



2019
CASE STUDY

Performing Vibration Analysis on a Tuning Fork Using High-Speed DIC

Understanding the vibration behavior of structural components is important in a wide range of mechanical design processes. How a particular structure vibrates, including its resonance frequencies and mode shapes, can help engineers determine operational limits and lifetime estimates. Traditionally, engineers have performed vibration analysis using sensor-based measurements and techniques, including accelerometers and Laser-Doppler vibrometers (LDV)—but these instruments have their limits.

That's where Digital Image Correlation (DIC) comes in. DIC utilizes high-speed cameras and specialized software to optically measure deformation, displacement and strain. This technique is rapidly gaining popularity for a number of reasons. Unlike accelerometers and LDVs, it is noncontact in nature, produces instantaneous full-field displacement maps instead of single-point values and is generally faster, quicker and cheaper than traditional sensing methods.

DIC can be applied to a number of fields, including vibration analysis. In this article, we'll explore how a group of researchers from LaVision utilized the technique to study the vibration behavior of a tuning fork. By using the right high-speed cameras—in this case, a pair of Phantom v1612s—the group demonstrated that DIC yields consistently accurate results when performing vibration analysis of a structure.



When it's too fast to see, and too important not to.®

THE EXPERIMENT

LaVision is a leading supplier of laser-imaging systems. The company's product portfolio includes advanced DIC systems and software for optical, full-field measurement of displacement, shape and derived material strain. LaVision researchers applied DIC to the vibration analysis of a tuning fork using two Vision Research high-speed cameras and LaVision imaging software.

The cameras, a pair of Phantom v1612s, achieve the high frame rates needed for vibration analysis without compromising image quality. For one, they can shoot up to 16,000 frames per second (fps) at full 1-megapixel resolution while delivering 16 Gpx/s throughput. They are also extremely light-sensitive—a critical feature for high-speed applications, which require more light than regular photography. To this end, the v1612s include an Exposure Index (EI) feature that brightens the image by increasing the camera's ISO.

For their object of study, the researchers selected a simple stainless-steel tuning fork that vibrates at a resonant frequency of 432 Hz. Prior to the test, they applied a speckle pattern to the surface of the two prongs. They then excited the fork using an impulse load—generated by a horizontal impact to the left prong. The cameras obtained images at a rate of 5,000 fps while their high resolution captured the fine, visual texture of the speckle paint pattern. All image acquisition, data processing and post-processing were performed in DaVis 8.3 laser-imaging software.

THE ULTRA-SENSITIVE PHANTOM v1612

When it comes to performing DIC analysis, 5,000 fps is fast. To record at such high speeds, the researchers needed a camera capable of high sensitivity. The Phantom v1612 integrates several advanced features that strike this balance, making it an excellent tool for researchers, scientists and engineers who need to capture high-resolution images at ultra-high speeds:

- 28 μm pixels collect a lot of light, resulting in a high native ISO of 32,000D (mono) and 6400D (color)
- 1- μs minimum exposure and 500 ns minimum exposure (with FAST option) at all frame rates and resolutions
- Extreme Dynamic Range (EDR) feature, which provides two different exposures within a single frame so areas that would otherwise be overexposed contain image detail
- Exposure Index (EI) controls, which increase the camera's ISO with minimal noise by adjusting the tone curve



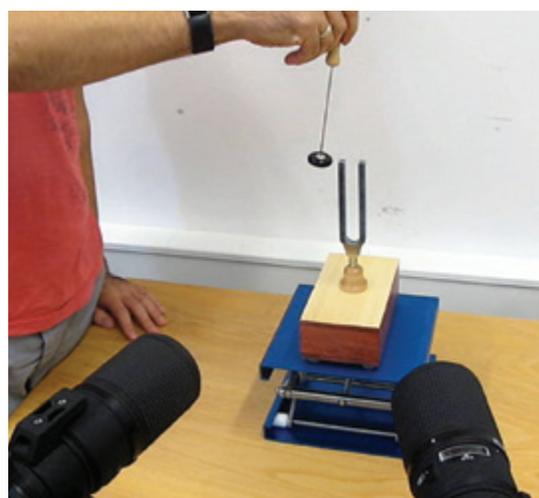
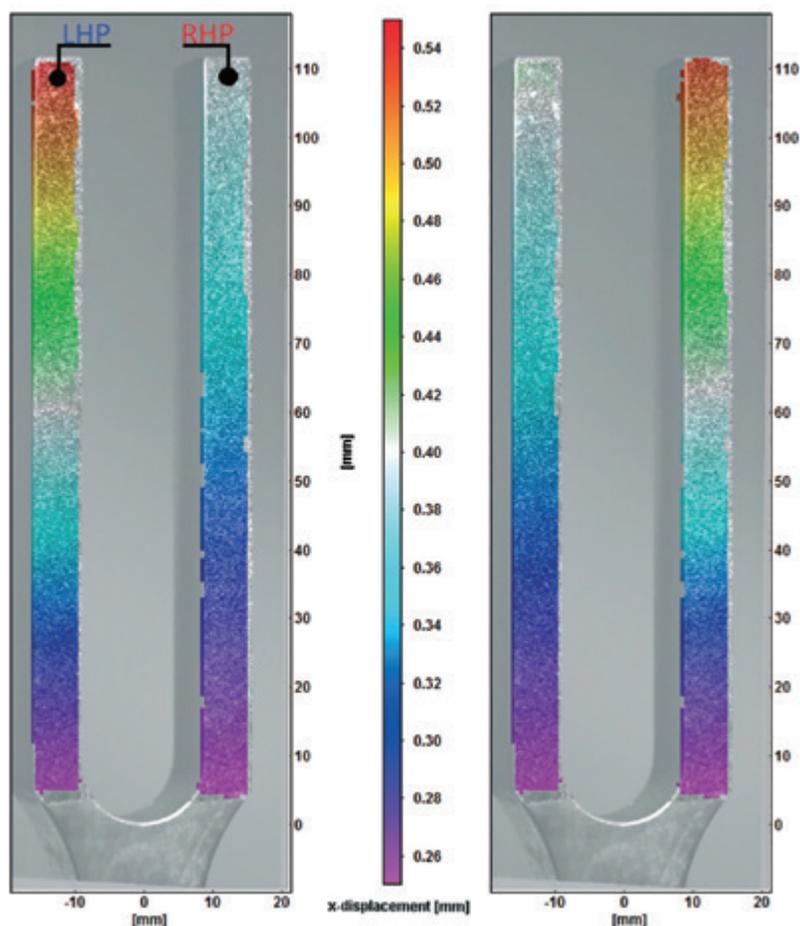
For their DIC experiment, researchers used two high-speed Phantom v1612 cameras, which can shoot up to 16,000 fps at full resolution.

PROCESSING DIC RESULTS

One of the advantages of using this full-field measurement technique is the ability to choose any position of a desired point or area on the object's surface. The researchers arbitrarily chose two points on each of the two prongs—one point on the right prong and one on the left. Sampling the displacement data at these two points yielded the time-domain signal used for post-processing. From this data, researchers also derived the velocity and acceleration of the fork's oscillations.

Using DaVis, the researchers next applied a power-spectrum density function to the displacement data provided by the two points, yielding the Fast Fourier Transform (FFT) of the signal. Via Fourier analysis, they were able to convert the signal from its original time domain to a representation in the frequency domain. Because tuning forks are designed to vibrate at one specific frequency, the FFT indicates only one peak at 432 Hz. Researchers sampled at the Nyquist rate of 864 Hz to avoid signal aliasing.

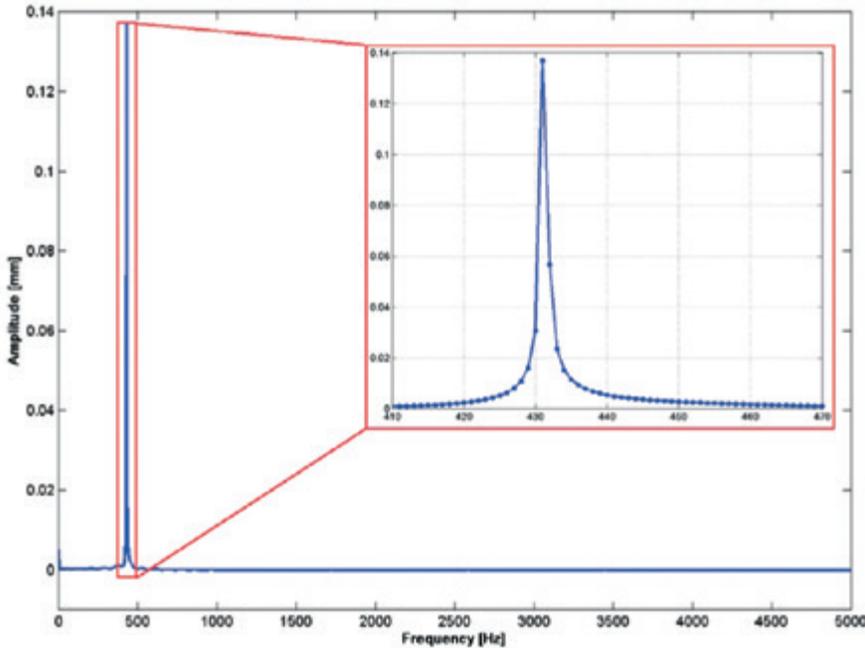
In addition to using the DIC displacement data to identify the frequency peaks of the tuning fork, the researchers animated the fork's vibration pattern by extracting Operational Deflection Shapes (ODS) in DaVis.



Using DaVis 8.3, the research team processed the displacement data at two points on each of the fork's prongs.

As the cameras acquired images at 5,000 fps, the researchers excited a stainless-steel tuning fork that vibrates at a resonant frequency of 432 Hz.

“This case example demonstrates that DIC, which uses a combination of high-speed cameras and advanced computer software, can perform successful vibration analysis of a structure.”



By applying a power-spectrum density function to the data, the researchers identified the resonant frequency of the tuning fork at 432 Hz.



The team also used the DIC data to generate Operational Deflection Shapes (ODS) of the tuning fork's vibration pattern.

CONCLUSION

This case example demonstrates that DIC, which uses a combination of high-speed cameras and advanced computer software, can perform successful vibration analysis of a structure. The Phantom v1612 cameras delivered the required resolution and frame rate, ensuring DIC analysis was a success. Using this technique, the researchers easily extracted additional measurements, identified the structure's resonant frequencies and even generated animations of its vibration pattern. These results can be compared with accelerometer or vibrometer data—while also taking traditional sensing techniques one step further.

Cover Image Courtesy of Warped Perception



Certain Phantom cameras are held to export licensing standards. Please visit www.phantomhighspeed.com/export for more information.