# COMPONENT DEVELOPMENT AND TESTING FOR FUEL HANDLING MACHINES IN SODIUM FAST REACTORS AT ARGONNE NATIONAL LABORATORY

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INTRODUCTION: In order to implement the advanced fuel handling machines (FHM) used in sodium cooled fast-spectrum reactors, a review of the start of the art revealed a paucity of information and data regarding the testing of the mechanical components that could be used. To address this knowledge gap, a Gear Test Assembly (GTA) and a Gripper Test Article (GrTA) have been designed and fabricated at Argonne National Laboratory (ANL) to test the primary components of an FHM using prototypic reactor-grade sodium at prototypic fuel handling temperatures. This work will discuss the design, testing, and results from GTA and GrTA achieved to date.

## 1. DESIGN CRITERIA FOR IN-VESSEL FUEL HANDLING MACHINES

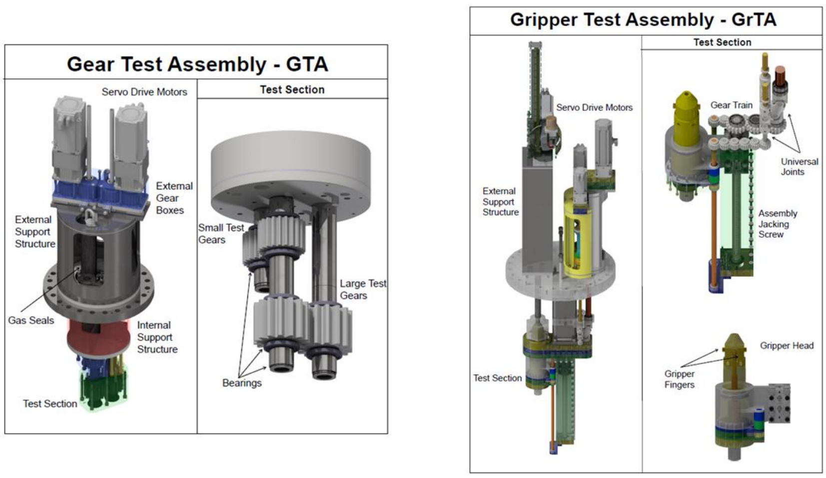


*FIG. 1. The design views for (left) GTA and (right) GrTA.*

A compactly designed fuel handling machine, created at Argonne National Laboratory, is based upon mechanisms used in previous designs like U.K.'s Prototype Fast Reactor as well as some untested mechanisms for sodium operation. A compact refueling machine supports a smaller scale primary reactor vessel that reduces the capital cost. A fully realized FHM would inform the design of the in-vessel refueling machines for commercial reactors such as the GEH PRISM reactor plant, the ARC-100 reactor, and the Natrium reactor in development by Terrapower, and others. Due to a lack of current operational experience and available literature regarding the use of the various mechanisms that must function while submerged in the liquid sodium at elevated temperatures, preliminary test articles have been developed. The Gear Test Assembly (GTA) was the first test article developed in this process and it examines the use of gears and mechanical bearings in high temperature liquid sodium. The lessons learned in the GTA testing informed the design of the next test article in the FHM development process, the Gripper Test Assembly (GrTA) [1]. The GrTA includes a full-scale gripper head, drive gearbox, and will operate under full prototypic loading.

### 1.1. Design

GTA was the first test article to be designed for use in ANL's Materials and Engineering Test Loop (METL) facility and is shown in Fig. 1.left [1-6] The central platform from which all parts are mounted is a standard ANSI 18" flange that bolts to an 18" test vessel whose volume is 150 L and can reach 538°C (1000°F). Two shafts, running through the flange and support structure, are connected to the motors and transport the load from the two motors to the gears and bearings through a shorter intermediate shaft as shown in the test section of Fig. 1.left. The test section is robustly designed to accommodate a variety of gears and bearings at various sizes up to 152.4 mm (6") in diameter. In summation, the GTA in its current configuration consists of four gears, eight total bearings for the gears and four axial thrust bearings.

### 1.2. Testing

GTA testing begins with the choosing, sourcing, purchasing, and/or fabrication of the gears and bearings that will be tested. Radial spur gears fabricated from heat-treated Inconel 718 or Hastelloy C-22HS, both nickel chromium alloys, have been tested as summarized in Table I for nine experimental campaigns.

TABLE 1. GEAR TEST ASSEMBLY EXPERIMENTAL CAMPAIGN RESULTS. *ONGOING

| Campaign | Gear Material | Bearing Material | Torque [Nm] | Revolutions |
|---|---|---|---|---|
| 1 | Inconel 718 | 52100 HT Steel | 400/150 | 1,314,855 |
| 2 | Inconel 718 | 52100 Steel | 450/150 | 346,000 |
| 3 | Inconel 718 | 52100 Steel | 450/150 | 392,000 |
| 4 | Inconel 718 | 52100 HT Steel | 450/150 | 316,500 |
| 5 | Inconel 718 | 52100 Steel | 450/150 | 143,750 |
| 6 | Inconel 718 | M50 Tool Steel | 150 | 17,615,145 |
| 7 | Inconel 718 | 52100 Steel | 150 | 205,200 |
| 8 | Hastelloy C-22HS | 52100 HT Steel | 300/150 | 1,058,880 |
| 9* | Inconel 718 | 52100 Steel | 120 | 287,460 |

The bearings used for each campaign are also displayed in Table I. New sets of Timken brand tapered roller (TR) bearings fabricated from 52100 bearing steel have been the predominant choice in all campaigns but Campaign #6. These tapered roller bearings, whose off-the-shelf version has no heat treatment, can operate at maximum temperature of 150°C. These bearings have been used in Campaigns #2, #3, #5, #7, and #9. A custom set of these tapered roller with a heat-treatment that pushes the maximum operating temperatures to 350°C have been used in Campaigns #1, #4, and #8. The custom heat-treatment for these otherwise off-the-shelf bearings increases the expense and pushes the lead-time to three to four months. For Campaign #6, a custom set of ball bearings purchased from another manufacturer and fabricated from M50 high speed tool steel were used. These bearings had a higher expense and the longest lead-time of eight to nine months.

After complete assembly and installation in a test vessel filled with sodium at 250°C, cyclical motor operations begin. One motor acts as the drive motor while the second motor is programmed to apply a periodic load whose torque profile is designed to mimic the loading profile found in core assembly manipulations subject to fuel handling maneuvers. The values for loading and duration were based on the data for the fuel handling maneuvers performed in the Fast Flux Test Facility (FFTF) with additional margin added. Cycles of motor operation repeats until either the experiment is stopped purposely, or the shafts cease to spin due to a failure in the system.

### 1.3. Results

A breakdown of the shaft revolutions for each campaign is given in Table I. The revolutions at torque provide the robust measure of gear and bearing performance. When failure as occurred, the source has been fragmentation of the bearing components which in some instances cascade through the gears leading to surface damage as shown in Fig. 2. In general, the non-heat treated tapered roller bearings last for several hundred thousand revolutions, while the heat-treated version operate over a million revolutions. The ball bearings used in Campaign #6 showed an order of magnitude better performance. Campaign #9 is ongoing as of this writing.

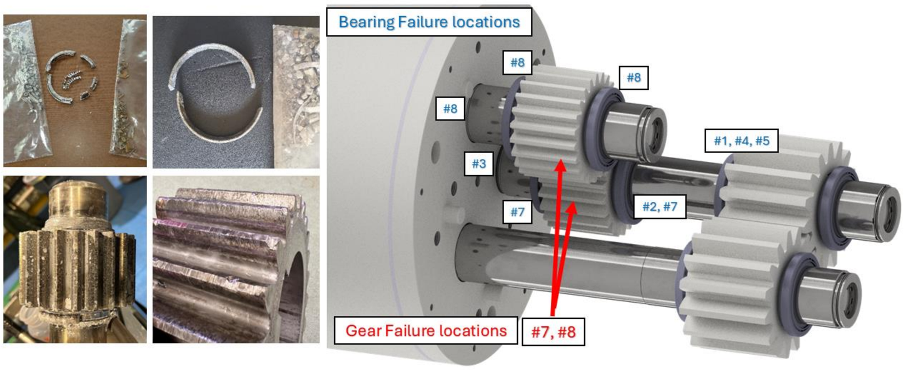


*FIG. 2. The GrTA assembled and actuated in air.*

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## 2. GRIPPER TEST ASSEMBLY

### 2.4. Design and Shakedown Testing

The Gripper Test Assembly (GrTA), Fig.1.right, is designed to simulate the gripper operation of the ANL FHM under expected mechanical loads and thermal conditions typical of SFR refueling operations. The myriad of mechanical components used in the design of this compact fuel handling machine include radial and thrust ball bearings, radial spur gears, ball screws, recirculating ball nuts, ball spline shafts, recirculating ball splines, universal joints, radial and thrust cylindrical roller bearings, fasteners, welds, various connection pin designs, and rolling contact joints. Components have been procured in a variety of materials of interest, including: Inconel 718, Stellite 20, Stellite 6, 440C stainless steel, M50 tool steel, and heat treated bearing steel. All other structural components below the main flange (in the sodium environment) are in 304 stainless steel. The initial assembly of the system has been completed [7], and air testing of the primary functionality was completed in 2024, Fig. 3.

## 3. SUMMARY

The technology development supporting a compact in-vessel fuel handling machine for sodium fast reactors has made significant progress over the previous several years at Argonne National Laboratory. The fabrication and testing of components in GTA and GrTA informs on the material and design choices implemented in FHM's and helps address gaps in both the operation of these components and the supply chain needed to produce these components for future development, testing, and implementation.

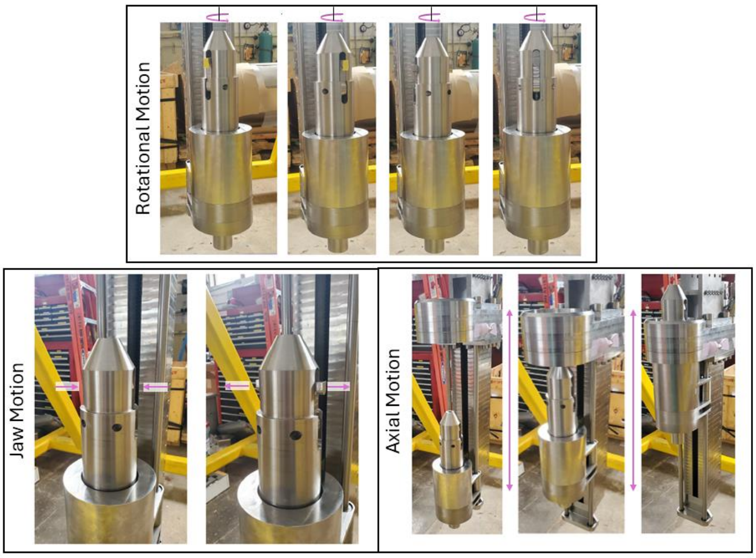


*FIG. 3. The GrTA assembled and actuated in air.*

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## ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy Office of Nuclear Energy's Advanced Reactor Technologies (ART) Fast Reactor Program. The submitted manuscript has been created by UChicago Argonne LLC, operator of Argonne National Laboratory ("Argonne"). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357.

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