Abstract

The focus of this study is on the sensing behavior of magneto-rheological elastomers (MREs) by experimentally characterizing their dielectric properties. An experimental setup which can detect the impedance changes of the MRE under compressive normal forces and deformations is developed. Un-oriented and oriented MRE samples with varying particle loadings are prepared and tested by using this setup. Experimental results show that the oriented MREs have lower impedance and have more changes of the impedance than un-oriented MREs in response to normal force deformation. The values of the impedance of all MRE samples decrease with increasing compressive force. This demonstrates that MREs are potentially capable of being used not only for tunable vibration absorbers (TVAs) but also for sensing force and displacement.

1. MREs

A magneto-rheological elastomer is a directional composite material that consists of magnetic particles that are aligned into chains or column-like structures which are embedded inside of a polymer matrix. The structures of the magnetic particles within elastomers are very sensitive to the external stimulus of either mechanical force or magnetic field, which results in two phenomena: magneto-rheology and magnetoresistance.

MRE samples with different iron particle concentrations were produced and tested for this study. Figure 1 depicts three of these samples. Iron particle concentrations varied by weight, and ranged from 30-80%. Each sample is a disk that measures 60 mm in diameter and 3 mm in thickness.

2. Experimental Study

2.1. Compression Fixture

A compression fixture was designed to isolate the MRE sample from the rest of the test set up. Two parallel plates (the same size as the samples) were placed on either side of the MRE sample. A thin, isolating, layer of electrical grade Teflon was placed as an insulator between the plates and the rest of the test fixture. Compression blocks, of equal diameter to the MRE sample, were mounted to the load cell in order to apply an evenly distributed load to the sample. Compression force was transferred from the load cell through the compression blocks to the sample. Figure 3 shows the experimental setup including compression fixture, load cell and LVDT.

2.2. Electrical Circuit

Figure 4 shows the electrical schematic of the circuit used to measure the impedance of the MRE samples. The circuit consists of an AC voltage source, a reference resistor, and the MRE sample, all in series. The Lock-in Amplifier is connected to take measurements across the reference resistor. Measuring the voltage across the reference resistor, it is possible to determine both real and imaginary parts of the MRE’s impedance.

2.3. Impedance Calculation

The equation for this circuit can be expressed as:

\[ V_s(t) = V_0 \sin(\omega t + \phi) \]

where \( V_s \) is the applied excitation voltage from the AC source, \( \omega \) is the excitation frequency, \( R \) is the resistance of the reference resistor, \( \phi \) and \( Y \) are the real and imaginary parts of the MRE impedance, respectively, and \( V_R \) and \( V_0 \) are the measured voltage and phase shift across the reference resistor. This equation can then be rewritten to give equations for the real and imaginary parts of MRE impedance alone, shown in equations two and three.

\[ R = \frac{V_R}{V_0} \]

\[ \phi = \arctan\left(\frac{Y}{R}\right) \]

For this experiment, the applied voltage was 1 V, the excitation frequency was 1 kHz and the known reference resistor was 99.4 kΩ. By measuring the voltage and phase shift angle across the reference resistor, the real and imaginary parts of the MRE’s impedance can be determined by (2) and (3). Knowing these values, the magnitude and phase angle of impedance for the MRE can be calculated using equations as follows.

\[ |Z| = \sqrt{R^2 + Y^2} \]

\[ \theta = \arctan\left(\frac{Y}{R}\right) \]

With these values, the change in MRE impedance can be displayed as the applied forces and displacements change. To measure the changes in MRE impedance with various applied forces, the compression fixture was assembled to the Instron machine. The system was calibrated for each sample to ensure that every run began with a pre-load condition of 0 mm displacement. An initial measurement of \( V_R \) and \( V_0 \) were taken to set a baseline value.

The Instron machine then compressed the sample at 1 mm/min to a set displacement value, and was held while measurements were taken from the Lock-in Amplifier. Once the measurement was completed, the Instron machine was returned to zero displacement and the test was repeated.

The DAQ system records the applied force, compressed displacement, voltage and phase shift across the reference resistor.

3. Results and Discussion

The MRE materials show elastic behavior under compression loading. As shown in Figure 5, the force applied increases as displacement increases. The un-oriented MREs have almost the same stiffness. The oriented MRE samples with higher iron concentrations are, as would be expected, much more rigid than the lower percentage MRE samples.

4. Conclusions and Future Work

The sensing capabilities of MRE materials have been studied by measuring the impedance changes of the un-oriented and oriented MRE samples with various particle concentrations under compressive loading. MRE Impedance decreases with increasing particle loading, and oriented samples have more changes than un-oriented. When compressed, MRE Impedance decrease with increasing compression force decreasing the stiffness.

Further work is required to fully understand the sensing capabilities of MRE materials by both static and dynamic tests. The ability of the MRE to sense stress and strain will also be examined in an on-track condition (applying a magnetic field to change the stiffness of the material). In addition to compressive normal forces, the effect of shear stresses on dielectric properties will be examined.

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