Dynamics of Nanomagnetic MR Elastomers

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Introduction

Magnetorheological (MR) elastomers can provide dynamic stiffness elements capable of operation over a range of conditions.[1] This controllability in response to an applied magnetic field is achieved by embedding magnetic particles into a crosslinked polymeric rubber matrix. During crosslinking or curing, each particle in the MR elastomer is held in position until magnetic or mechanical perturbations introduce changes in the configuration of the embedded particles. The dynamics of this response is critical to the functionality of MR elastomers in automotive applications such as variable stiffness suspension systems and active damping components.

Methods and Materials

We use high-intensity x-ray synchrotron radiation from the undulator source at MHATT-CAT's sector 7 to make novel measurements of real-time particle dynamics in MR elastomers. Through small-angle transmission scattering of transversely coherent x-rays, the phase of the wavefront will shift with the relative motion of the particles, resulting in a time-dependent interference pattern known as speckle. MR elastomer samples were excited by cycling the applied magnetic flux density (1 Tesla) while scattered speckle patterns were recorded with a CCD camera operating in direct detection mode. Since the camera can detect speckle images on millisecond timescales, subtle changes in the diffraction as a function of magnetic field can be recorded as a movie. Through speckle analysis we are able to measure the relaxation dynamics of magnetic particles embedded in the polymer matrix. The small-angle scattering configuration is shown in Fig. 1.

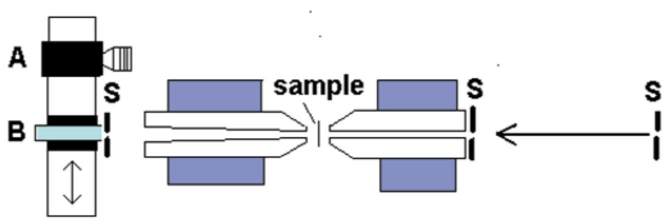

FIG. 1. Small-angle scattering arrangement for MR speckle experiments at 7-ID. The detector carriage on the left supports a CCD camera (A) and a scintillator detector (B), either of which can be positioned in the beam. The sample is placed between the pole pieces of an electromagnet; an axial hole provides access for the monochromatized undulator beam; S are slits.

Results and Discussion

Figure 2 shows a single frame from a sequence of images recorded at two-second time intervals during an experiment in which the magnetic field was cycled from positive to negative saturation. The magnetic ferrite particles[2] were approximately 100 - 300 nm in size and constituted ~25% of the sample by volume. The coherent speckle character of the small-angle scattering from the ferrite nanoparticles is clearly evident extending beyond the shadow of the backstop (horizontal band), which subtends an angle of 0.107 mr at the CCD detector. Diffraction vectors in the range ~2 – 50 x 10^{-4} Å^{-1} can be accessed by this small-angle scattering arrangement.

Autocorrelation analysis of the speckle intensity is underway in order to measure the relaxation time associated with particle motion following magnetic excitation.

These measurements are the first of their kind on a magnetorheological elastomer, and they demonstrate the feasibility of using coherent undulator beams to probe relaxation dynamics in bulk, optically opaque samples on short time scales relevant to practical applications.

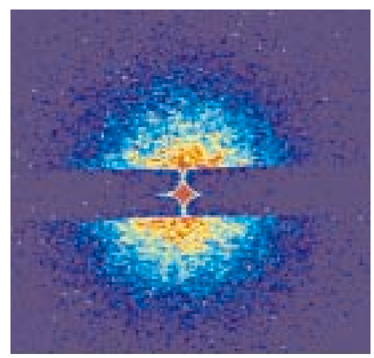

FIG. 2. Small-angle coherent beam scattering from MR elastomer material containing magnetic nanoparticles. Incident beam diameter ~ 10 µm.

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References

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[2] Magnox Pulaski Inc. TMB-X-1530.