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Characterization of an ETREMA MP 50/6 Magnetostrictive Actuator

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ABSTRACT

This report presents the Displacement (Strain) - Current characteristic of an ETREMA MP 50/6 magnetostrictive actuator. This actuator is made of Terfenol-D and displays giant magnetostriction. The displacement - current characteristic shows significant hysteresis behaviour that depends on the rate at which the input is applied. Another important property of ferromagnetic hysteresis – the wiping out property, was also observed in the experiments.

1 Introduction

The ETREMA MP 50/6 actuator is a magnetostrictive actuator. The aim of the characterization experiment is to verify features of the magnetostrictive hysteresis effect such as minor-loop closure and rate dependency. The fine displacements of the actuator (of the order of microns) were measured with an LVDT sensor. However, the LVDT sensor being extremely sensitive is very difficult to calibrate. In section 2, the calibration of an LVDT based measurement system is discussed. The characterisation experiment for a magnetostrictive actuator is then presented in section 3.

2 The LVDT Sensor

An LVDT is an electromechanical transducer that produces an electrical output proportional to the displacement of a separate movable core.[1] It consists of a primary coil and two secondary coils symmetrically spaced on a cylindrical form(Figure 1). A free-moving rod-shaped magnetic core inside the coil assembly provides a path

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for the magnetic flux linking the coils.

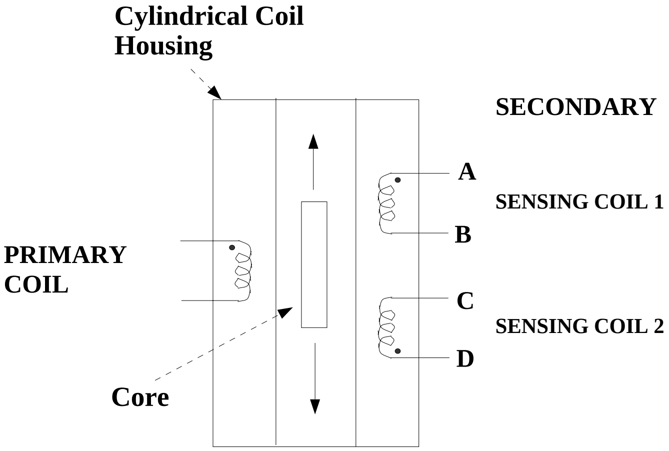

Figure 1: Schematic of an Lucas-Schaevitz LVDT Transducer.

When the primary coil is energized by an external AC source, voltages are induced in the two secondary coils. These are connected in series opposing so the two voltages are of opposite polarity. Therefore, the net output of the transducer is the difference between these voltages, which is zero when the core is at the center or null position. When the core is moved from the null position, the induced voltage in the coil toward which the core is moved increases, while the induced voltage in the opposite coil decreases. This action produces a differential voltage output that varies with changes in core position. The phase of this output voltage changes abruptly by 180 degrees as the core is moved from one side of null to the other. For the experiment described in this report, the wires B, C of the secondary were connected together, so that the voltage between the terminals A, D is an estimate of the displacement of the core from its null position.

Some of the features of an LVDT sensor that make it attractive to magnetostrictive motion measurement are,

- Frictionless Measurement - There is no physical contact between the core and the coil structure. This is very desirable considering the fine displacements that are to be measured.
- Infinite Resolution and Null Repeatability - The frictionless operation of the LVDT combined with the induction principle by which the LVDT functions gives it the above mentioned properties.
- Cross-Axis Rejection - An LVDT is predominantly sensitive to the efects of axial core motion and relatively insensitive to radial core motion. Hence, it can be used in applications where the core does not move in an exactly straight line.

Unfortunately, the characteristic of the LVDT Sensor is nonlinear and this makes its calibration very important.

2.1 Calibration of the LVDT Sensor - Amplifier Unit

The LVDT chosen for the hybrid motor was the Lucas Schaevitz 005 MHR mainly because of its sensitivity and also because of its miniature size and low weight. It has a nominal linear range of ±0.125 mm. The LVDT transducer requires an additional instrument for the excitation of the primary coil and for the amplification of the sensing coil signals. The unit chosen for the hybrid motor application was the Lucas Schaevitz ATA-101 Analog Transducer Amplifier. The basic operation, controls and adjustments are described in the ATA-101 manual.[2]

Here the steps necessary for successful calibration of the unit are described as it was a most arduous and time consuming task for the authors.

We describe the set up for calibration. The coil structure is attached to a rigid body which is preferably attached to an optical bench. The core is then mounted on a micrometer slide with a sufficiently low least count. The slide is also firmly attached to the optical bench/base plateform. The object is to move the core in and out of the coil housing while noting the voltage output of the ATA-101 amplifier.

1. First the offset of the transducer is adjusted as follows. The input is disconnected and the zero screw on the ATA-101 amplifier module is adjusted, till it reads zero volts. Then the input is reconnected and the precise null position (zero voltage) is obtained by mechanically moving the core.
2. Then move the core to half the full scale value(0.0125 inches), inside the coil. The authors had to invert the suggested connections in the ATA-101 manual, so as to get a positive voltage. At this point, the manual suggests that the Span control screw on the amplifier module is adjusted to get a reading between 5 and 6 Volts. The authors could only obtain slightly less than 5 Volts. Then the Phase control screw on the ATA-101 module is adjusted to get a maximum reading which was found near the clock-wise end. The settings inside the module, switch 5 is ON while switches 6, 7, 8 are OFF.
3. The core is then moved back to the mechanical 'ZERO' position, and the zero screw is adjusted so that the output reads 0 Volts.
4. Then the core is moved to the plus full scale displacement(0.0125 inches) and the Span control screw is adjusted to read 10 V.
5. At this point, the authors went back to the zero position (mechanically) to ensure that the voltage output was indeed zero volts. If it was not, then we adjusted the zero screw. We could get the voltages at the zero and the plus full scale end to agree within 10 mV.
6. The amplifier output voltage is then measured at intermediate points between the plus and minus full scale readings and the results are plotted(Figure 2). This step is repeated enough times to make sure that the relationship between the core displacement and the ATA-101 output voltage is one-one.

As can be seen from Figure 2, the output voltage vs the displacement of the core shows a nonlinear relationship. This can be taken into account by writing a MATLAB function that inverts the observed voltage and yields the core displacement.

3 Characterization of the Terfenol-D Actuator

The characterization experiment was performed on a 50/6 MP magnetostrictive actuator marketed by ETREMA Products Inc. This actuator incorporates a permanent magnet bias and preloaded springs for prestress. Figure 3 shows the cross-section of this actuator. The unit length is 10 cm and the unit diameter is 3.4 cm. The housing is made of aluminum while the push-rod which is the moving unit is made of stainless steel. The length of the Terfenol-D rod is 5.13 cm and its diameter is 0.6 cm. The prestress is adjustable from 0 to 3 Kpsi while the permanent magnet bias is approx. 425 Oe. Its rated load is 490 N. The displacement of the push rod vs the input current for the two actuators according to ETREMA Products Inc. are shown in Figures 4(a) and 4(b) respectively.

The experiment was performed on only one of the actuators because only one of them gave results close to the factory specified data. All the data in this report pertains to the same MP 50/6 actuator. The method for the

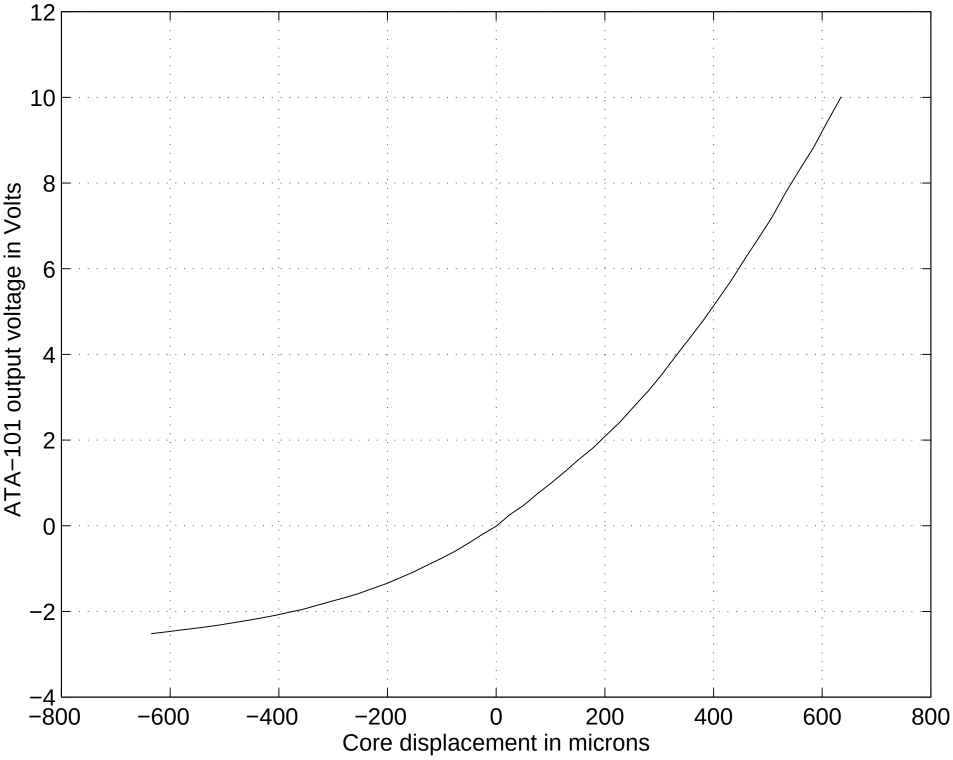

Figure 2: LVDT Transducer Characteristic.

experiment is captured by Figure 5. For signal generation and data acquisition, Integrated systems Inc.'s AC-100 rapid prototyping station[3] was used. Software tools provided by ISI for the AC-100 system facilitate the design and simulation of controllers, generate C/FORTRAN/Ada code for the controller which can then be downloaded to a digital signal processing (DSP) chip. The DSP chip executes the controller in real time.

The signals shown in Figures 7(a) and 7(b) were designed using the SystemBuild, the visual modeling and simulation component of the MatrixX product family. The C code for the signal generation routine was then downloaded onto the DSP chip in the AC-100 system in the ISL lab. The real-time signal had to be amplified using a KEPCO bipolar operational power supply/amplifier so that the current waveform was as shown in Figure 7. The displacement of the Terfenol-D actuator was measured by the LVDT Sensor which was mounted on the Hybrid Motor as shown in Figure 6.[4] When one of the actuators was being tested, the power supply to the other was disconnected. Thus the differential voltage output of the LVDT was only due to the displacement of actuator under test. As described in the previous section, this voltage was amplified using the ATA-101 signal conditioner. The amplified signal was then sampled by the AC-100 system and stored as a data file. This datafile was analyzed using the Xmath system analysis and visualization software of the MatrixX product family. The results are shown by Figures 7 and 8.

Figure 7(a) shows part of a butterfly shaped curve that is the characteristic of a magnetostrictive material. It is not symmetric about zero current, which is the result of a permanent magnet bias that is part of the ETREMA MP50/6 actuator. It is interesting to note that for positive current the characteristic is linear! Figure 7(b) shows clearly that minor-loops have a tendency to close, which is a very important feature that any theoretical model of the actuator must have.

Figure 8 shows the rate dependence of the Displacement-Input Current hysteresis loops. The frequency is 50

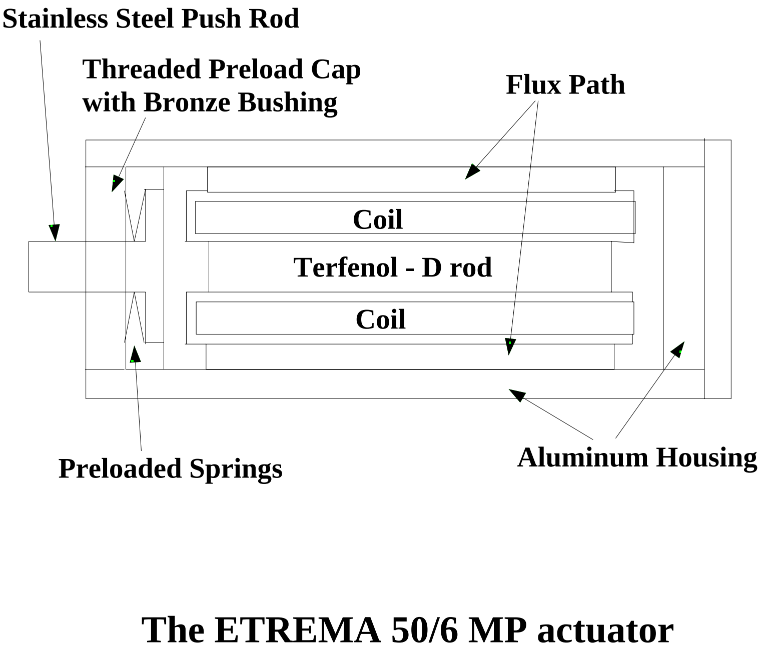

Figure 3: Cross-sectional details of the magnetostrictive actuator.

Hz as opposed to the 0.5 Hz in Figure 7. The butterfly shape in Figure 8(a) is wider, possibly due to eddy current losses. Figure 8(b) shows the minor-loop closure is satisfied even at higher frequency.

4 Conclusion

An experiment was performed to verify important properties of the magnetostriction effect like minor-loop closure and rate dependence. As the displacements obtainable from an ETREMA MP 50/6 magnetostrictive actuator is of the order of microns, it was necessary to use sophisticated sensing techniques for its measurement. The experimental results published in this report will be valuable in theoretically modeling magnetostriction, and compensating for the hysteresis by designing appropriate control laws. This experiment also showed how useful a rapid prototyping station like the AC-100 station at the ISL is in saving effort and time and at the same time, reducing the errors that could have otherwise crept in without the automation.

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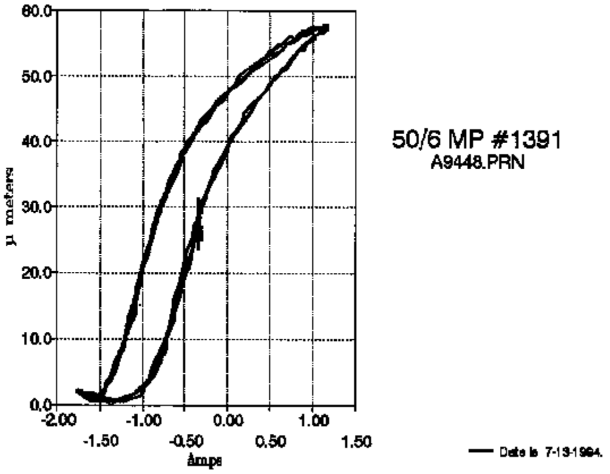
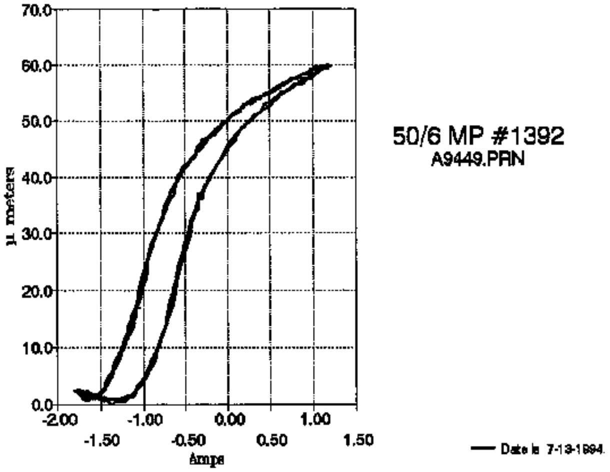


(a) The displacement vs input current curve for actuator 1.



(b) The displacement vs input current curve for actuator 2.

Figure 4: Characteristics of the magnetostrictive actuators.

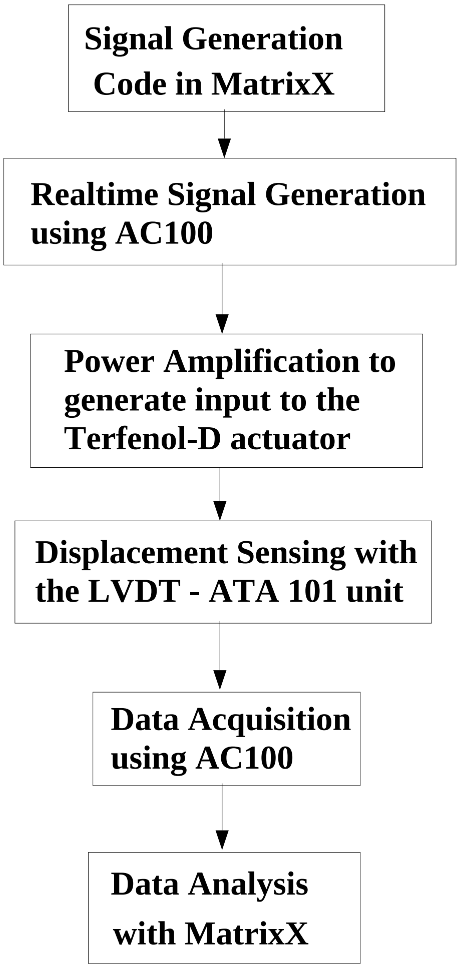


Figure 5: The Experimental Methodology.

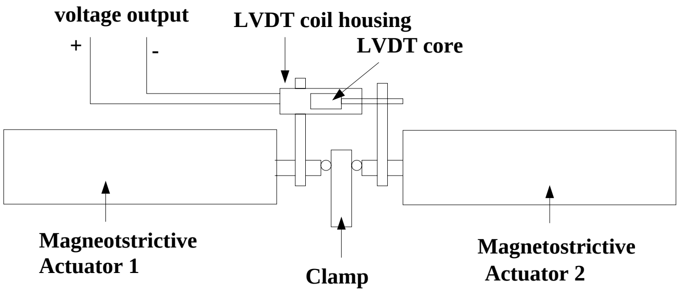


Figure 6: Schematic of the displacement sensing by the LVDT sensor.

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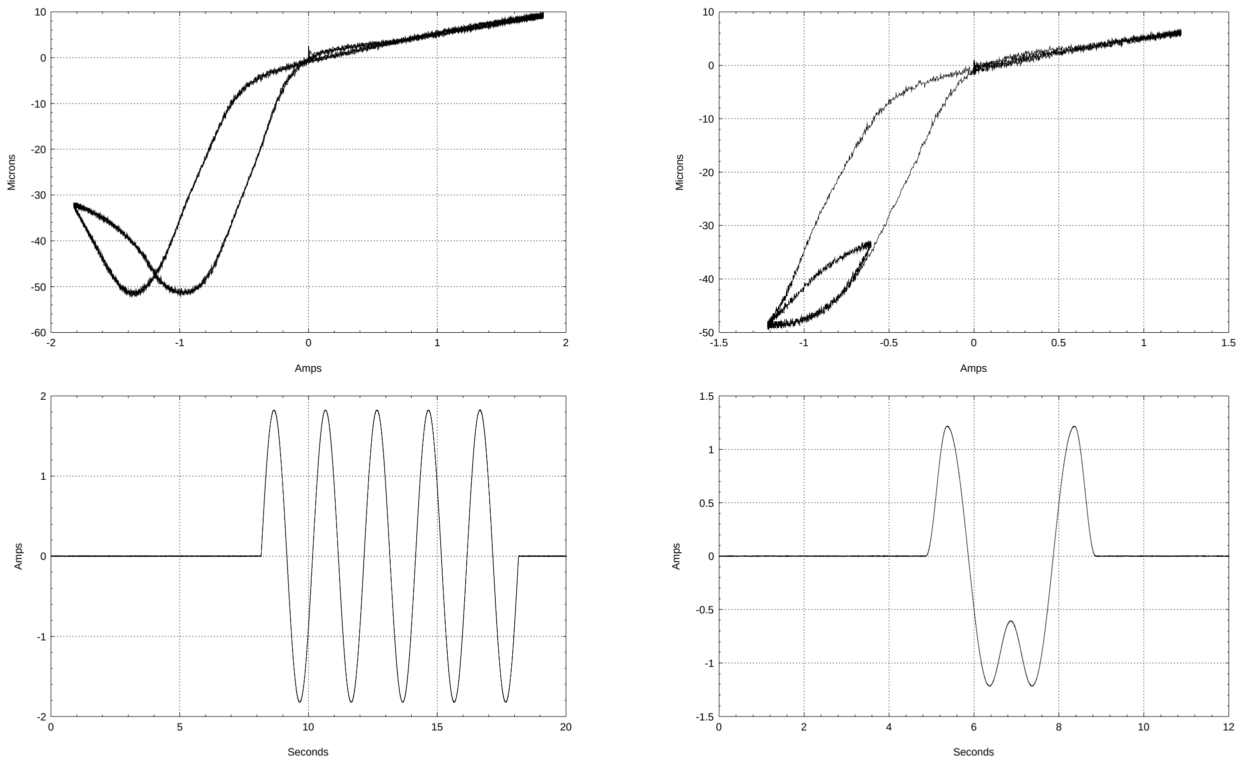

(a) Displacement vs Input Current curve displays hysteresis.

(b) The minor loops close on themselves.

Figure 7: ETREMA MP-6 Actuator Characteristics.

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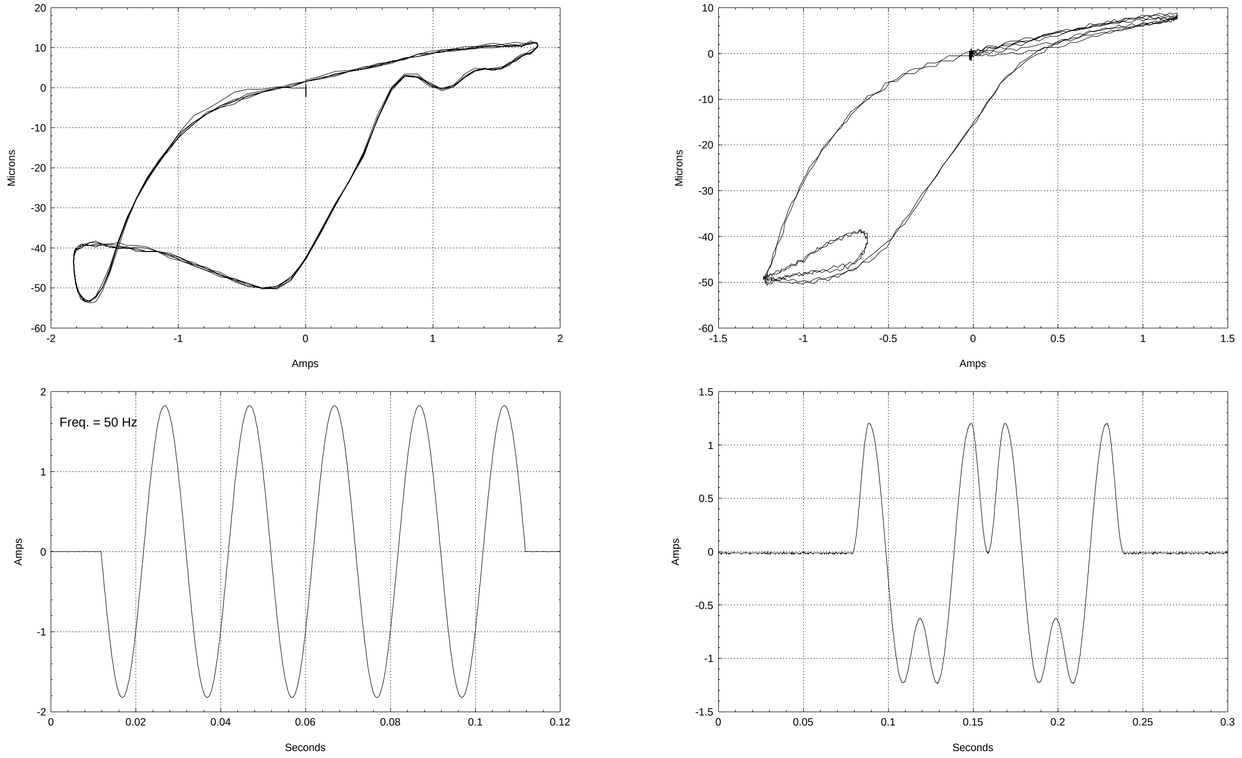

(a) Displacement vs Input Current curve.

(b) Minor loop closure property.

Figure 8: ETREMA MP-6 Actuator High Frequency (50 Hz) Characteristics.

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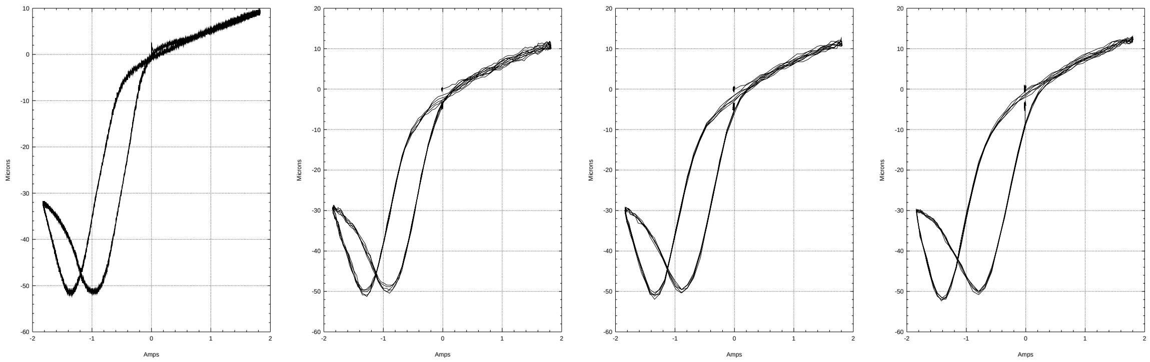
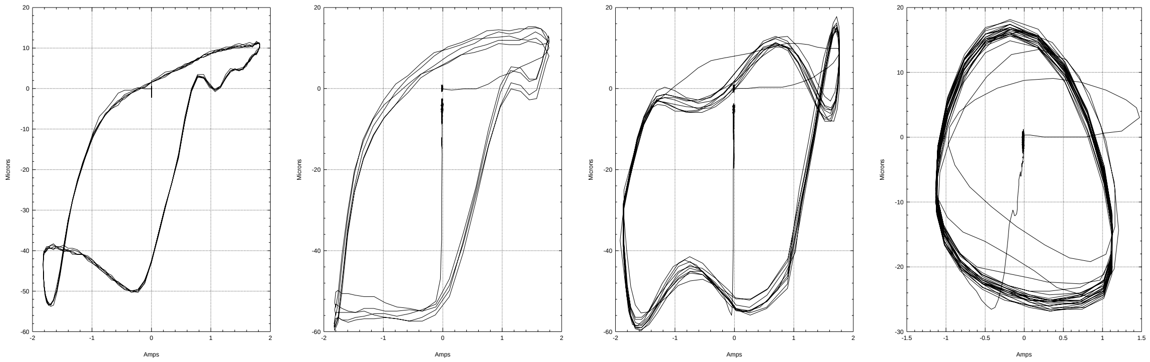


(a) Input frequency = 0.5 Hz.

(b) Input frequency = 1 Hz.

(c) Input frequency = 5 Hz.

(d) Input frequency = 10 Hz.



(e) Input frequency = 50 Hz.

(f) Input frequency = 100 Hz.

(g) Input frequency = 200 Hz.

(h) Input frequency = 500 Hz.

Figure 9: ETREMA MP 50/6 Actuator characteristic at different driving frequencies.

5 REFERENCES

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[2] Lucas Control Systems Products, 1000 Lucas Way, Hampton VA 23666, *ATA-101 Analog Transucer Amplifier and ATC-101 Analog Transducer Controller.*

[3] G. A. Kantor, "Linear control theory as applied to smart structures," Master's thesis, University of Maryland at College Park, 1995.

[4] R. Venkataraman, "A hybrid actuator," Master's thesis, University of Maryland at College Park, May 1995.