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THE MEASUREMENT OF MESO-SCALE TORSION SPRINGS

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Introduction

The characterization of meso-scale torsion springs is important for Sandia National Laboratories (SNL) applications relying on the miniaturization of mechanical mechanisms. Designers continue to push the limits for springs, and are faced with significant uncertainty in the quantification of the static, dynamic and fatigue behavior of small torsion springs. Since commercial systems do not exist that meet the requirements for range, accuracy or dynamic response, work was performed at SNL to develop a measurement system for the characterization of meso-scale torsion springs.

Meso-Scale Torsion Springs

- coil diameters & lengths = 4mm maximum
- wire diameters = 50-500μm
- operational torques = 0.5-2.0mN•m
- initial preloads = 0.5-1.5mN•m
- operational spring rotations = ±10-15°
- cycle rates = 100Hz maximum

FIGURE 1. An Elgiloy meso-scale torsion spring with 0.175mm wire diameter, 3.8mm spring length and 2.5mm coil diameter.

Measurement System Requirements

- torque range = 0.1-10mN•m
- spring rotation = ±15°
- traceable calibration
- in situ, dynamic measurements at 100Hz maximum

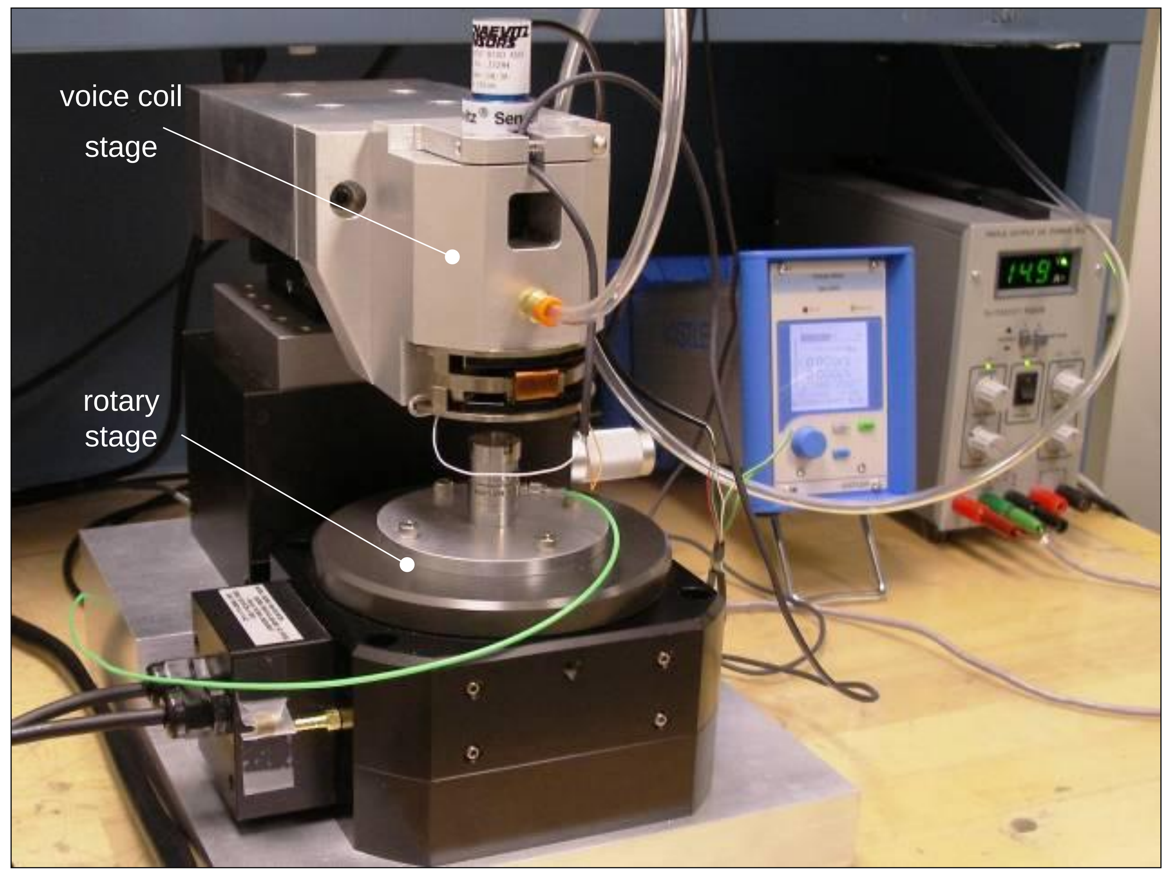

FIGURE 2. The prototype system for the measurement of meso-scale torsion springs.

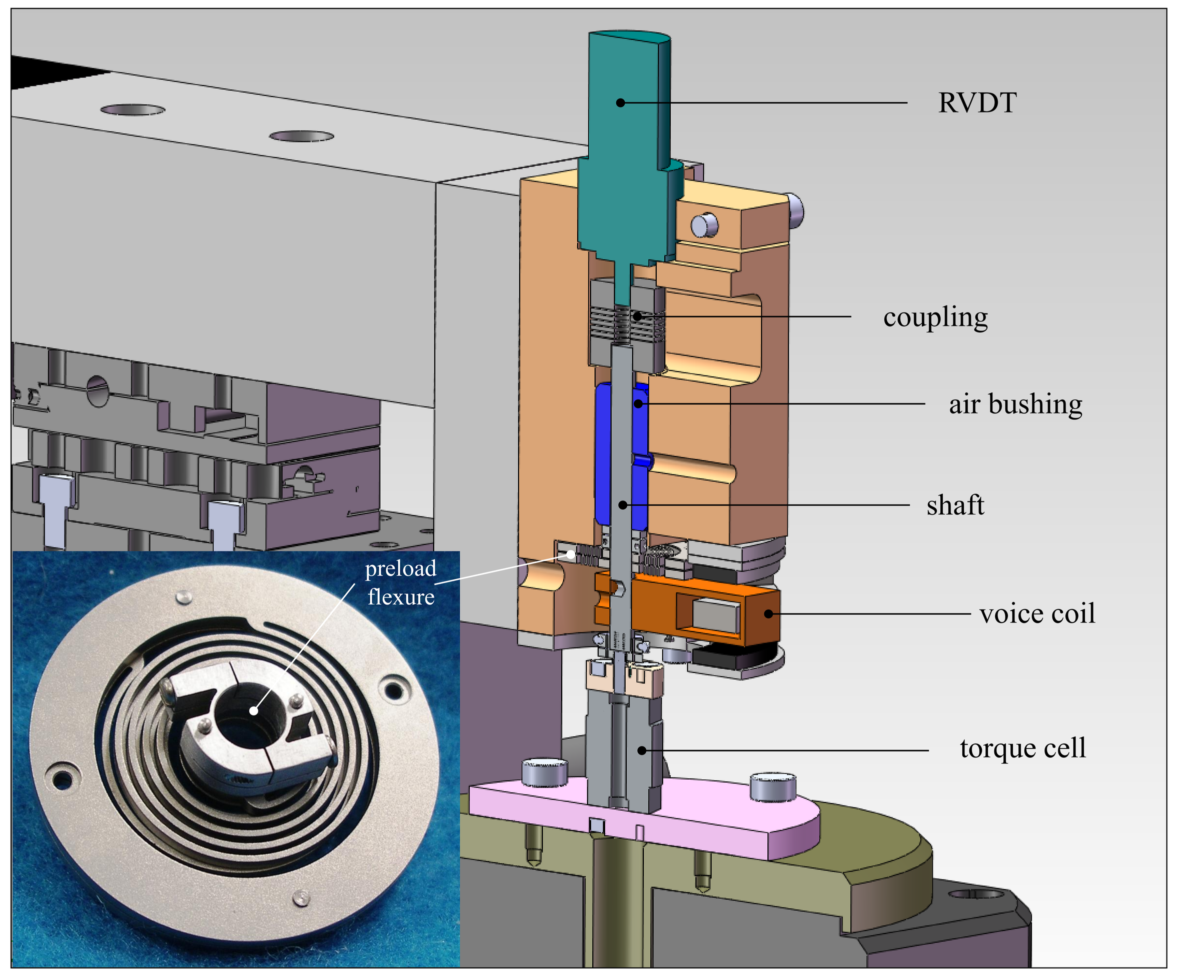

FIGURE 3. A cross-sectional view identifying critical elements of the actuation mechanism.

System Components

Kistler 9329A torque cell with 5015A charge meter

- measurement range = ±1mN•m to ±1N•m, threshold = 0.03mN•m
- charge amplifier drift rate = ±0.03mV/sec

Aerotech ADRS0150 rotary stage

- 360° continuous rotation, resolution = sub-10-âsec
- provides preload rotations

BEI-Kimco RA29-11-002A rotary voice coil

- range = ±16°, peak torque = 226mN•m
- provides high frequency spring motion

0.25in New Way air bushing & shaft

- provides low friction, high stiffness fixed pivot point for the voice coil actuator

Schaevitz R30D rotary variable differential transformer (RVDT)

- linear measurement range = ±30°, 3dB bandwidth = 500Hz

Preload flexure

- combines planar flexures flipped 180° about their central axis & pinned together to provide a symmetrical spring rate
- 20° preloads insure coiling loads for both springs across their ±15° range of motion
- designed for ±15° of rotation at 10Hz open loop (limited by voice coil torque)

Controls

- coordinate motion using the Aerotech NViewMMI interface & LabView
- DAQ uses a NI-BNC-2090 BNC terminal block
- voltage control signals converted to a current signal using a Newtons4th LPA05A wideband current amplifier with 10x gain
- closed loop feedback achieved at 2kHz using PID with modified amplitude control

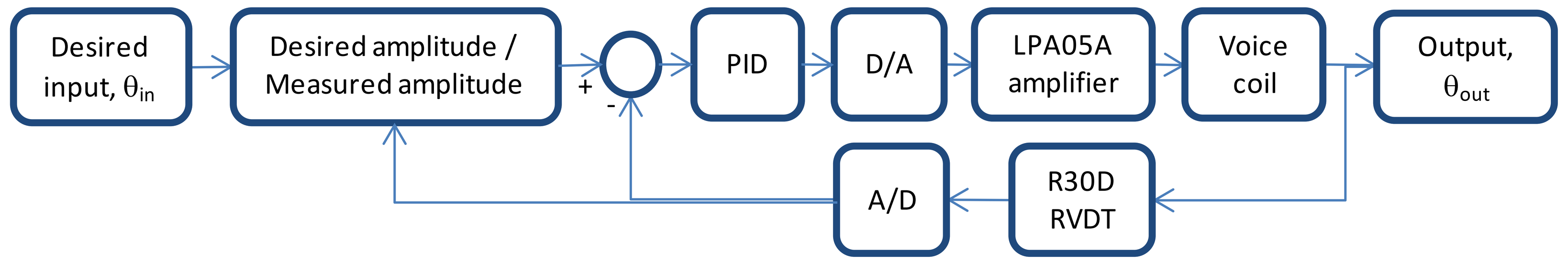

FIGURE 4. Voice coil controller block diagram using amplitude control.

Voice Coil Actuator Testing

Closed loop transfer function

- model fit using a 1 DOF, damped, spring-mass system
- 3dB crossover at 35Hz, 0.75 damping ratio
- best controller response for K_p = 0.07, K_d = 1.0, K_i = 1×10^{-6}

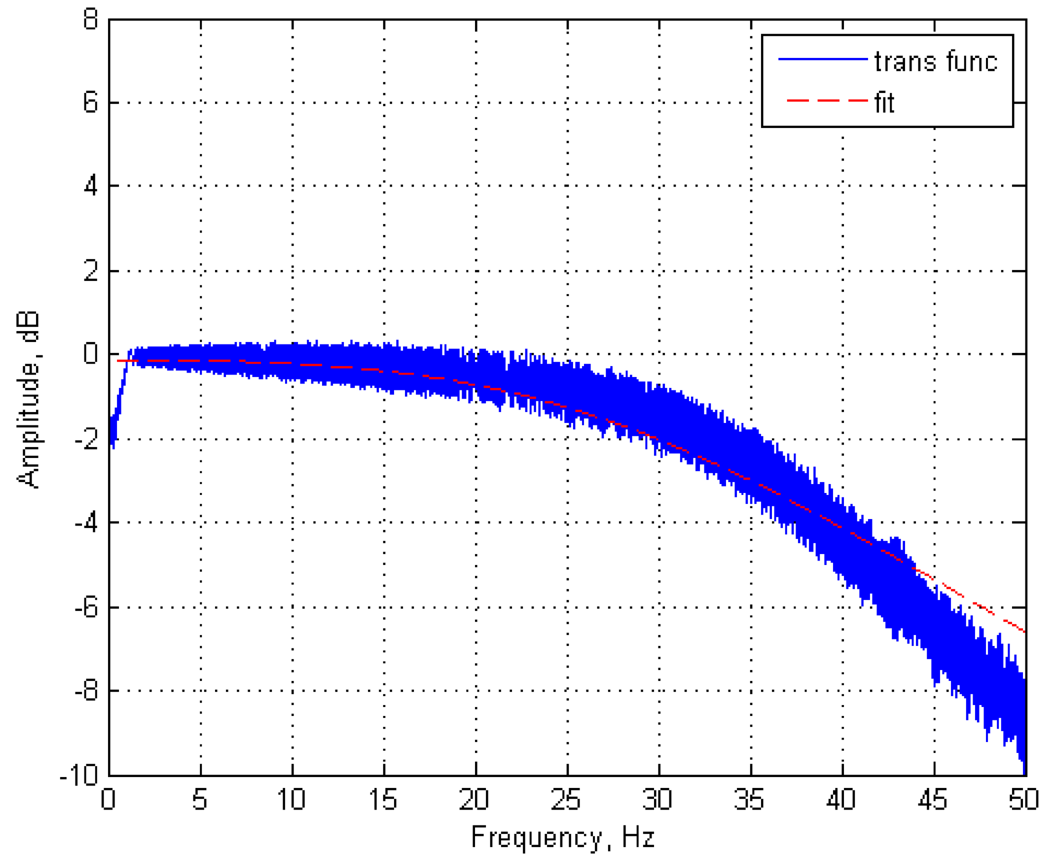

FIGURE 5. Voice coil actuator PID closed loop transfer function.

Voice Coil Actuator Testing

Closed loop response

- step response using a 27° step input
  - overshoot = 1.33°, settling time = 40msec
- sine response using a 30Hz, ±15° sine wave input
  - amplitude error = 0.35°, phase error = 52.3°

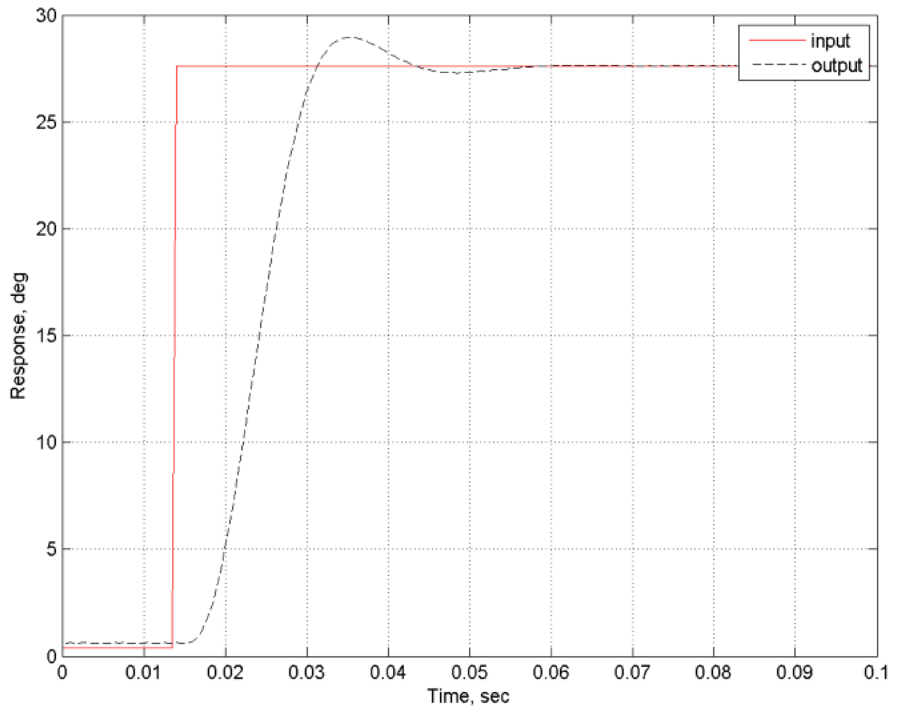

FIGURE 6. Response to a 27° step input.

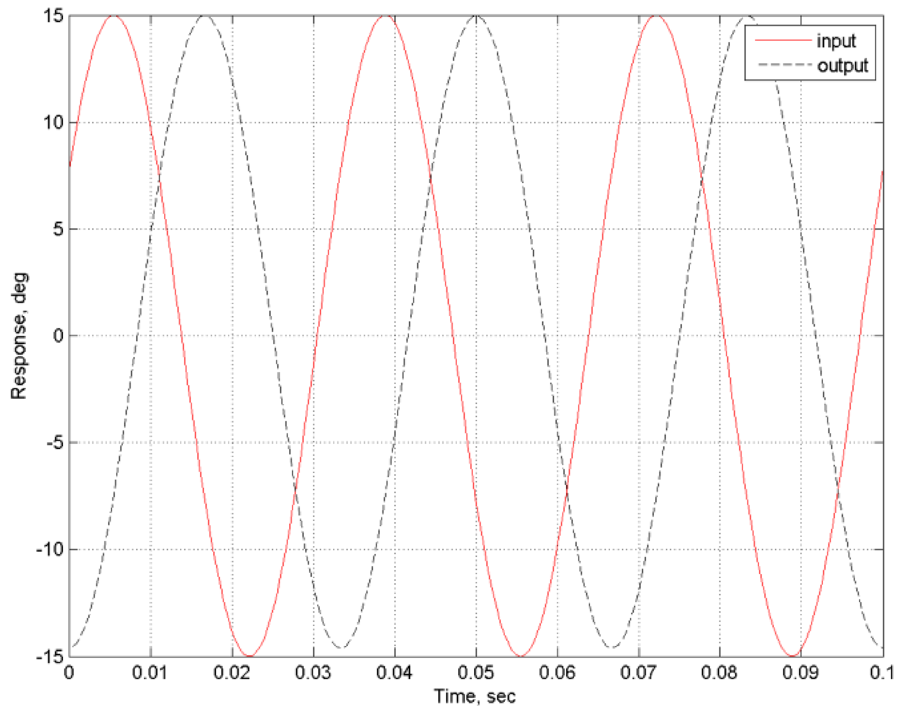

FIGURE 7. Response to a 30Hz, ±15° sine wave input.

Spring Testing

Torque values are within the tolerance range of the tested spring design, an early indication of system success. Initial insight into dynamic spring response has also been achieved as the internal friction between the coil windings has been observed to contribute 5-10% of the torque required to rotate the torsion springs. This internal friction is quantified by the step change that occurs at the extremes of spring travel.

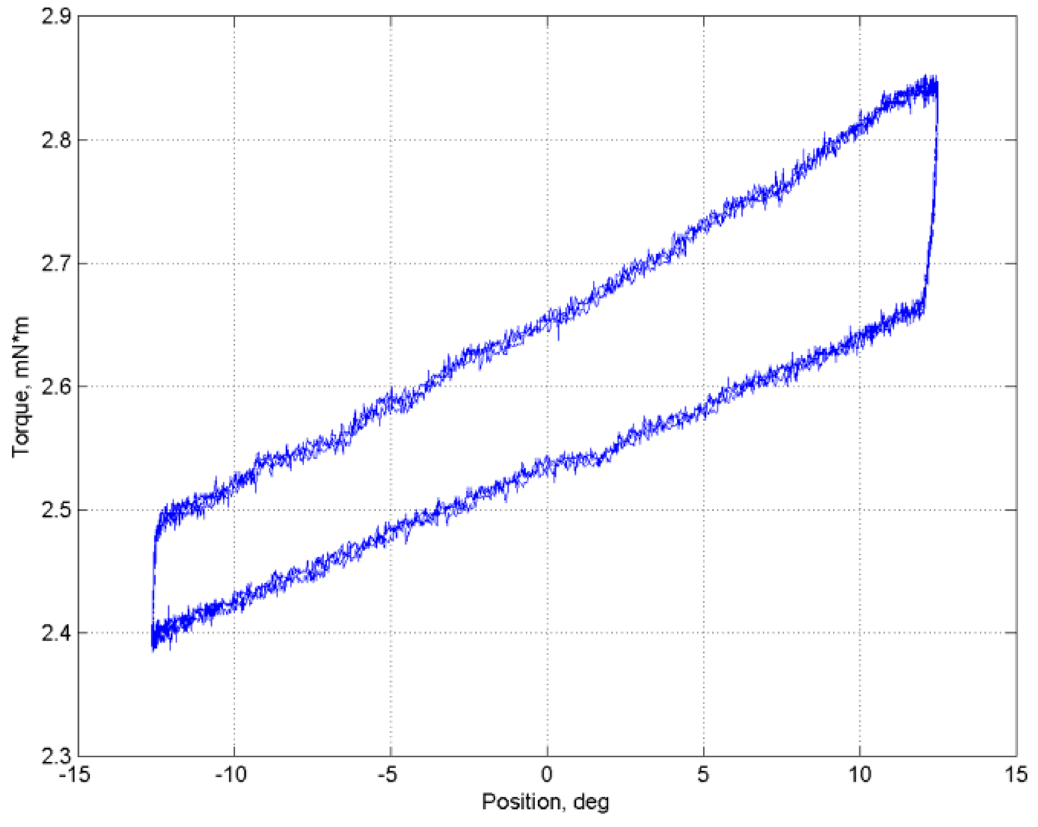

FIGURE 8. Torsion spring data from a 1Hz, ±12.5° sine wave with a 82.5° preload.

Conclusions & Future Work

The development of a prototype system for the dynamic torque testing of meso-scale torsion springs has been summarized. Improvements have been realized using a preload flexure mechanism and an improved closed loop feedback loop. Initial spring data has been collected demonstrating the dynamic response of torsion springs under loading.

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