U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Office Of Nuclear Energy
Sensors and Instrumentation
Annual Review Meeting

Embedded I&C for Extreme Environments

Roger Kisner
Oak Ridge National Laboratory
NEET Program

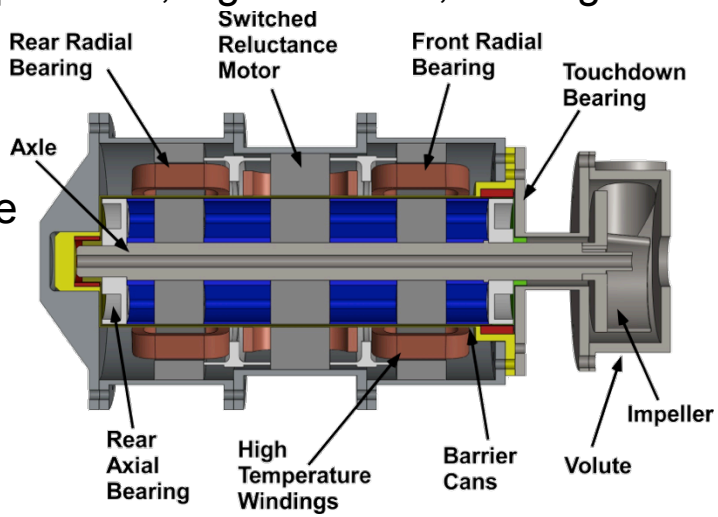
October 28-29, 2015

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Project Overview

Goal, and Objectives

- Demonstrate performance gains possible using embedded I&C in extreme environments — high temperature, radiation, high pressure, high vibration, and high EMF conditions
- Demonstrate a magnetically suspended canned-rotor motor using functional embedding
- Affect nuclear power industry's ability to make more reliable, efficient, & less costly components



Participants

- R. Kisner
- A. Melin
- A. Drira
- D. Fugate
- C. Johnson
- D. Holcomb

Key Milestones & Deliverables	
FY 2015	•Bench-scale testbed designed and built •Stable feedback control of bench-scale active magnetic bearings achieved
FY 2016	•Loop-scale component design finalized •Loop-scale component manufactured & assembled
FY 2017	•Component with embedded I&C integrated into loop •Testing/evaluation of performance enhancements and fault tolerance complete

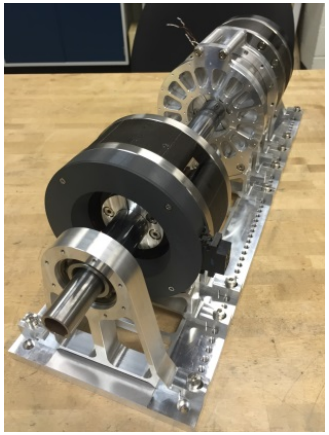
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

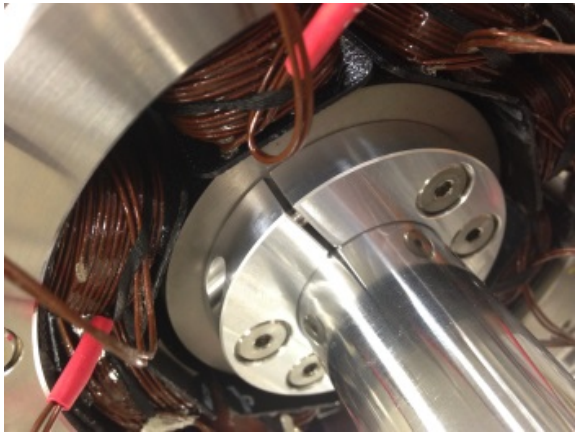
- **Construction of electromechanical test bed for magnetic bearing demonstration**

Results: Finished bench-scale testbed for magnetic bearings and motor drive. This design based on work performed in FY2012 and FY2014, which included conceptual design, failure-modes and effects analysis, modeling, and simulation.

Accomplishments: The bench-scale test bed gives a work platform for the remaining tasks for fabricating a working motor/pump. Sensors and control hardware and software are installed on the test bed. Real-time control system has been tested. Stable control has been achieved.



Test Bed



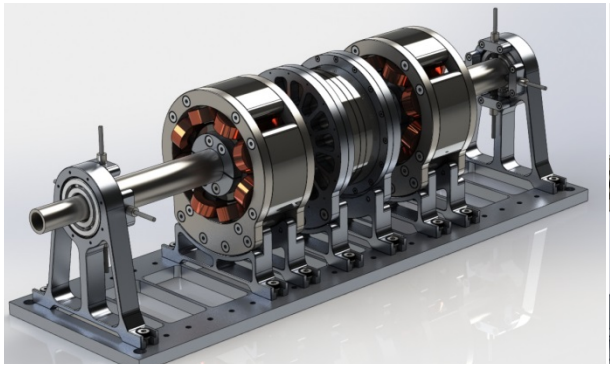
Suspension Bearing

Thrust Bearing

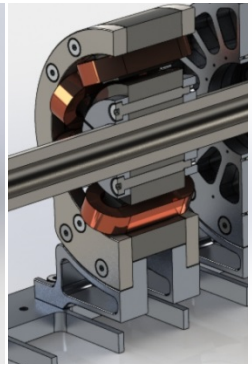
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

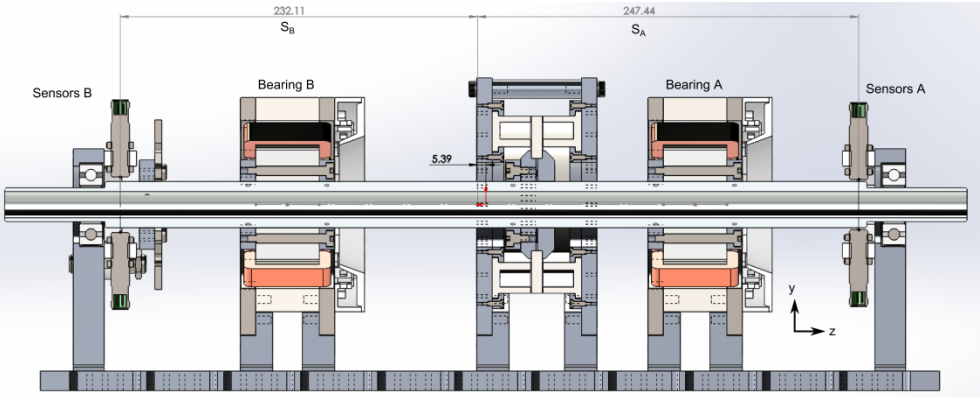
- **Mechanical, magnetic, and control design was accomplished using the modeling, simulation, and visualization capabilities of MATLAB and SOLIDWORKS**



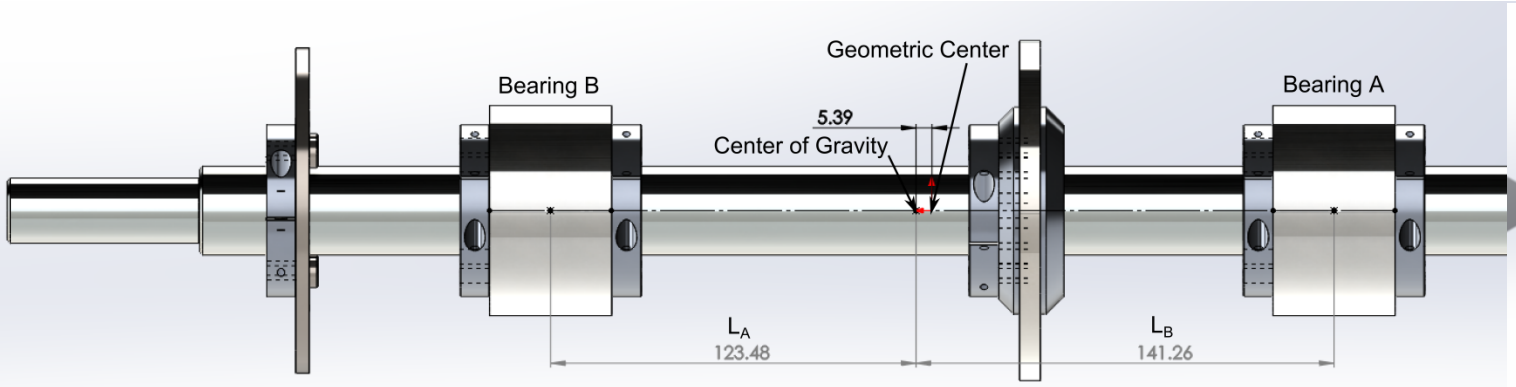
Test Stand Rendering



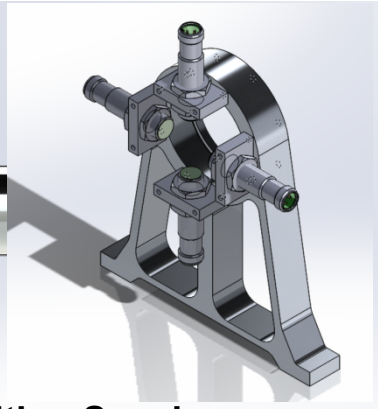
Bearing Cutaway



Side View Cutaway



Shaft Side View

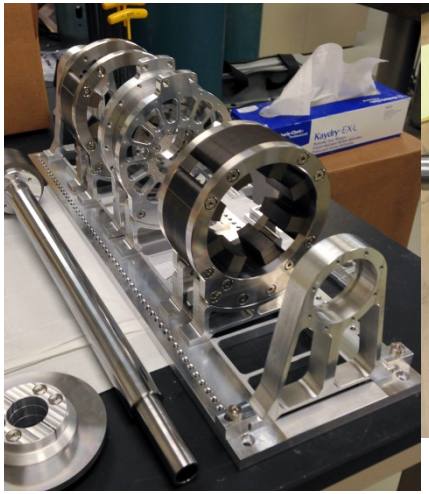


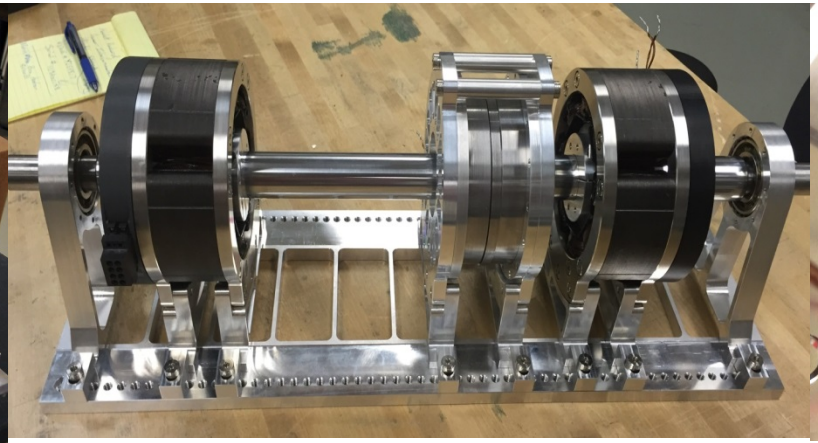
Position Sensing

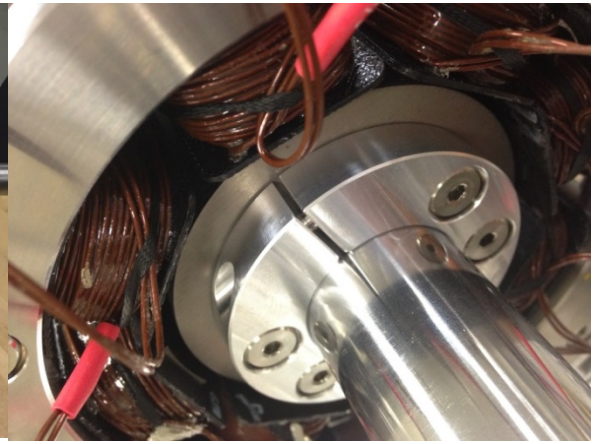
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

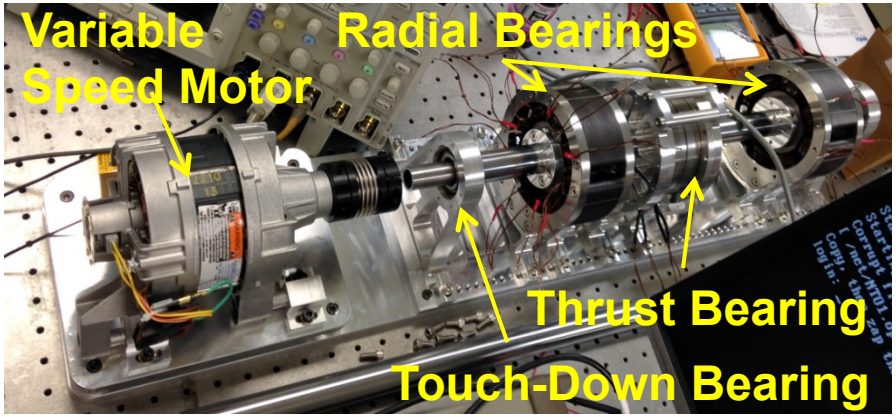
Accomplishments

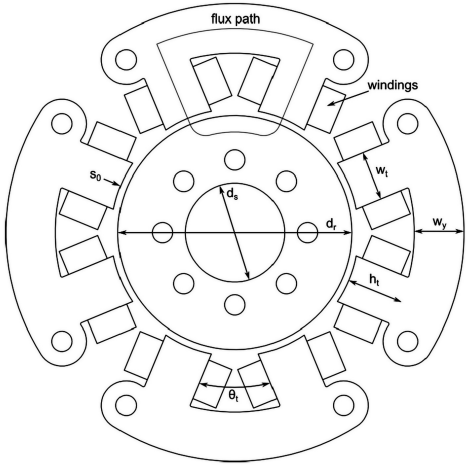
- The test bed has become a physical reality









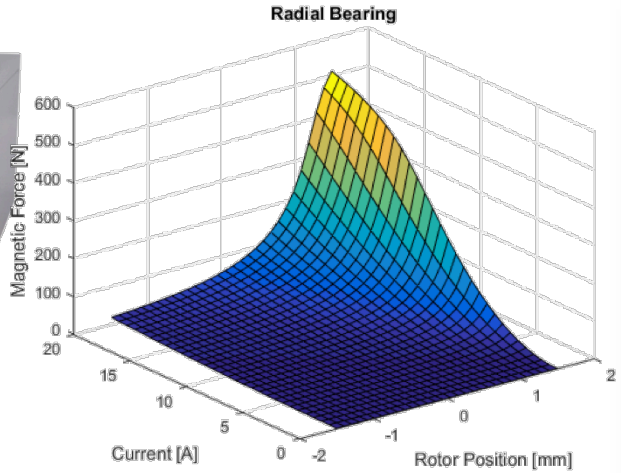


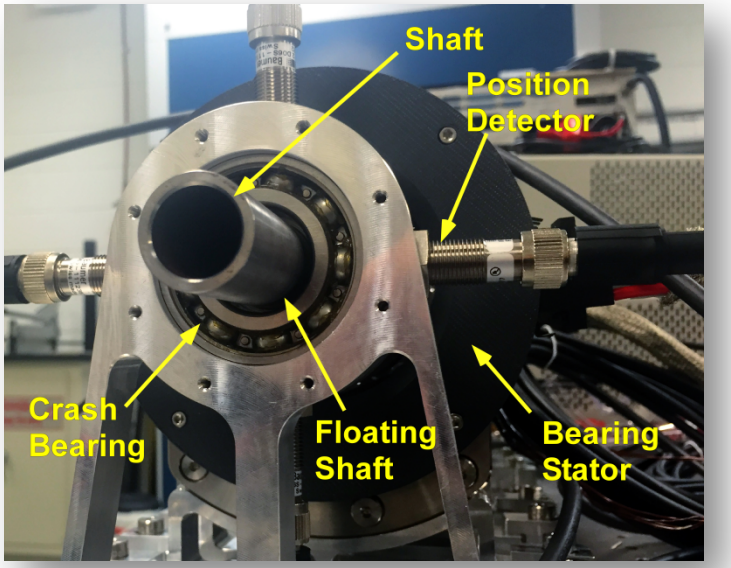
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

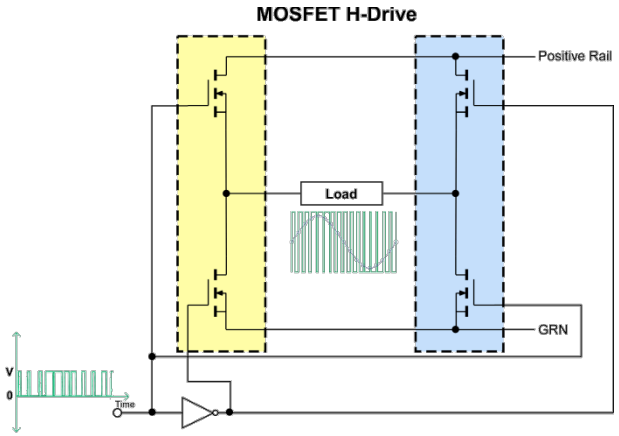
Accomplishments

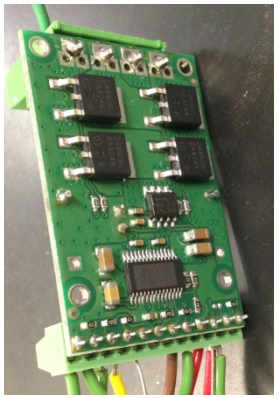
- The team achieved stable suspension of axial rotor in active magnetic bearing stator housing

Speedgoat Real-Time Controller









X, Y: 24VDC, 80A ea.
Z: 24VDC, 31A

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

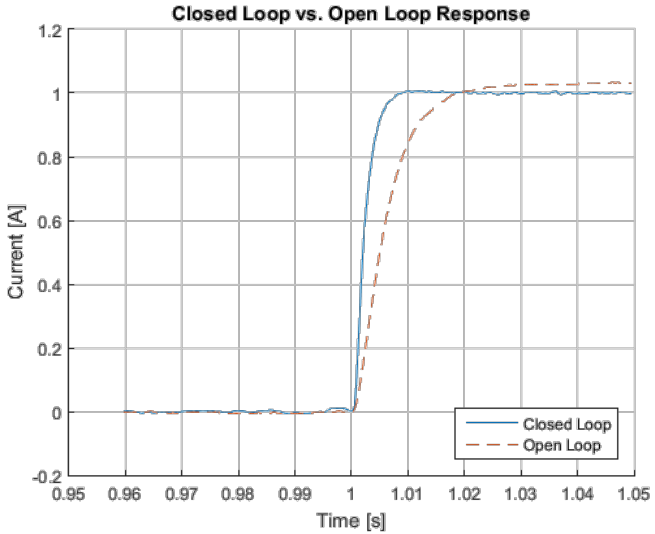
Accomplishments

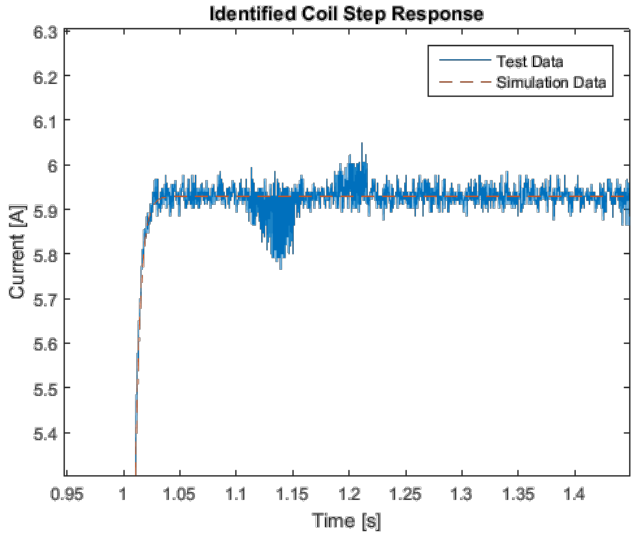
Report delivered

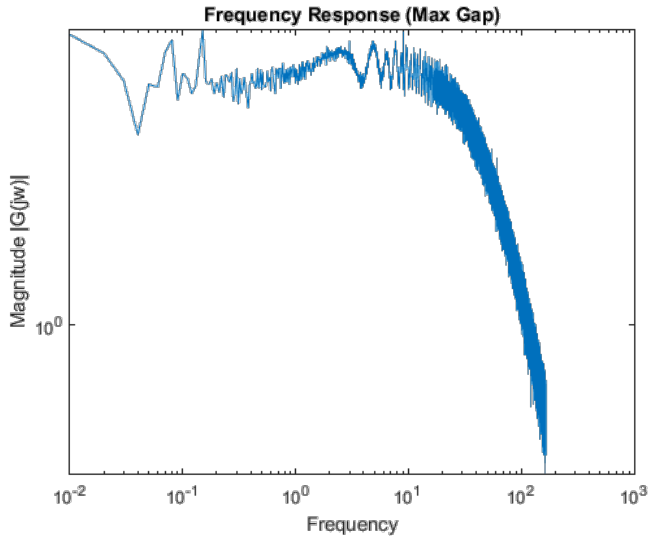
Embedded Sensors and Controls to Improve Component Performance and Reliability – Bench-scale Testbed Design Report, ORNL/TM-2015/584

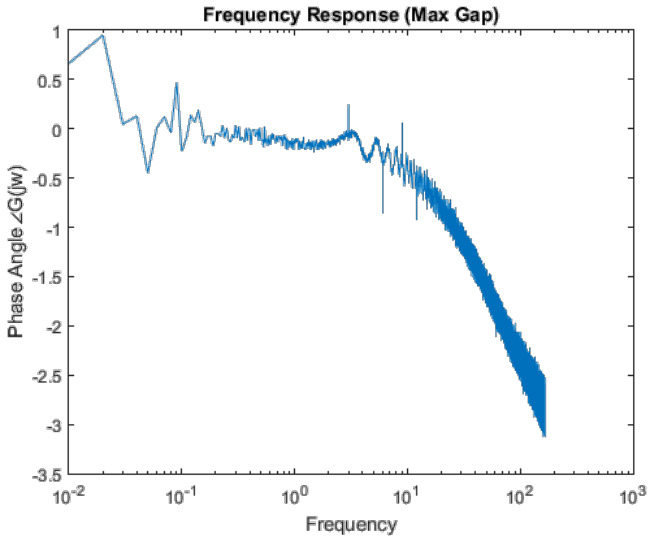
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments





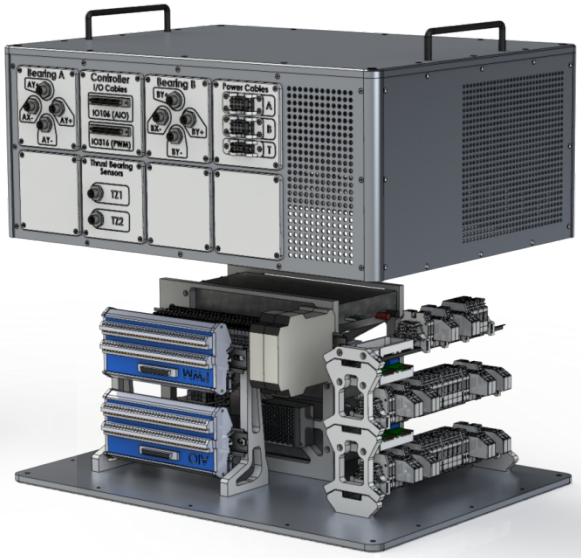




U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Next

- **Next immediate steps are concentrate on the electronics**
  - Enclose the system



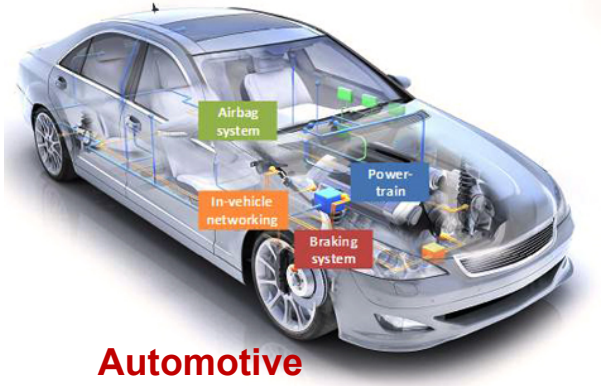
- **System Identification**
- **Compare different control strategies (PID, LQG, Nonlinear,…)**
- **We want to explore position measurement without separate sensor**

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Technology Impact

- **Sensors and controls have not typically been embedded in nuclear power reactor components (compared with other industries)**
  - Aircraft
  - Industrial
  - *Transportation*
  - *Electric Power*
- **Modern jet engines have experienced a 1000X reliability improvement with embedded I&C**
- **Existing nuclear system components have limitations for new reactor concepts related to size, mass, temperature …**
- **This technology is crosscutting**


Locomotive AC Traction Motors



Automotive


Delta Wing Aircraft

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Technology Impact

- Successful completion of this project will yield cross-cutting sensor and control technologies for nuclear power reactors
- The embedding of sensors and control always involves multi-disciplinary design integration techniques
- The loop-scale embedded I&C testbed and demonstration platform is an excellent resource for future research into embedded instrumentation and control technologies for extreme environments
- Performance testing at bench-scale and small loop-scale will yield quantifiable measures of the performance improvements due to embedded I&C
- Future projects can extend this work to high temperature demonstration systems and eventually to full-scale systems

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Conclusion

- The project is demonstrating the performance, reliability, and cost benefits of embedded I&C on a relevant prototypic reactor component – a high-temperature coolant pump
- Technical benefits of embedded systems are improvements in reliability, potentially less challenges to safety, and operating life extension of crucial components
- Programmatic benefit of embedded systems is lower cost components
- A demonstration of embedding serves to draw attention to the need for the new technical approach