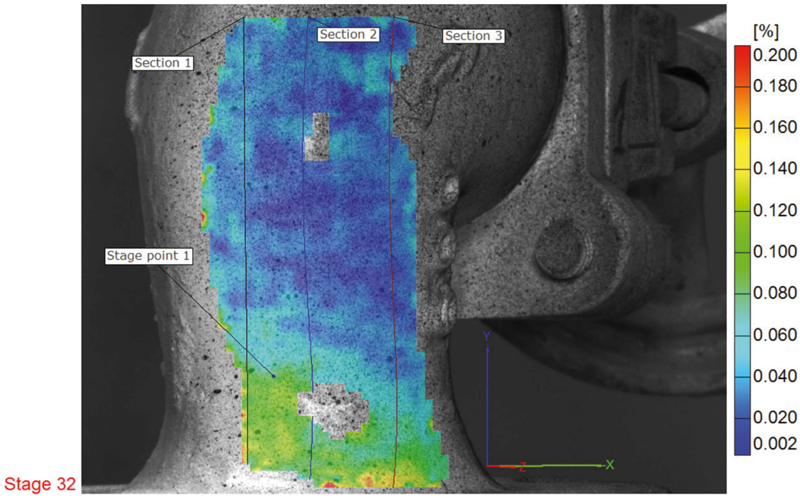

Fig. 2. Von Mises strain field for axial loading of 30.1 kN

Von Mises strain values are also presented as function of Section length in Figure 3. Highest strain values on the intersection were between 0.10 and 0.15 %, while the values on the spherical part are between 0.01 and 0.04 %. Von Mises strain as a function of strain stage, i.e. time, for Stage point 1 is presented in Figure 4, ondicating the change of the von Mises strain from the state before loading (Strain stage 0) over the maximum loaded condition (Strain stage 32) to the unloaded state (Strain stage 33). The 3D DIC method has some limitations (Mitrovic et al., 2017). As the 3D computation of the measuring points is based on pixels that need to be seen from the right and left camera with the individual facet pattern, a correct 3D computation and strain computation is not possible for sample edges. So high strain values (red color) that can be seen on strain field edges represent system errors and are not taken into consideration.

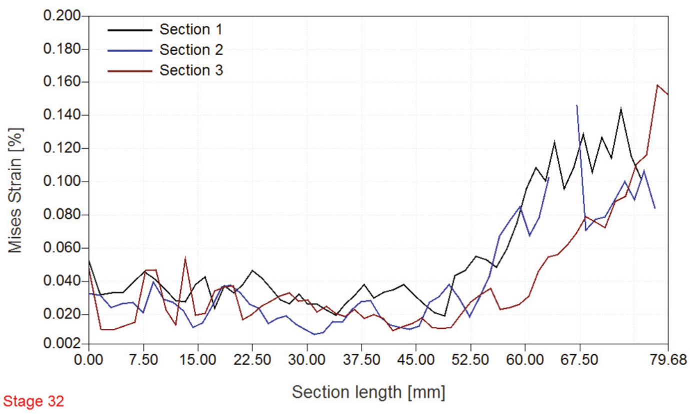

Fig. 3. Von Mises strain as a function of section length for Sections 1, 2 and 3

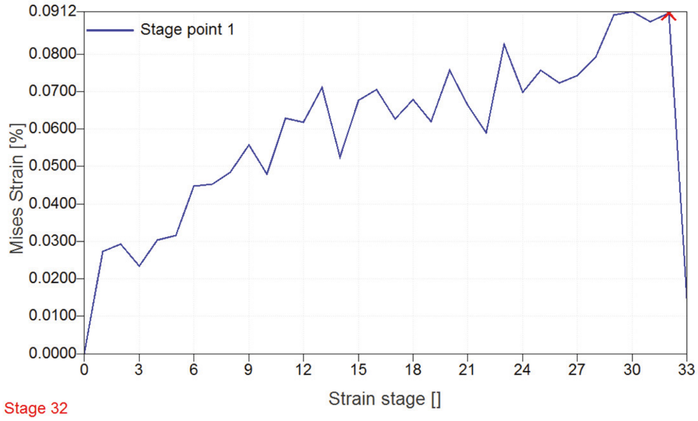

Fig. 4. Von Mises strain as a function of strain stage for Stage point 1

4. Conclusions

In this paper, globe valve housing (sphere/cylinder intersection) was subjected to external axial loading caused by pipeline dilatations. The area of interest was analysed using full-field 3D DIC method. Highest measured von Mises strain values around 0.15 % were recorded on cylinder/sphere intersection. Determining strain state of critical areas enables better understanding of complex structures and provides an opportunity for further development and improvement for practical industrial application.

Acknowledgements

This research was supported by Ministry of Education, Science and Technological Development of Republic of Serbia under Projects TR35031 and TR35040.

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