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Thermomechanical field measurements by hybrid stereocorrelation

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Abstract — Multidimensional thermomechanical fields are measured by a hybrid stereovision system via global stereocorrelation. This procedure will be applied to the analysis of a thermal fatigue test to monitor crack initiation in the newly developed FLASH setup.

Key Words — Hybrid stereocorrelation, shape correction, IR and visible cameras, thermal fatigue test

Introduction

In order to investigate the thermal fatigue occurring in the cooling system of nuclear power plants, an experimental setup, the so-called FLASH (THErmal Fatigue by LASer or Helium pulses) setup is designed to perform high cycle (about several 10^6) thermal fluxes onto the surface of austenitic stainless steel with excellent stability of thermal loading [1]. With the prediction of finite element analyses, it is deduced that the largest strain variations during cyclic loading are in the out-of-plane direction resulting in several micrometer out-of-plane displacements [2]. In the present work, it is shown that 3D displacement fields and 2D Lagrangian temperature fields can be measured thanks to a hybrid stereovision setup via global stereocorrelation. The stereovision system is composed of one infrared camera and one visible light camera.

Experimental setup

The specimen are plates made of a 316L(N) austenitic stainless steel ($270 \times 40 \times 7$ mm^3), which are continuously heated by an electrical current (Joule Effect). The thermal loadings are performed by a pulsed laser (TruPulse 156, λ = 1056nm) on the center of specimen at a frequency of 1Hz with a pulse duration of 50ms. The incident pulsed power is adapted to obtain the desired temperature variation. A focusing optic allows a top-hat power density to be distributed over a 5-mm in diameter disk. An infrared camera (x6540sc FLIR, definition: 640×512 pixels) is used to measure the 2D temperature field, *and* the 3D displacement fields with a high magnification lens allowing for a pixel resolution of 15µm. A visible light camera (MIRO M320S, Vision Research, definition: 1920×1080 pixels) with a pixel resolution of 10µm corresponds to the second device of the stereovision system. The specimen is put inside an airtight chamber filled with helium to eliminate possible excessive oxidation that would alter the surface emissivity, the speckles to enable for DIC analyses, the thermal exchanges between the specimen and the laser beam (absorptivity) or helium atmosphere (convection).

(a) (b)

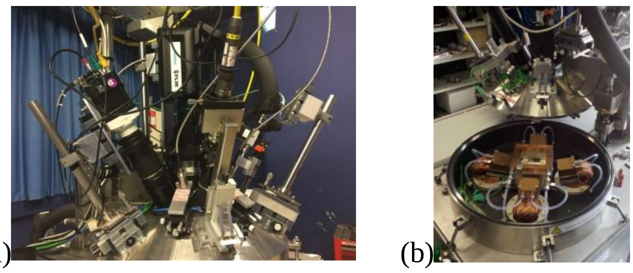

Figure 1 (a) Overview of FLASH setup, (b) inner chamber

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Hybrid stereocorrelation

The projection matrices are determined with an open-book calibration target [3]. The surface metrology, which is described with a NURBS model, is obtained by moving its control points to match the actual surface. The use of an integrated algorithm [4] determines the sought unknowns. Once the Newton-Raphson iterative procedure converges, the outputs give the NURBS description of the surface of interest, and its corresponding motions. This pseudo-displacement field indicates the full kinematic field describing the distance between the calibration target and the actual surface. With the restriction of measuring only rigid body motions (three translations and three rotations, i.e., a subspace of all possible displacement fields), the observed surface is precisely repositioned without introducing the misalignments previously observed [5]. Once the calibration procedure is accomplished, it is possible to measure the 3D mechanical response of the material under cyclic thermal loading by registering the reference and deformed images. The hybrid stereo residuals are minimized by estimating the motions of the control points in the deformed images with the same type of correlation procedure as explained before. The measured displacement and temperature fields are illustrated in Figure 2. The in-plane displacement fields (U_x and U_y) describe biaxial expansion and the out-of-plane component (U_z) shows a hump in the center of the laser beam, which corresponds well with the temperature distribution.

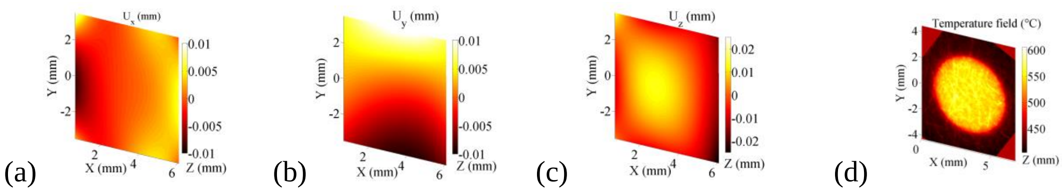

Figure 2 Displacement and temperature fields in the presence of a laser shock.
(a) U_x (b) U_y (c) U_z (out-of-plane direction) (d) temperature of the surface of interest

Conclusion

Full field measurements of temperature and displacement on the surface of the specimen are performed with a hybrid stereovision system via isogeometric stereocorrelation. The current configuration of the FLASH setup, which uses two cameras in different wavelengths, induced challenges resulting from individual camera properties (i.e., pixel resolutions, depth of field, digital / gray level distributions and relaxation of gray level conservation in presence of the laser beam). All these features could be addressed thanks to global stereocorrelation. Introducing a third device (another visible light camera) will allow for a larger field of view and a higher sensitivity to the underlying kinematics thanks to a multiview formulation.

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