Digital image correlation (DIC) & testing of aerospace components for Hydrogen Powered Gas Turbines

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Abstract

Digital Image Correlation (DIC) is an advanced, non-contact, full-field imaging technique that comprehensively monitors and detects geometric deformations and strains across the surfaces of various structures and materials subjected to mechanical load **[1]**. This method relies on cross-correlating features/patterns observed on a specimen's surface **[2]**. The DIC accuracy is derived from the speckle pattern applied to the specimen's surface. The speckle pattern consists of randomly arranged regions with distinct contrast between light and dark pattern areas; it operates as a tracking mechanism for the deformation of the underlying specimen. The correlation algorithm utilised within the DIC software is based on the premise that the motion of the speckle pattern accurately reflects the behaviour of the underlying specimen **[3]**. This algorithm efficiently identifies local variations in the speckle pattern to establish displacement fields by comparing images acquired before and after deformation **[3]**. By tracking these variations, the computation of strain and deformation becomes feasible, thereby facilitating the identification of failure mechanisms within the specimens. DIC has been extensively utilised and researched at elevated temperatures. Recently, there has been an increasing interest in its application at cryogenic temperatures, particularly within sectors such as aerospace and clean energy.

DIC presents unique challenges in both the experimental setup and the materials under investigation in cryogenic environments. The identified challenges include environmental, thermal, and optical disturbances, variations in material behaviour, and constraints associated with conventional measurement methods. The introduction of cryogenic fluids, such as liquid nitrogen or helium, into an environmental chamber for specimen cooling can create substantial temperature discrepancies between the specimen, the sensors, and the chamber enclosure **[4]**. Furthermore, the stability of the low-temperature environment within the chamber is susceptible to disruption by heat transfer from the surrounding room-temperature environment or from different heat inputs. In the context of optical disturbances, maintaining a clear line of sight is essential for the cameras to capture the specimen's deformation effectively. In sub-zero environments, frost or ice may accumulate on both the specimen surface and the chamber window due to residual gases **[4]**. This phenomenon involves a temperature-dependent refractive index around the chamber window that presents optical path errors, causing defocus in camera systems, reducing image resolution, distorting captured images leading to ineffective result analysis **[4]**.

At cryogenic temperatures, the material's emissivity plays an indirect role as thermal effects are noticeable. Although DIC primarily employs visible-light imaging rather than thermal emissions; metals exhibit low emissivity, which presents two critical challenges for its application at cryogenic temperatures. Thermal

nonuniformity is a key challenge, as metal surfaces exhibit a reduced rate of radiative heat transfer to the chamber environment; thus, localised mechanical heating fails to achieve equilibrium rapidly across the specimen surface. Thermal gradients can accumulate, distorting the distinct speckle pattern on the specimen surface before reaching heat-loading equilibrium, generating DIC micro-scale measuring errors. The quality of speckle patterns is a crucial consideration, as they are typically created with ceramic paints applied at elevated temperatures. At sub-zero temperatures, the ceramic paints become brittle and susceptible to cracking. This brittleness leads the DIC correlation algorithm to misinterpret the cracks in the speckle patterns as deformations occurring in the underlying specimen. This misinterpretation can result in incorrect identification of the specimen's failure mechanisms.

This research investigates tensile and fatigue mechanical testing of hydrogen-powered gas turbines' components, utilising the DIC technique at sub-zero temperatures. The evaluation of the underlying specimen deformation will be achieved by identifying the optimal speckle pattern coating. Two speckle pattern coatings have been recognised within this study: PDMS (Polydimethylsiloxane silicone) combined with TiO_2 (titanium dioxide) and $Al(H_2PO_4)_3$ (aluminium dehydrogen phosphate) in conjunction with SiO_2 (silicon dioxide) and TiO_2. These combinations are deemed especially suitable for withstanding extreme conditions due to the integration of elastomers, which mitigate brittleness in the pattern. Before applying to the specimen's surface, these coatings require fabrication and will be developed and evaluated utilising both nano and micro particles for comparative analysis. Following the preparation of the speckle pattern coatings on the specimen, a small-scale cryogenic environmental chamber has been designed and manufactured to facilitate the testing of the specimen, incorporating an integrated tensile mechanism. The chamber has been designed to address the challenges of setting up and operating DIC at cryogenic temperatures, such as thermal discrepancies, unobstructed specimen view, and crystallisation, while also progressing towards larger-scale chambers and specimens.

References

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