In Application

Vibration Analysis of Tuning Fork Oscillations using High-Speed DIC

Introduction

Understanding the vibration behaviour of a structural component is an important task in a wide range of mechanical design processes. The vibration parameters of a structure will determine its operational limits and estimated lifetime. These vibration parameters, which include resonance frequencies, associated mode shapes or operational deflection shapes (ODS) and damping ratios, are derived from time-domain signals of the structural response under loading conditions.

In this study, we present the use of full-field, high-speed Digital Image Correlation (DIC) for the recovery of the vibration behaviour of a tuning fork. The use of DIC in the field of vibration analysis presents considerable advantages when compared to classical sensor measurements (accelerometers), or Laser-Doppler Vibrometers (LDV), due to the non-intrusive nature of this imaging-based technique, as well as the fact that DIC produces instantaneous full-field displacement maps as opposed to single-point values.

Experimental Setup

The stereo 3D DIC experimental set-up consists of two high-speed Phantom cameras which were used at a frame rate of 10 kHz to acquire the data. A stainless-steel tuning fork with a resonant frequency of 432 Hz was prepared before the tests, by applying a speckle pattern on the surfaces of the two prongs. The tuning fork was excited using an impulse load generated by a horizontal impact on its left prong at 2.95 s after the start of the image acquisition. The image acquisition, data processing and post-processing were performed in DaVis 8.3.

Results

The raw images from the two cameras of the 3D DIC set-up were processed using a Least-Squares Matching (LSM) algorithm with subset size of 17 x 17 $pixels^2$ and a step size of 6 pixels. An affine shape function and a 6^{th} order spline sub-pixel image interpolation scheme, are used in the matching process. The resulting (x,y,z) displacement maps describe the motion of the tuning fork after the impulse load is applied, and two representative snapshots of the displacement maps, overlaid on the camera raw image, are presented in Figure 1. One advantage of using a full-field measurement technique is the possibility of choosing any position of a desired interrogation point or area, after the measurements are performed. In this study, two interrogation points are arbitrarily chosen on the two prongs of the tuning fork - the Left-Hand Prong (LHP) and the Right-Hand Prong (RHP) - as indicated in Figure 1. Sampling the displacement data at these two points yields the time-domain signal that can be used for post-processing or even comparison with sensor data.

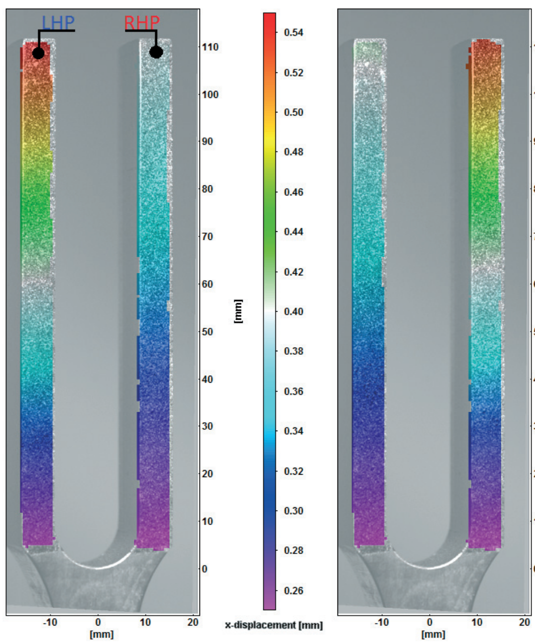

Figure 1. *DIC results at two time steps*

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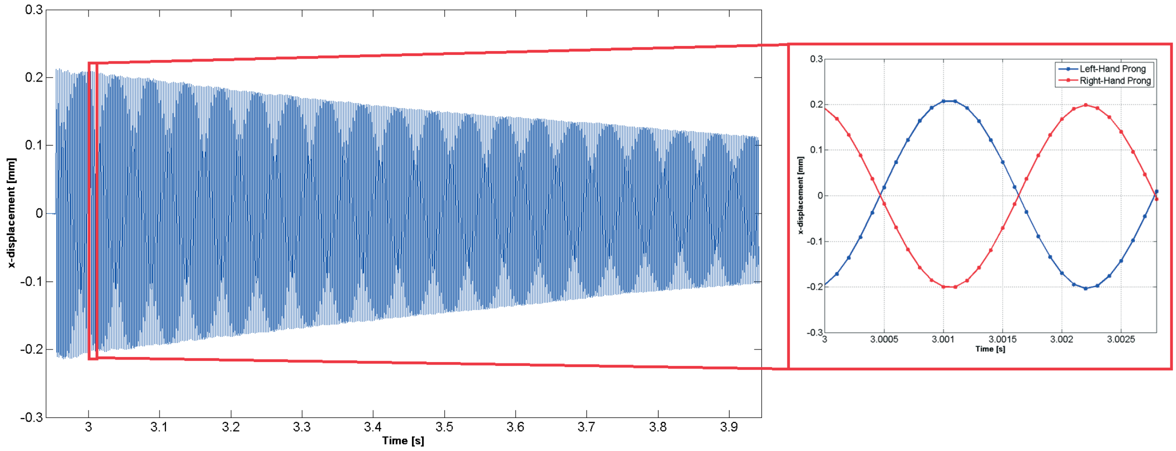

***Figure 2.** Horizontal displacements of the tuning fork prongs*

Another important aspect that can be easily quantified based on DIC measurement data, is the isolation of vibrations and rigid body motions of a structure, which can be done seamlessly in DaVis, using a built-in feature. In this present test, the removal of the rigid body motion-induced displacements yields the pure oscillatory behaviour of the tuning fork prongs. Figure 2 illustrates the time-domain signal of the predominant horizontal displacement component, as extracted from the left-hand and right-hand prongs, respectively.

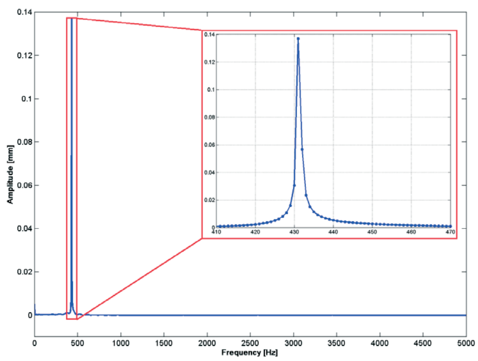

***Figure 3.** FFT of time-domain signal of tuning fork prong displacement*

In a next step of the vibration analysis, a power-spectrum density function can be applied to the displacement data to retrieve the Fast Fourier Transform (FFT) of the signal, which in turn allows the identification of the resonant frequencies of the structure. In this test case, the fundamental resonant frequency of the tuning fork, at 432 Hz, is identified as illustrated in Figure 3. The mode shape of the tuning fork associated with this fundamental frequency is also recovered using the Proper Orthogonal Decomposition (POD) function in DaVis, and the animated mode shape is illustrated in Figure 4.

It can be seen from this study, that using a high-speed 3D DIC system and the versatile DaVis software platform, one can perform in-depth vibration analysis of a structural component. Furthermore, because of the full-field three-component displacement data which can be recovered in DaVis, one can easily extract additional relevant information such as strain distribution, velocity and acceleration results that can be easily compared with accelerometer and/or vibrometer data.

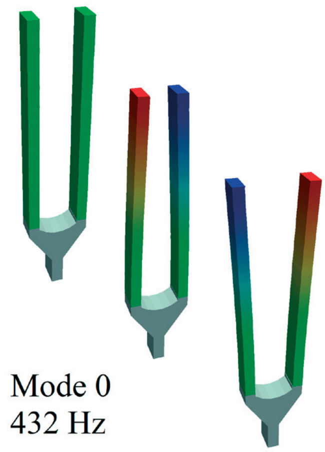

***Figure 4.** Fundamental mode shape of tuning fork at 432 Hz (visualized in ParaView®)*

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