Molten Salt Pump Progress at ORNL

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MSR Workshop 2022

Oak Ridge National Laboratory

October 11-12, 2022

Pumps are the heart of the system

- Impact system reliability and safety
- Needed now for MSR technology demonstrations and risk reduction
- Challenges
  - Accommodating thermal expansion, mounting methods
  - Radiation effects on motors
  - Hermeticity & seals
  - Flow assisted corrosion, erosion, cavitation?
  - Thermal management – thermal stresses, creep, & creep-fatigue
  - Maintenance
  - Double duty? – sampling, free surface, stripping/degassing
  - Supply chain
- Scaling of solutions to larger pumps

Molten Salt Pump Experience:
Historic Expansive Effort

- Many pumps were required to support historic MSR technology development
  - More than 10 designs with over 96 years operation time
  - All short-shafted (no salt-wetted bearings) except one long-shafted prototype
- Largely successful, with some challenges
  - Shaft seals – hermicity and oil
  - Shaft bearings (non-salt wetted) – leakage from housings
  - Clearances – accounting for heating cycle and creep
  - Aerosols and entrainment
  - Accommodating radiation
  - Most were small: LFB was a research workhorse (approx. 1.1 m^3/h @ 28 m head (4.8 gpm @ 92 ft))
    PKP was largest (approx. 340 m^3/h @ 120 m head (1500 gpm @ 380 ft))

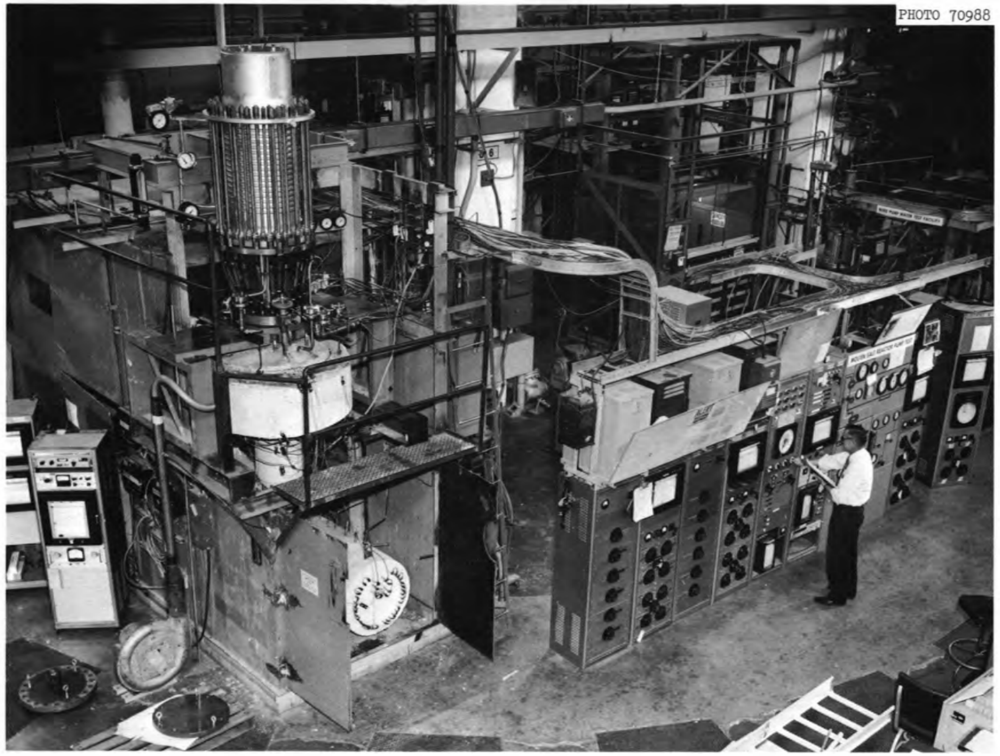

Fig. 4. Photograph of Molten-Salt Pump Test Stand.

Smith, P G. DEVELOPMENT OF FUEL- AND COOLANT-SALT CENTRIFUGAL PUMPS FOR THE MOLTEN-SALT REACTOR EXPERIMENT. U.S.: **ORNL-TM-2987**, 1970. doi:10.2172/4106980.

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K. R. Robb, P. K. Jain, T. J. Hazelwood, "High-Temperature Salt Pump Review and Guidelines – Phase I Report," **ORNL/TM-2016/199**, May 2016.

Seeing Progress:
LSTL → FASTR

- Liquid salt test loop (LSTL) pump effort started ~2010
  - Limited commercial interest in molten salt pumps
  - Collaborated with Wenesco on volute, impeller, and shaft
  - Designed remainder of pump in-house with custom fab.
- Non-contacting gas-lubricated shaft seal
  - Scalable to much larger sizes (power)
  - No oil lubricant/coolant needed
  - Minimal heat generation
  - Designed with small gas consumption
- FLiBe-Tritium loop pump ~2018, limited commercial interest
  - Small scale of pump, custom material choice
- FASTR salt loop pump effort started ~2019
  - Competitive sourced from Nagle Pumps, Inc.

LSTL Pump

>35 GPM, 20 ft
alloy 600

FASTR Pump

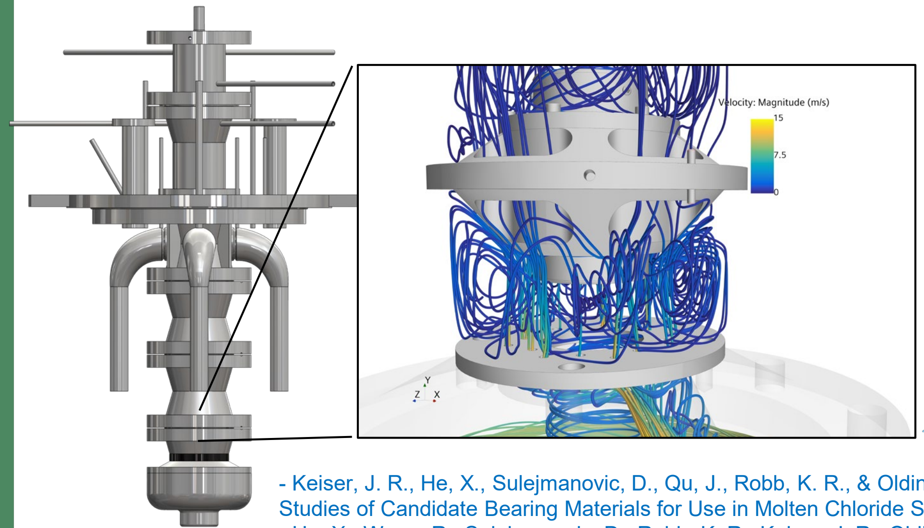
>70 GPM, 29 ft
alloy C-276

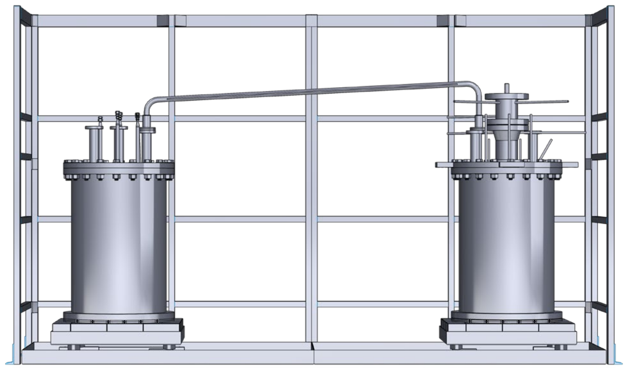
- Aaron, A. M., Cunningham, R. B., Fugate, D. L., Holcomb, D. E., Kisner, R. A., Peretz, F. J., ... & Yoder Jr, G. L. (2015). High temperature fluoride salt test loop, **ORNL/TM-2012/430**, Oak Ridge National Lab., Oak Ridge, TN USA.
- Rader, J. D., Felde, D. K., McFarlane, J., Greenwood, M. S., Qualls, A. L., & Calderoni, P. (2017). Tritium Management Loop Design Status, **ORNL/TM-2017/511**, Oak Ridge National Lab., Oak Ridge, TN USA.
- Robb, K. R., Mulligan, P. L., Yoder Jr, G. L., Smith, K., & Massengale, J. (2019). Facility to Alleviate Salt Technology Risks (FASTR): Preliminary Design Report with Failure Modes and Effects Analysis, **ORNL/TM-2019/1370**, Oak Ridge National Lab., Oak Ridge, TN USA.

LSTL & FLiBe Sponsored by DOE-NE ART
FASTR Sponsored by DOE-EERE SETO

Innovative Components:
Salt-Wetted Bearings

- Most all previous and current pumps are “short shafted”, do not require salt-contacted bearings
- Larger pumps and/or higher head pumps may require salt-wetted bearings (e.g. solar)
- No demonstrated salt-wetted bearings exist
- Methodical approach to material selection, corrosion tests, tribological bench tests, full scale bearing tests





Candidate Selection
18 Materials

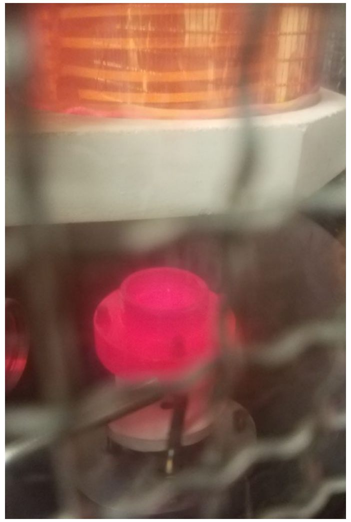
Corrosion Test Static Capsules
10 Materials

Tribology Bench Test
5 Materials, 7 Pairs

Tribology Test with Particulate Added
2 Material Pairs

Full-Scale Bearing Test
1 Material Pair

Capsules, 750°C 500 h



Pin-on-disc test 750°C in Salt

In Collaboration With
Hayward Tyler

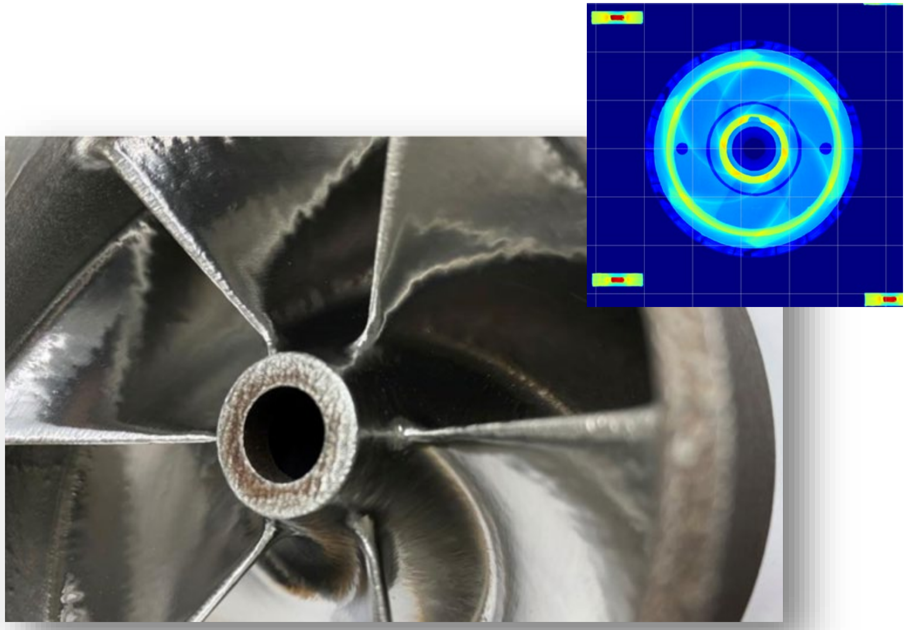
- Keiser, J. R., He, X., Sulejmanovic, D., Qu, J., Robb, K. R., & Oldinski, K. (2022). Material Selection and Corrosion Studies of Candidate Bearing Materials for Use in Molten Chloride Salt. *Journal of Solar Energy Engineering*, *145*(2), 021001.
- He, X., Wang, R., Sulejmanovic, D., Robb, K. R., Keiser, J. R., Oldinski, K., & Qu, J. (2021). Tribological behavior of ceramic-alloy bearing contacts in molten salt lubrication for concentrating solar power. *Solar Energy Materials and Solar Cells*, *225*, 111065.
- He, X., Robb, K. R., Sulejmanovic, D., Keiser, J. R., & Qu, J. (2021). Effects of particle size and concentration of magnesium oxide on the lubricating performance of a chloride molten salt for concentrating solar power. *ACS Sustainable Chemistry & Engineering*, *9*(14), 4941-4947.

Sponsored by DOE-EERE SETO

Innovative Components:
Additive Manufacturing

- Example application: Impeller
  - Designed and created impeller in collaboration with Kairos Power and Manufacturing Demonstration Facility
  - Lower weight designs, less kinetic/stored energy
  - Less material loss/finish machining

- Opportunity for thermal management
  - Integral cooling channels
  - Imbedded I&C
  - Complex geometries, e.g. flow diodes



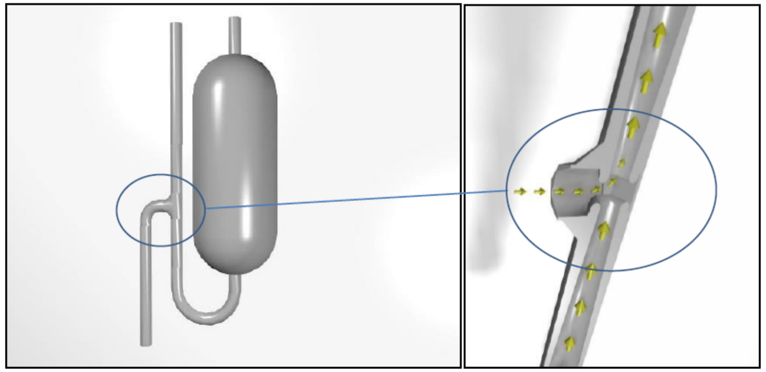
In Collaboration With
Kairos Power

https://www.energy.gov/ne/articles/national-lab-3d-prints-key-component-kairos-powers-new-molten-salt-reactor

Supported by DOE-NE TCR

Innovative Approaches:
Pumping with Power Fluidics™

- Investigated potential applications of Power Fluidics™ for molten salt applications
  - The technology uses pneumatics and the venturi effect to drive flow instead of traditional pump impeller
  - Currently used in waste tanks with aggressive chemical and radiological environments
- Several advantages: no salt wetted moving hardware (impeller, valves, bearings), limited maintenance, electronics/controls located far away from fluid, inherent metering of flow
- Several salt applications identified: primary/secondary sides, salt sampling, fuel salt additions/removal, passive DRACS augmentation with stored pressure, irradiation test loops, and more



Example configuration

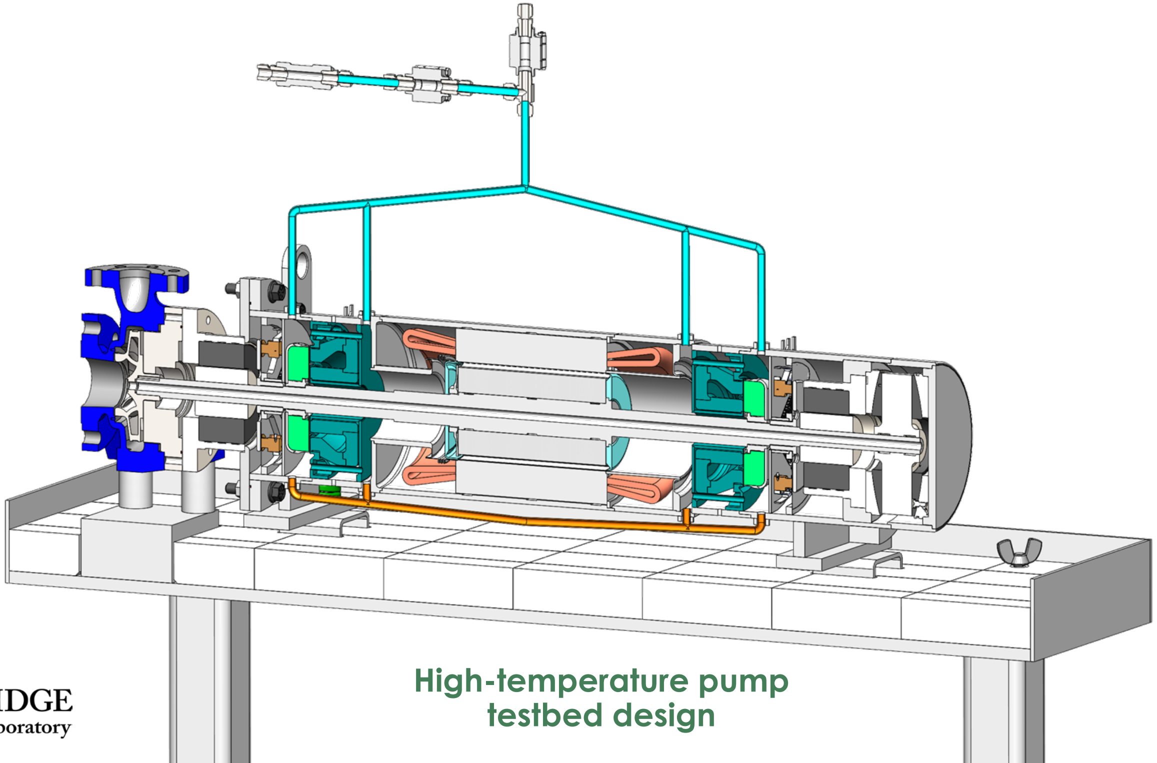
In Collaboration With
NuVision Engineering

K. Robb, D. Holcomb, "Evaluation of Power Fluidic Pumping Technology for Molten Salt Reactor Applications," **ORNL/TM-2020/1551**, June 2020.

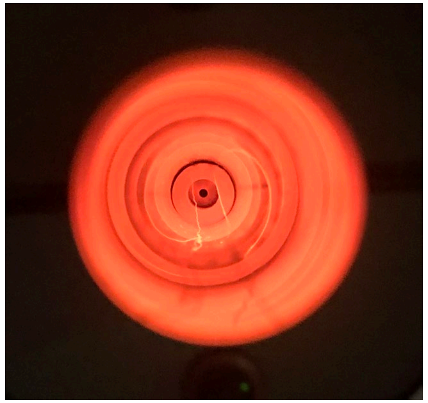
Sponsored by DOE-NE GAIN

Innovative Approaches:
High Temperature Magnetically Levitated Pump

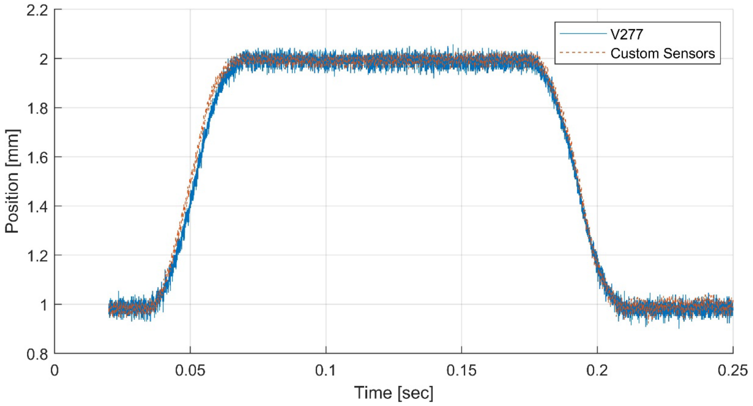
- Magnetically levitated shaft, eliminates rotating seals and mechanical bearings
  - Advanced feedback control system levitates shaft
  - Developed position sensor that operates at 700 °C and senses through 1 mm thick metallic barrier
- Designed for 700°C operation



High-temperature pump testbed design



Position sensor response at 800°C compared to low-temp. commercial sensor (V277)



In Collaboration With
Univ. of Tenn. and Hayward Tyler

Sponsored by ARPA-E

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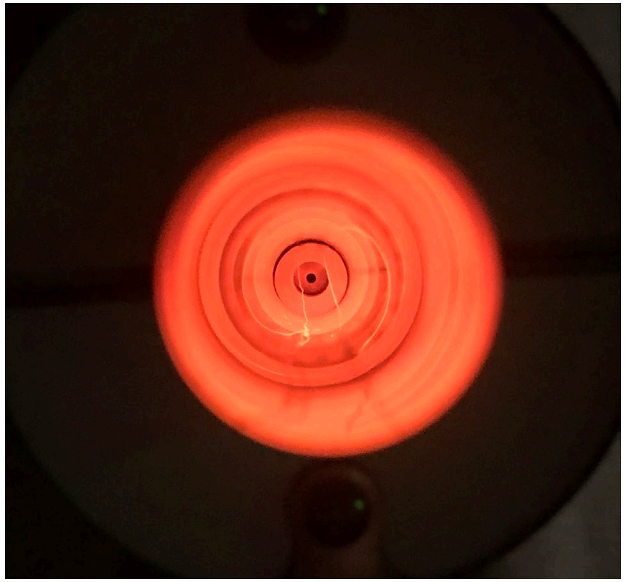
Acknowledgements

- Support for this work includes several programs and offices including: DOE-NE (GAIN, ART), DOE-EERE (SETO), and ARPA-E (MEITNER)
- These projects were executed by a large team of researchers, support staff, and collaborators.

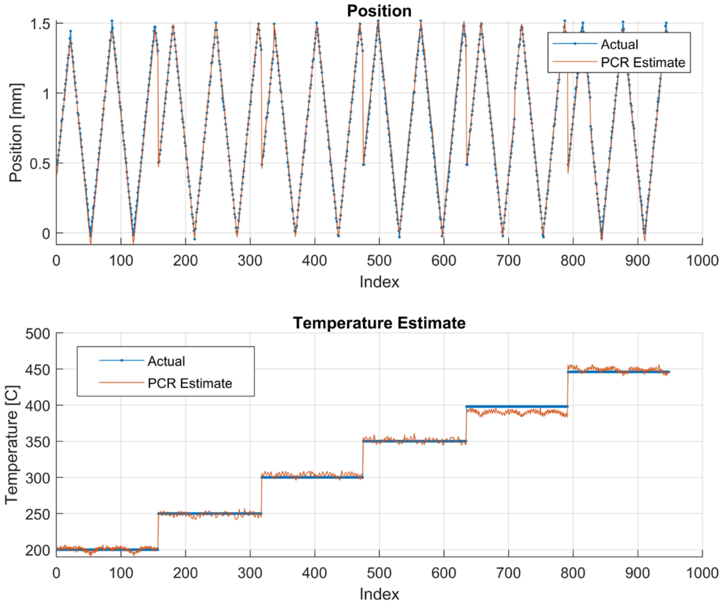
Backup

High Temperature Sensors

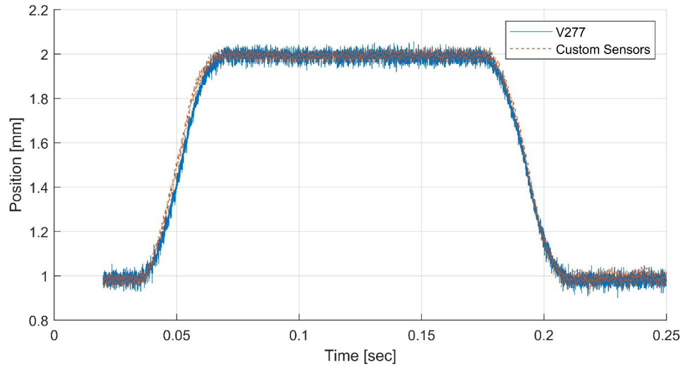
- **Problem:** Develop position sensor that can operate at 700 °C and sense through 1 mm thick metallic barrier.
- Successfully demonstrated performance equal to commercial position sensors at 800 °C.
- Sensor temperature can be estimated as well.



Sensor being tested at 800 °C



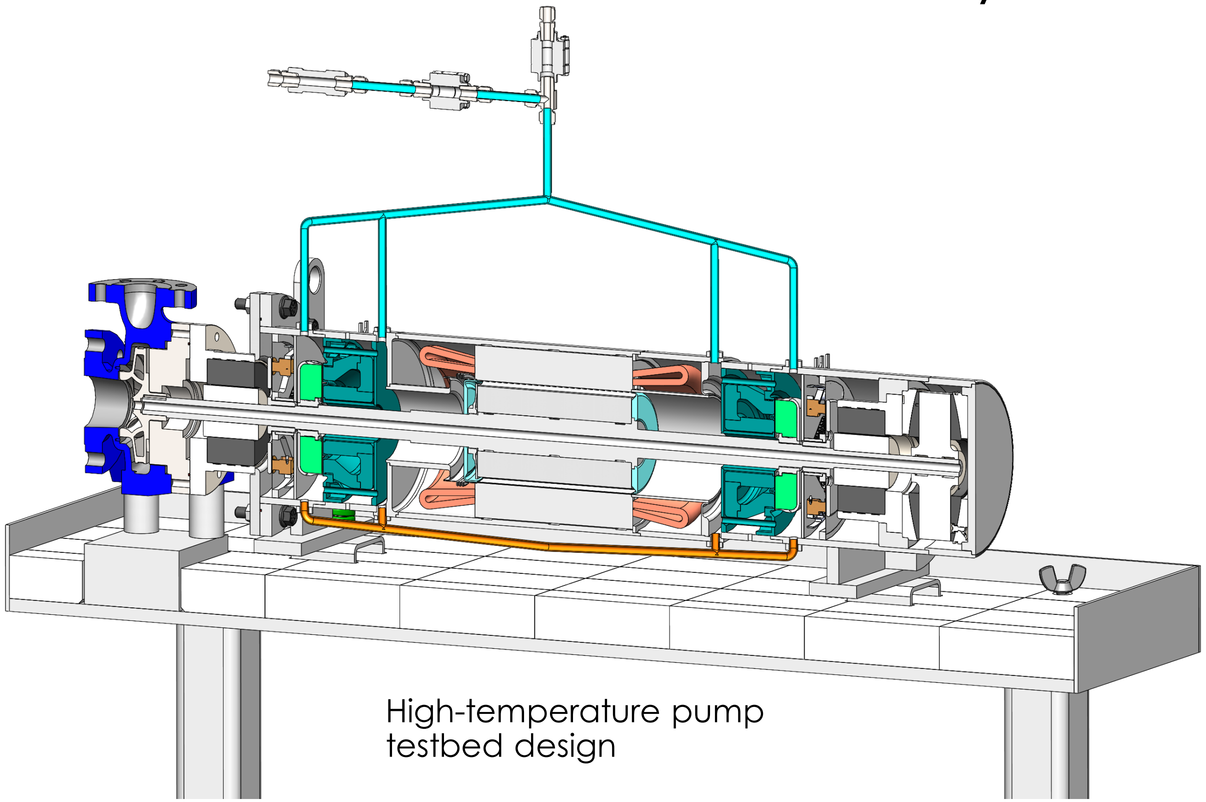
Sensor Temperature Estimation



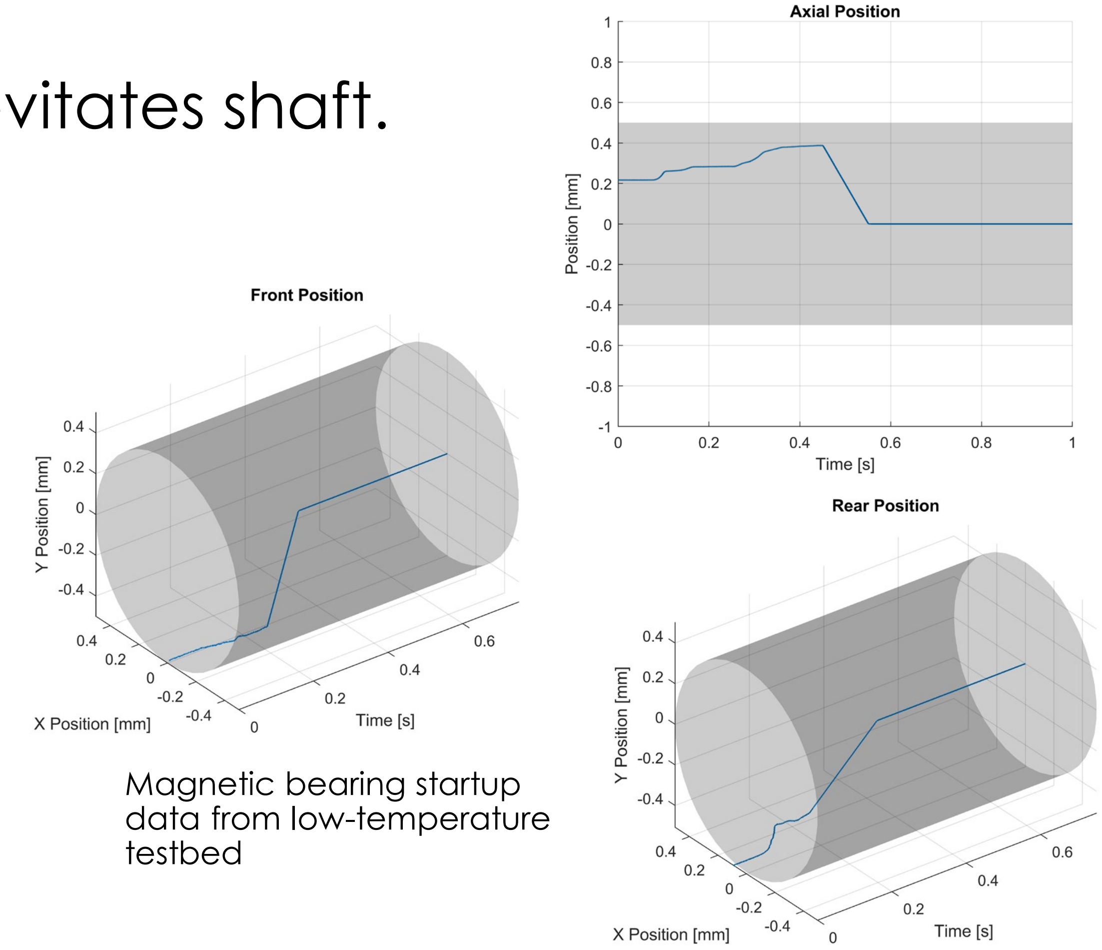
Sensor response at 800 °C and low-temperature commercial position sensor (V277)

High Temperature Magnetically Levitated Pump

- Designed for operation at 700 C.
- Shaft is magnetically levitated to eliminate rotating seals and mechanical bearings.
- Advanced feedback control system levitates shaft.



High-temperature pump testbed design



Magnetic bearing startup data from low-temperature testbed

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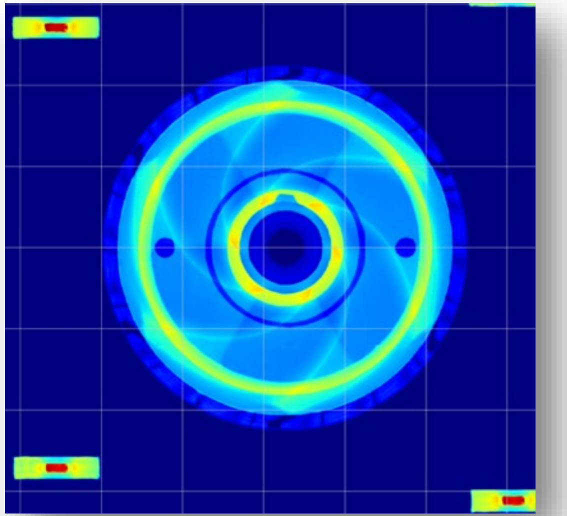
TCR program has a demonstrated track record of working with industry that will be key to its technology demonstrations



“The innovation embodied in the TCR program strategy, and the opportunity to have close physical proximity to its major AM work, were central factors in our Kairos decision to locate our Hermes reactor adjacent to ORNL in eastern Tennessee.

Kairos has already benefited directly from advances led by the TCR program’s development work. We will have ORNL-TCR AM hardware in our Hermes reactor.”

Kairos Power