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4D X-RAY MICROTOMOGRAPHY OF VIBRATING MULTISCALE STRUCTURES

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1. Introduction

Some pioneer studies have been proposed to image the 3D structural evolutions of biological oscillators using synchrotron X-ray microtomography, allowing to quantify low-frequency motions below 5 Hz [1]. More recently, 3D images of fly muscles during wingbeat at 145 Hz were obtained [2]. However, in order to tackle some current scientific issues in voice biomechanics [3], breakthroughs are still expected in 4D X-ray acquisition and reconstruction procedures to both improve the spatio-temporal resolution and study the vibration of multiscale structures at higher frequencies. Thus, the main objective of this study is to characterize the 4D strain-induced microstructure evolutions of soft fiber-reinforced tissue-like materials subjected to mechanical vibratory loadings up to 400 Hz, as encountered in human phonation.

2. Materials and Methods

Samples and vibration tests – Slender composites strips (10x2x2mm³) made of glass fibers/beads (typical length 50 μ m and volume fraction 5 %) embedded in a soft silicone matrix were mounted in a specifically designed vibro-mechanical tensile set-up. They were subjected to sinusoidal oscillations (from 50 to 400 Hz) around different tensile pre-stretches varied from 0 to 0.9 (Fig. 1a).

Imaging process – Samples were imaged with a voxel size of 2^3 and $10^3 \mu\text{m}^3$ at the SOLEIL-Psiché beamline [4]. Scanning and reconstruction parameters (frame rate, angular repartition of projections per cyclic phase...) were optimized to minimize blurring artifacts obtained when imaging a moving structure. To do so, prior numerical simulations were conducted on ideal vibrating (fibrous/spherical) particles of known 3D geometry. Then, 4D X-ray images with retrospectively gated projections were performed using optimal parameters.

3. Results and Conclusion

Typical 4D images are reported in Fig. 1b, illustrating the case of a fibrous composite vibrating at 100 Hz around a tensile pre-stretch of 0.5. The optimal vibratory amplitude to apply (resp. frame rate) was found around 60 μm (resp. 1033 Hz).

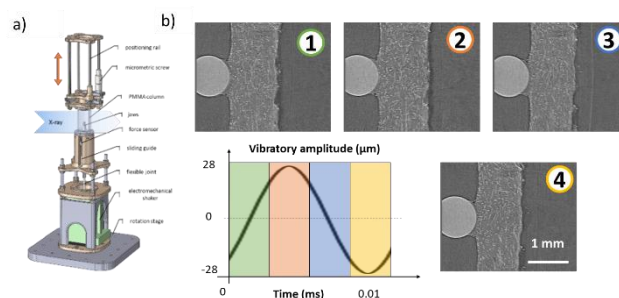


Figure 1. (a) Scheme of the custom vibrating tensile set-up; (b) 4D X-ray tomographic images of a fibrous sample (SOLEIL, mid-vertical slices, 10 $\mu\text{m}/\text{px}$, selection of 4 phases out of 30 of the periodic cycle).

For each case, the optimization procedure allowed a successful reconstruction of 30 phases of the periodic cycle, with promising image quality for quantitative kinematical field analyses (DVC) and particle tracking methods at the fiber scale. The relevance of the methodology will be discussed by comparing the results derived from several (un)optimized scanning and reconstruction procedures.

4. Acknowledgements

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5. References

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