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A novel method for repeatedly generating speckle patterns used in digital image correlation

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ABSTRACT

Speckle patterns play a key role in Digital Image Correlation (DIC) measurement, and generating an optimal speckle pattern has been the goal for decades now. The usual method of generating a speckle pattern is by manually spraying the paint on the specimen. However, this makes it difficult to reproduce the optimal pattern for maintaining identical testing conditions and achieving consistent DIC results. This study proposed and evaluated a novel method using an atomization system to repeatedly generate speckle patterns. To verify the repeatability of the speckle patterns generated by this system, simulation and experimental studies were systematically performed. The results from both studies showed that the speckle patterns and, accordingly, the DIC measurements become highly accurate and repeatable using the proposed atomization system.

1. Introduction

Over the past few decades, Digital Image Correlation (DIC) [1–4] has become a widely-accepted and effective deformation measurement method in the mechanical characterization [5–7] and other image analysis fields [8] because of its advantages of full-field measurement, non-invasive characteristics, simple manipulation and reusability in various tests [3,4]. Since the DIC method was first proposed by Peters and Ranson [9], many efforts have been made to improve the accuracy and efficiency of DIC algorithms. To begin with, the components of DIC algorithm itself have been analyzed with the aim of improving the accuracy and efficiency. The reported studies on subset size [10], interpolation scheme [11,12], shape functions [13], correlation criteria [14] and convergence criteria [15] have produced significant results. Novel DIC algorithms [16–18] have also been established, generating improved performance.

The DIC method is based on the speckle images that were captured before and after the deformation, and a unique and reproducible speckle pattern is a primary prerequisite in the DIC measurement. Over the past few decades, many techniques were used to generate the speckle pattern on the surface of the test specimens. Computer-generated images were also commonly used due to its well-controlled deformation and reduced noise conditions. In actual laboratory experiments, the original feature of object surface [19], chemical etching of object surface [20], hand drawing [20], paint spraying [10,17,19], laser beam [21] and even speckle projections [20] were used to produce the unique speckle patterns. Among these techniques, original features of object surface provided the least uniqueness of speckle pattern and thus yielded a high error in the DIC measurement [20]. The manual drawing was quite time-consuming in case of large amount of testing specimens. The laser beam and the projection of virtual speckle patterns on the object surface could cause reflection effects in the image capturing [21,20]. The paint spraying was thus widely used in the DIC measurement. In addition, studies have compared the error caused by speckle pattern generated by different techniques. It was found that the paint spray yielded the least error in the DIC measurement. However, not all the speckle patterns generated by manual spraying could generate a low error in the DIC measurement. Pan et al. [10] reported that speckle patterns prepared on the same object through spraying paints by different people might demonstrate different grayscale distribution characteristics such as different image contrasts and speckle sizes. Accordingly, the DIC measurements conducted by different people thus yielded substantially different results even though the specimen, the actual deformation state and the subset size were all identical [10,19,22]. Therefore, a systematic technique for generating the speckle pattern with high repeatability is needed.

To determine an optimal or unique speckle pattern is the prerequisite of repeating the optimal pattern. Various characterization parameters are proposed to evaluate each speckle pattern, such as the image histogram [10,23], the speckle size (radius) [24–26], mean intensity gradient [19] and mean subset gray value fluctuation [23]; meaningful results can thus be obtained. Specifically, the unique image histogram with two peaks with a wide range led to accurate results [23]; the optimal speckle

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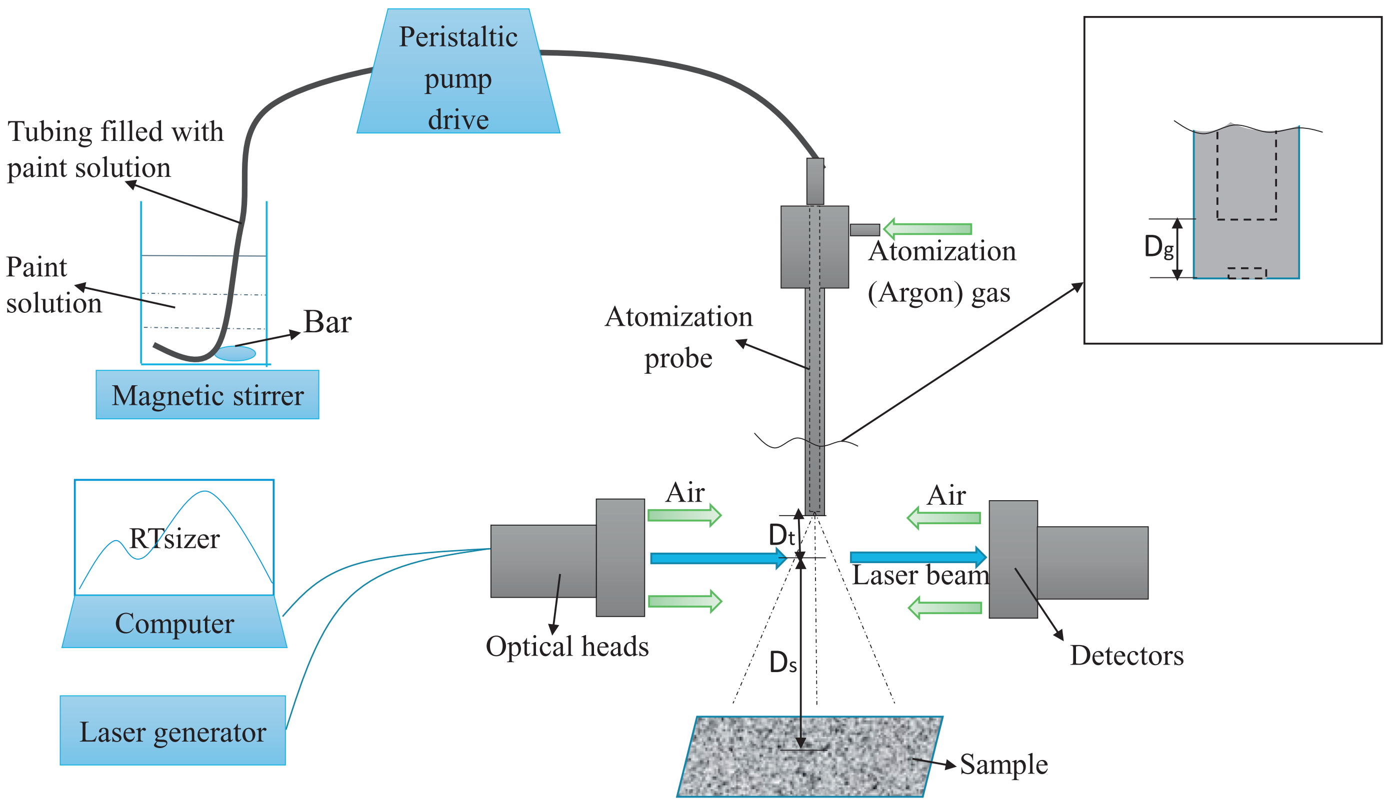

Fig. 1. Schematic illustration of the atomization system used to generate the speckle pattern. D_t and D_s are the distances from the level of laser beam to the tip of plasma probe and sample, respectively. D_g is the distance between the tip of inner layer and outer layer of plasma probe.

size ranges from 2 to 5 pixels [26]; the larger the mean intensity gradient [19] and the subset fluctuation [23], the smaller the DIC errors. These findings contributed to determining the optimal speckle pattern and already to predicting the DIC performance. Speckle patterns, however, are mostly generated by manually spraying the paint onto the testing samples, and this notably results in an unavoidable risk of pattern repeatability failure related to the different operators and laboratories. Until now, there has not existed a controllable method to generate morphologically repeatable speckle patterns. The DIC error related to the variation of speckle patterns could not be controlled because the optimal speckle pattern could not be successfully reproduced.

The objective of this study was to propose a novel method for controllably generating speckle patterns using an atomization system and doubly verifying this method using both experiments and simulations. The speckle pattern generation process is controlled by several process configuration parameters, and by adjusting the combination of these parameters, different speckle patterns can be generated. The ability of this system to generate speckle pattern variety and repeatability is verified by analyzing simulations and experiments. This article is organized in sections, including schematics of the atomization system and speckle pattern generation and repeatability analyses. In the repeatability analysis, a numerical rotation test and a practical rotation experiment using two lenses for image capturing are used to verify the repeatability of the atomization system under various conditions.

2. Methods

2.1. Atomization system

Fig. 1 illustrates the atomization system used in this study to generate the speckle patterns and their replicates. To generate a speckle pattern on a sample, the black paint (Tremclad Rust Paint, flat, Canada) is diluted with paint thinner (ACE, 18002001, Canada) in a 10:6 paint-to-thinner ratio to reduce the friction in the pipe caused by the high viscosity of the original paint. The container of the diluted paint solution is placed on a magnetic stirrer, with a magnetic bar inside the container to avoid the delamination of the paint solution. A peristaltic pump drive (Masterflex HV-77,201-60, Parmer Instrument Company, Canada) is then used to drive the paint solution from the container into the inner layer of the atomization probe through the silicone tubing (Masterflex, Silicone tubing L/S16, Parmer Instrument Company, Canada). At the same time atomization (Argon) gas flows into the outer layer of the atomization probe (Machine shop, Université de Sherbrooke) from the right port. When the paint solution and Argon gas descend and meet in the gap at the bottom of the atomization probe tip (in the sub-figure of Fig. 1), the paint solution is blown out of the probe in the form of small droplets. Underneath the tip of the atomization probe there are two optical heads (Model:RTS5114 1 of 2, Series no: 34215/15, Malvern Instrument Limited, UK), with air coming from the both sides to prevent the contamination of lens of optical heads and a laser beam from laser generator (Model: RTS5114 2 of 2, Series no: 34215/15, Malvern Instrument Limited, UK) passing from left to right head. There are laser detectors in the right optical head to capture the morphological information of the paint solution droplets. The signals from the detectors are then transferred to a computer and analyzed by the RTsizer software (Malvern Instrument Limited, UK) to visualize the droplet size and distribution. With the interaction of the Argon gas, air and laser beam, the paint solution is blown into small droplets, and fall on the sample placed midway beneath the two optical heads. In this way, the speckle pattern is generated on the sample surface.

In Fig. 1, D_g denotes the distance between the inner layer and tip of the atomization probe; while D_t and D_s denote the distances from the level of laser beam to the tip of atomization probe and to the sample, respectively. In this system three configuration parameters are adjusted to change the size distribution of the sprayed paint droplets: the paint solution delivery speed v_p, D_g, and the flow meter reading D_f related to