Mechanical Engineering Doctoral Defense

Modeling Cardiac Function With Particle Image Velocimetry

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abstract

The application of novel visualization and modeling methods to the study of cardiovascular disease is vital to the development of innovative diagnostic techniques, including those that may aid in the early detection and prevention of cardiovascular disorders. This work focuses on the application of particle image velocimetry (PIV) to the study of intracardiac hemodynamics. This is accomplished primarily though the use of ultrasound based PIV, which allows for in vivo visualization of intracardiac flow without the requirement for optical access, as is required with traditional camera-based PIV methods.

The fundamentals of ultrasound PIV are introduced, and the visualization routine is then compared to optical PIV; this is a highly developed technique with proven accuracy; through rigorous examination it has become the "gold standard" of two-dimensional flow visualization. Results show good agreement between the two methods.

It was found that compression plastic flow has negligible influence on flexural behavior in epoxy resins, which are stronger in pre-peak and post-peak softening in compression than in tension. The second model was a piecewise-linear stress strain curve simplified in the post-peak response. Beams and plates with different boundary conditions were tested and analytically studied. The flexural over-strength factor for epoxy resin polymeric materials were also evaluated.

Using a mechanical left heart model, a multi-plane ultrasound PIV technique is introduced and applied to quantify a complex, three-dimensional flow that is analogous to the left intraventricular flow. Changes in ventricular flow dynamics due to the rotational orientation of mechanical heart valves are studied; the results demonstrate the importance of multi-plane imaging techniques when trying to assess the strongly three-dimensional intraventricular flow.

The potential use of ultrasound PIV as an early diagnosis technique is demonstrated through the development of a novel elasticity estimation technique. A finite element analysis routine is coupled with an ensemble Kalman filter to allow for the estimation of material elasticity using forcing and displacement data derived from PIV. Results demonstrate that it is possible to estimate elasticity using forcing data derived from a PIV vector field, provided vector density is sufficient.

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