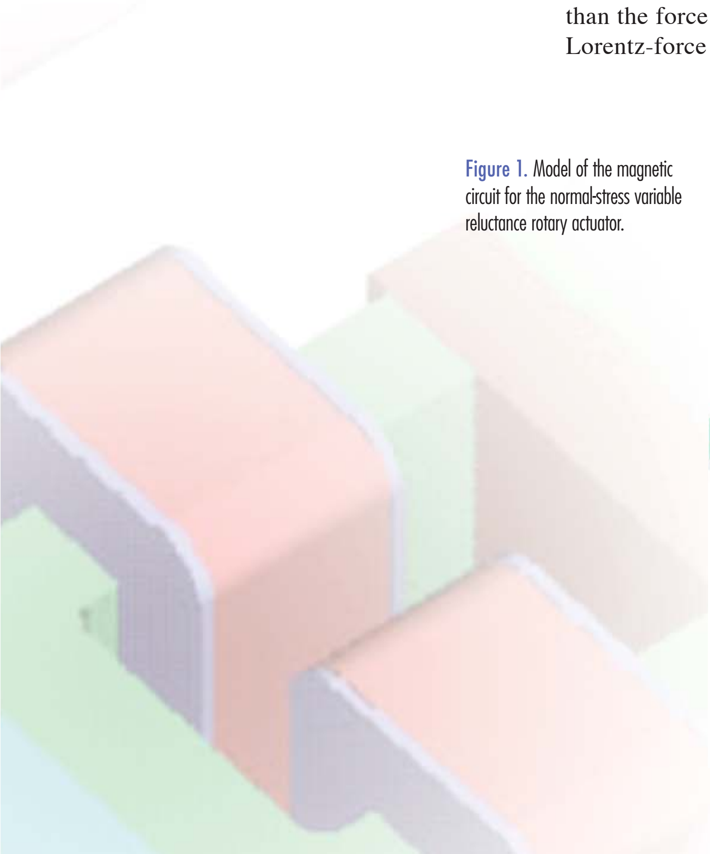
Short-Stroke Rotary Fast Tool Servo for Single-Point Turning High-Energy-Density Physics Targets

For more information contact **Richard C. Montesanti**
(925) 422-7361, montesanti1@llnl.gov

This project developed a 10-kHz rotary fast tool servo (FTS) capable of 10-μm peak-to-peak (PP) motion at low frequencies and 2.5-μm PP motion at 10 kHz (500 g). A FTS provides a diamond-turning machine with a high-speed axis that allows the production of non-axisymmetric or textured surfaces on a workpiece that is rotating on a spindle at relatively high speeds. Our 10-kHz rotary FTS leverages on proof-of-principle from our successful 2-kHz rotary FTS developed during the previous years of this project.

The heart of the 10-kHz FTS is a normal-stress variable reluctance actuator having a flexure-guided rotor with an integral tool holder. The actuator is designed to produce a magnetic force-density an order of magnitude higher than the force density of a typical Lorentz-force actuator or shear-stress variable reluctance actuator. We merged the moving masses of our actuator and the payload into a single moving mass by attaching the tool arm directly to the rotating element of the actuator. This avoids the usual uncoupled-mode resonance of a servo system, and sets a relatively higher frequency non-rigid body mode of the moving mass as the lowest frequency uncontrollable mechanical resonance. Placing the displacement feedback sensor directly behind the tool, and careful design of the support structure, allow hiding certain flexible modes of the system to further improve high-frequency performance. When combined with a high-force-density actuator, the merged mass approach provides the high torque-to-inertia ratio needed for a 500-g tool-tip acceleration. Adjusting well-understood design parameters in future versions will allow achieving 1000 g and beyond.



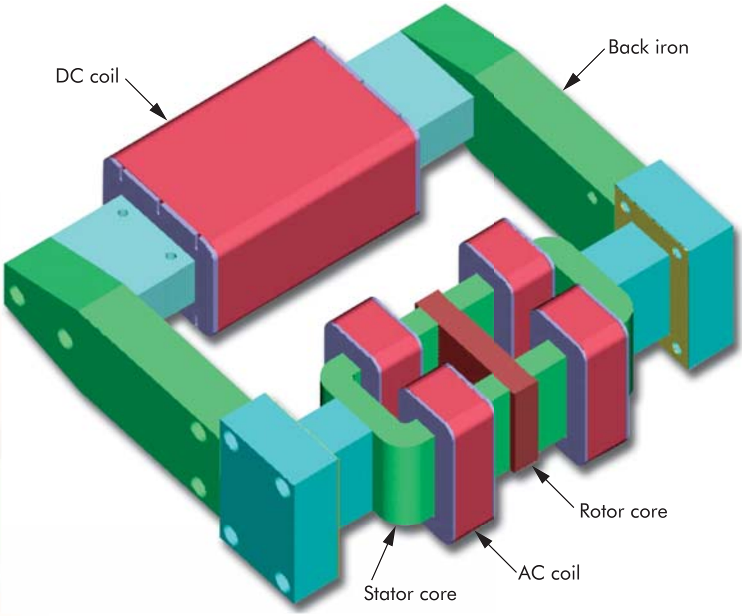


Figure 1. Model of the magnetic circuit for the normal-stress variable reluctance rotary actuator.

Project Goals

The goal of this project is to advance the state of the art in high-speed precision machine tools, specifically, to develop a FTS capable of producing a closed-loop motion of the tool tip at frequencies up to 10 kHz while producing optically smooth surfaces on diamond-turnable materials. Our original goal of a 5-μm PP stroke at 10 kHz (1000 g) was reduced to 2.5 μm PP (500 g) during a trade-off decision to have a more mechanically robust system with a higher likelihood of surviving anticipated tests for this prototype.

Relevance to LLNL Mission

High-energy-density experiments play an important role in corroborating the improved physics codes that underlie LLNL's stockpile stewardship mission. New and anticipated experiments to be conducted at NIF require extending LLNL's current capability for fabricating prescribed textured surfaces on a variety of diamond-turnable materials. 10-kHz bandwidth is an order of magnitude higher than commercially available FTS's and will enable reasonable production rates of the desired target surfaces and accommodate the surface cutting speed requirements of certain plastic target components.

FY2004 Accomplishments and Results

We developed software tools based on first-principle physics and closed-form engineering equations and used them to design and optimize the highly integrated mechanical-magnetic-electrical systems for the actuator and its payload. We completed and documented the detailed mechanical and electrical designs for the system, and procured all of the components. We presented two conference papers, and filed the second of two patent applications. As this work progresses, we will assemble the mechanical, magnetic, and electrical hardware; develop and integrate the control system; characterize the FTS performance with bench tests; and integrate the FTS with a diamond-turning machine to perform cutting tests on a workpiece.

Figure 1 shows a model of the magnetic circuit for this actuator. The rotor core is a rectangular prism suspended between two opposing C-shaped stator cores with nominal air gaps of 50 μm at the four pole faces.

Figure 2 shows a model of the rotor mounted to one of the stator housings via the outer ends of four of the eight flexures. Figure 3 shows a built-up model of the fully assembled 10-kHz rotary FTS.

Related References

1. Montesanti, R. C., and D. L. Trumper, "High Bandwidth Short Stroke Rotary Fast Tool Servo," *Proceedings of the American Society for Precision Engineering Meeting*, **30**, pp. 115-118, 2003.

2. Montesanti, R. C., and D. L. Trumper, "Design and Implementation of the Control System for a 2 kHz Rotary Fast Tool Servo," *Proceedings of the American Society for Precision Engineering Spring Topical Meeting on Control of Precision Systems*, pp. 28-33, April 2004.

3. Montesanti, R. C., and D. L. Trumper, "A 10 kHz Short-Stroke Rotary Fast Tool Servo," *Proceedings of the American Society for Precision Engineering 2004 Annual Meeting*, **34**, pp. 44-47, 2004.

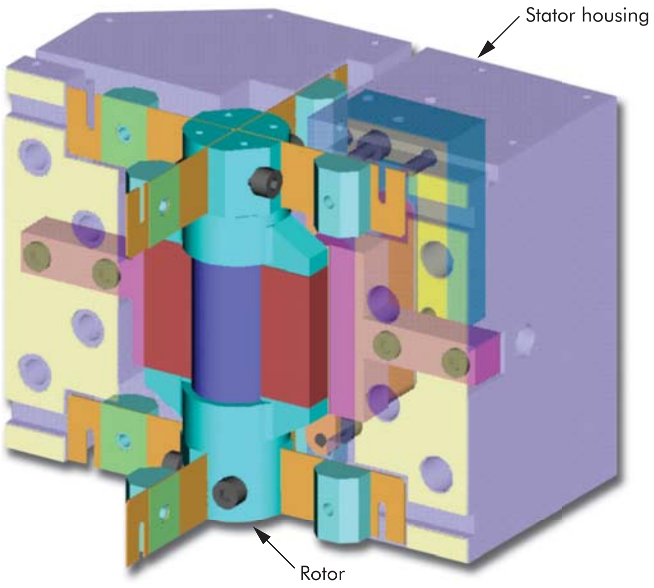


Figure 2. Model of the rotor mounted to one of two stator halves with flexures.

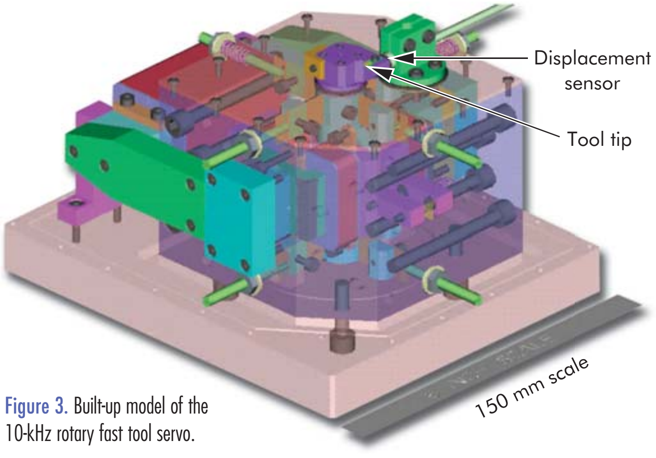


Figure 3. Built-up model of the 10-kHz rotary fast tool servo.