ANL-ART-178
ANL-METL-19

Gear Test Assembly – Status Report for FY2019

Nuclear Sciences and Engineering Division

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Argonne National Laboratory

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1. Executive Summary

The final stages of pre-sodium commissioning were completed for the Gear Test Assembly (GTA) in late 2018 and all the components were moved to building 308 for final preparations for insertion into the Mechanisms Engineering Test Loop (METL). The GTA was fully assembled in the experimental test assembly workstation and all supporting electrical and hardware systems were installed on the METL Mezzanine. The GTA was installed in Test Vessel 1 after performing a final systems check, and the vessel and article were raised to operating temperature and held for two weeks to bake-out any moisture present in the components. Test Vessel 1 was filled with sodium and a purification process was completed using the cold trap system. When the sodium was sufficiently clean, Test Vessel 1 was isolated from the rest of METL, and experimental operation of the GTA commenced. The experimental operations consisted of rotating two shafts using Parker servomotors to apply a prototypic torque of a fuel handling mechanism removing and inserting a sodium fast reactor fuel assembly. This removing and inserting motion was repeated until the system seized, indicating component degradation of either the gears or the bearings in the test gearbox. A total of 19,600 cycles were completed, corresponding to the removal and insertion of 9,800 fuel assemblies. The system was shut down and then prepared for removal. The Flexicask System was successfully used to remove the GTA from Test Vessel 1 while keeping both vessel and article inert during the process. The GTA was installed in the Carbonation System, where the process of slowly reacting the sodium away using moist CO_2 has been started. Once the GTA is fully cleaned, it will be disassembled and the gears will undergo the same NDE process performed before testing to quantify the wear that occurred. A report on this, along with the data analysis from the experimental operations will be submitted in late 2019.

2. Introduction

The Gear Test Assembly (GTA) is an experimental apparatus designed to test mechanical components used in advanced fuel handling systems of liquid-sodium cooled fast-spectrum nuclear reactors. The GTA consists of a test gearbox housing two Inconel gears that are fully submerged in sodium. The test gearbox includes steel tapered roller bearings to allow for free shaft rotation. The gears are installed on 316 stainless steel shafts that penetrate an 18” ANSI flange used to mate the GTA to the test vessel. The shafts are rotated using two Parker brand servomotors mounted on the top of an upper weldment outside of the sodium environment. A dynamic shaft seal system is used to isolate the sodium and argon space in the test vessel from the outside environment. Vibration sensors are mounted inside and outside the sodium to monitor the health of the gears as the system operated. Figure 1 shows a model of the GTA. Refer to the previous fiscal year report for more details on the design and fabrication of the GTA (Reference 2).

The system is designed for maximum flexibility by accommodating various sizes of normal and parallel helical spur gears and hydrodynamic journal bearings. The system can also be modified to test helical spur gears, worm gears, and straight or spiral bevel gears as well as hydrostatic or roller bearings with minimal replacement of parts inside the liquid sodium testing area. Resulting data will be taken using vibration probes, torque sensors, tachometers, thermocouples, level sensors, etc. and compared with data recorded by the METL system on sodium flow rates, purity and temperatures. There is considerable reserve capacity in the system for additional measurements and measuring devices. There will also be extensive pre- and post-test metallurgical analysis of the gears to determine the onset and evolution of mechanical failure.

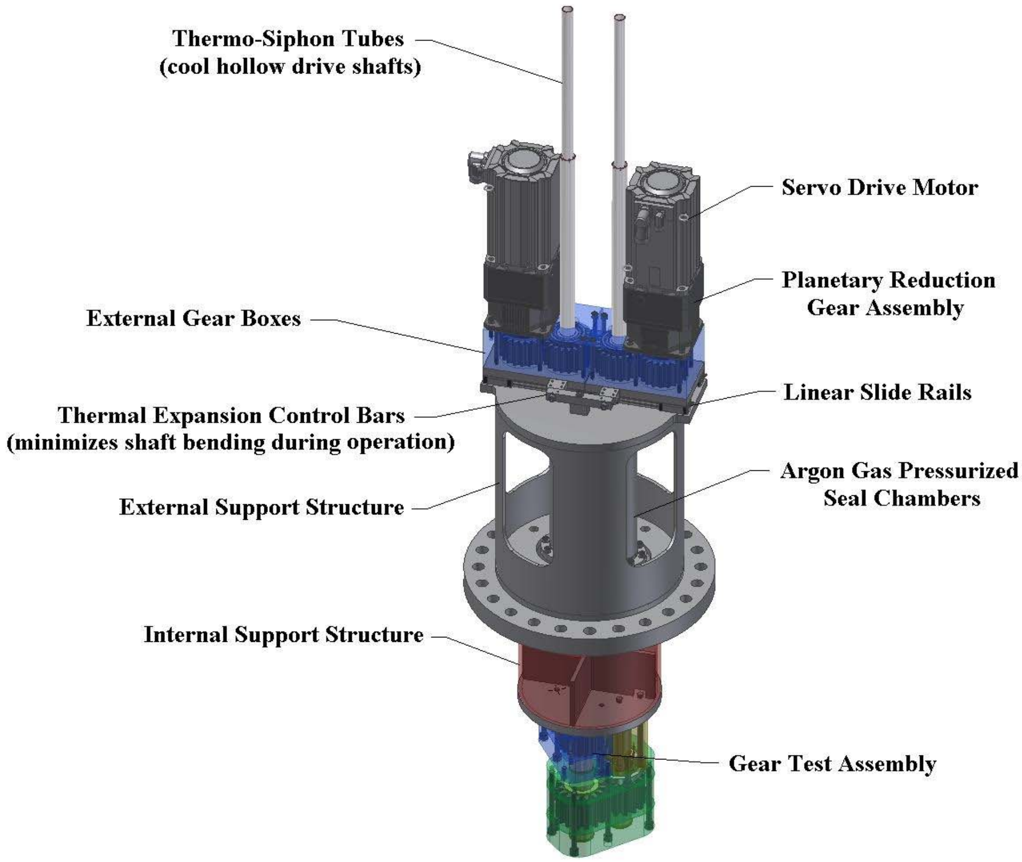

Figure 1 – Gear Test Assembly – Computer-Aided Design Model

3. Completion of Pre-Sodium Commissioning

At the end of Fiscal Year 2018, the Gear Test Assembly (GTA) work focused on the pre-sodium commissioning phase. The mechanical design had been updated to use traditional roller bearings in place of the original hydrodynamic bearings. This design change allowed the shafts to rotate freely despite the re-machined parts being slightly out of tolerance, and therefore progress with the pre-sodium commissioning continued. The final mechanical system that needed to be tested was the dynamic shaft gas seal. Figure 2 displays an exploded view of the dynamic shaft seal for the GTA. The sodium and argon cover gas space inside the vessel is isolated from the environment using a compressed graphite seal. A cylinder of graphite (#9) is slid onto each shaft and is positioned in a pocket machined in the flange. A load spreader (#7) and custom Belleview washers (#6) are slid on next. Graphite is compressed into the pocket volume when the gas chamber (#1) is fastened to the flange. Silicone and Viton Shaft Seals (#18 and #19) are used to seal the top of the gas chamber to the shaft. The top of the chamber is sealed so that the pressure in the chamber can be increased to a level slightly higher than the test vessel. This ensures that if there is any leak past the graphite seal, the clean argon from the gas chamber enters the test vessel preventing any potential sodium vapor release.

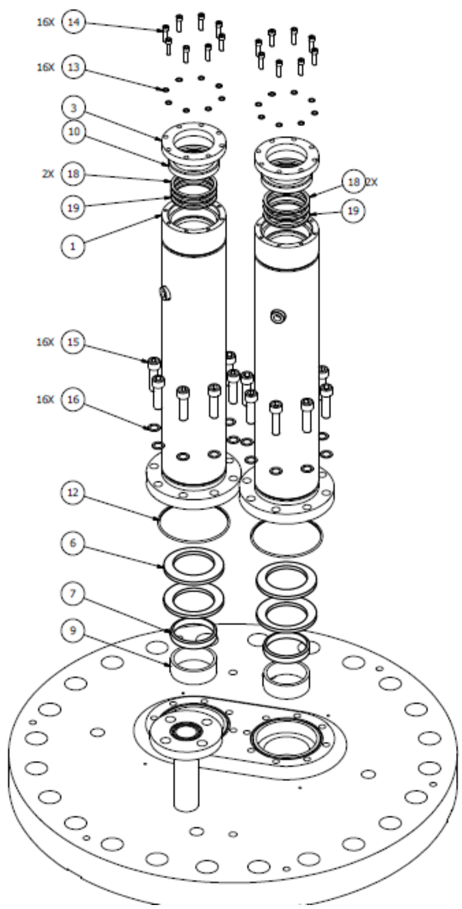

Figure 2: Exploded view of dynamic shaft seal.

The dynamic shaft seal system was fully assembled and tested by pressurizing the gas chamber with argon. A leak path was found between the flange and the gas chambers using liquid leak detector (Figure 3). After disassembling the seal system, a crack was found that connected the pocket machined for the graphite cylinder to the surrounding bolt hole pattern. This required a modification to seal properly the gas chamber to the flange. A 1/32” thick graphite gasket was designed to cover the entire mating surface between the gas chambers and the flange, and crushable metal washers were used for all the gas chamber screws (Figure 4). Successful testing of the seal system was accomplished after installing these modifications.

Figure 3: Bubbles in liquid leak detector.

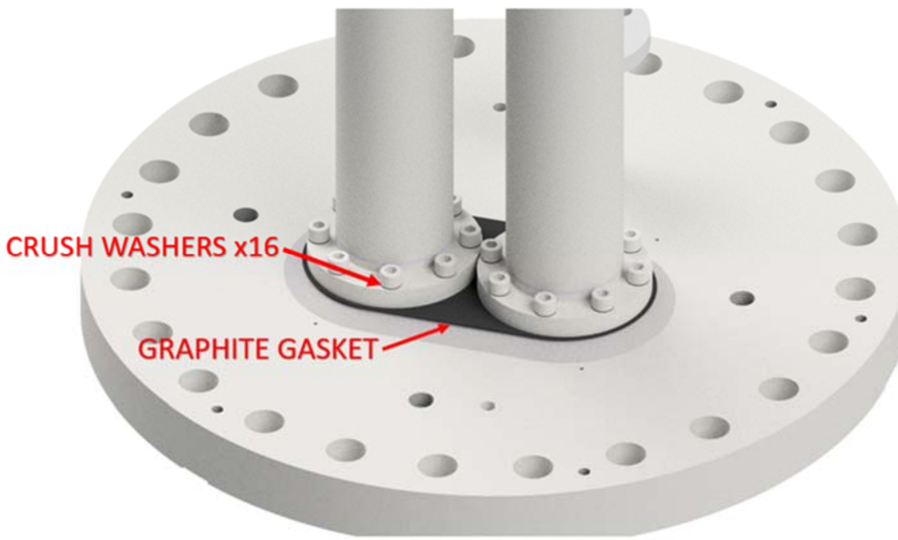

Figure 4: 1/32" thick graphite gasket used to seal the chambers to the flange.

4. Preparing GTA for METL

In early October 2018, all necessary pre-sodium work was completed in Building 206 and the GTA was moved to Building 308. The GTA was assembled in the experimental test assembly workstation on the METL Mezzanine to ready the system for insertion into METL (Figure 5). A work control document (WCD) was generated to cover the GTA experimental work (WCD #57532.0) and entered into Argonne's work planning and control system (called AWARE). A Safety Review Committee met on October 3, 2018 to review the WCD and discuss any required changes. These changes were addressed and approved October 10, 2018. The WCD was then fully approved and authorized December 6, 2018.

Figure 5: GTA fully assembled on METL Mezzanine.

All the electrical hardware that supports the GTA was moved from Building 206 and installed in Building 308. QEW2 trained staff performed all of the electrical work. **Error! Reference source not found.** shows the 480VAC transformers, 480VAC Meltric switch-rated receptacles, and the 24VDC I&C Panel for the GTA project. The 480VAC transformers are fed with the building's 480VAC 3-phase Delta and output the 480VAC 3-phase WYE required by the motors. The Meltric receptacles provide cord-and-plug control for the motor controllers. The I&C Panel includes the following hardware:

- Parker ACR Programmable Motor Controller
- Parker EPX2 HMI
- NI cDAQ-9188XT
    - NI9428 Analog Output Card –SSR and Solenoid Valve Control
    - NI9208 4-20mA Input Card – Pressure Transducer and Torque Sensor Input
    - NI9213 Thermocouple Card – Temperature Input
    - NI9234 Voltage Input Card – Vibration Sensor Input
- Watlow EZ-Zone RM Integrated Controllers
- Watlow EZ-Zone Remote User Interface Modules.
- Futek Torque Sensor Amplifier
- 24VDC SSRs
- Ethernet Switch

Figure 6: GTA Electrical 1/3 – 480 VAC Transformers (bottom), GTA I&C Panel (top-left), and 480 VAC Meltric Receptacles for Motors (top-right).

The I&C Panel is fed with 24VDC from a DC Power Panel that houses a 480W 24VDC power supply. Separating the power supply from the I&C Panel removes any hazardous electrical energy from the I&C Panel, thereby allowing safer access for troubleshooting. A 480VAC Remote Disconnect Box is located between the 480VAC Meltric receptacles and the Compax3 Motor Controllers. This allows the operator to control remotely the power supplied to the motors by opening or closing 480VAC solid-state relays. The Heater Power Panel supplies 240VAC to two heater zones on the GTA. Each zone consists of several heaters fed from distribution blocks within the panel. Each zone is controlled using a 240VAC SSR that operates off PID parameters set by the Watlow EZ-Zone hardware located in the I&C Panel. The main feed to the Heater Power Panel is controlled using another 240VAC SSR that can be remotely switched by the operator. All three panels are single energy source, cord-and-plug controlled, and are DEEI approved. Figure 7 shows these three panels mounted on the north wall of the Building 308 high bay.

Figure 7: GTA Electrical 2/3 – Heater Power Panel (left), 480 VAC Remote Disconnect Panel (middle), DC Power Panel (right).

The GTA uses two Parker servomotors to rotate the shafts and provide the torque to load the gears. These motors are powered from Parker brand Compax3 Motor Controllers that include individual braking resistors. Each Compax3 can be used to operate an individual servomotor, and coordinated motion is achieved using the Parker brand ACR Motor Controller located in the I&C Panel. Figure 8 shows the two Compax3 Motor Controllers and their associated braking resistors.

Figure 8: GTA Electrical 3/3 – Compax3 Motor Controllers (bottom) and Motor Braking Resistors (top)

The GTA requires individual argon gas control to operate properly the dynamic shaft gas seals. As mentioned earlier, the gas chambers used in the seal system need to be pressurized to a level slightly above METL's test vessel cover gas pressure. Too low of a pressure could allow argon cover gas, and potentially sodium vapor, to escape the test vessel into the gas chamber. Too much pressure could over stress the seal and cause premature failure. A gas manifold was constructed to properly control the gas supply to the chambers (Figure 9). Argon is fed to the manifold from METL's argon supply via an isolation valve provided at each test vessel. A regulator steps down the pressure to 5 psig. The supply can be isolated locally with isolation valve ISO_V1, or remotely with solenoid valve ACT_V1. Pressure in the manifold is monitored using pressure transducer PT1. Over pressurization is controlled by a 25 psig pressure relief valve PRV1. Two supply lines that lead to the gas chambers can be isolated using SUP_V1 or SUP_V2, and pressure can be monitored via pressure gauges PG1 and PG2. Figure 10 shows the gas manifold as it is installed in Building 308.

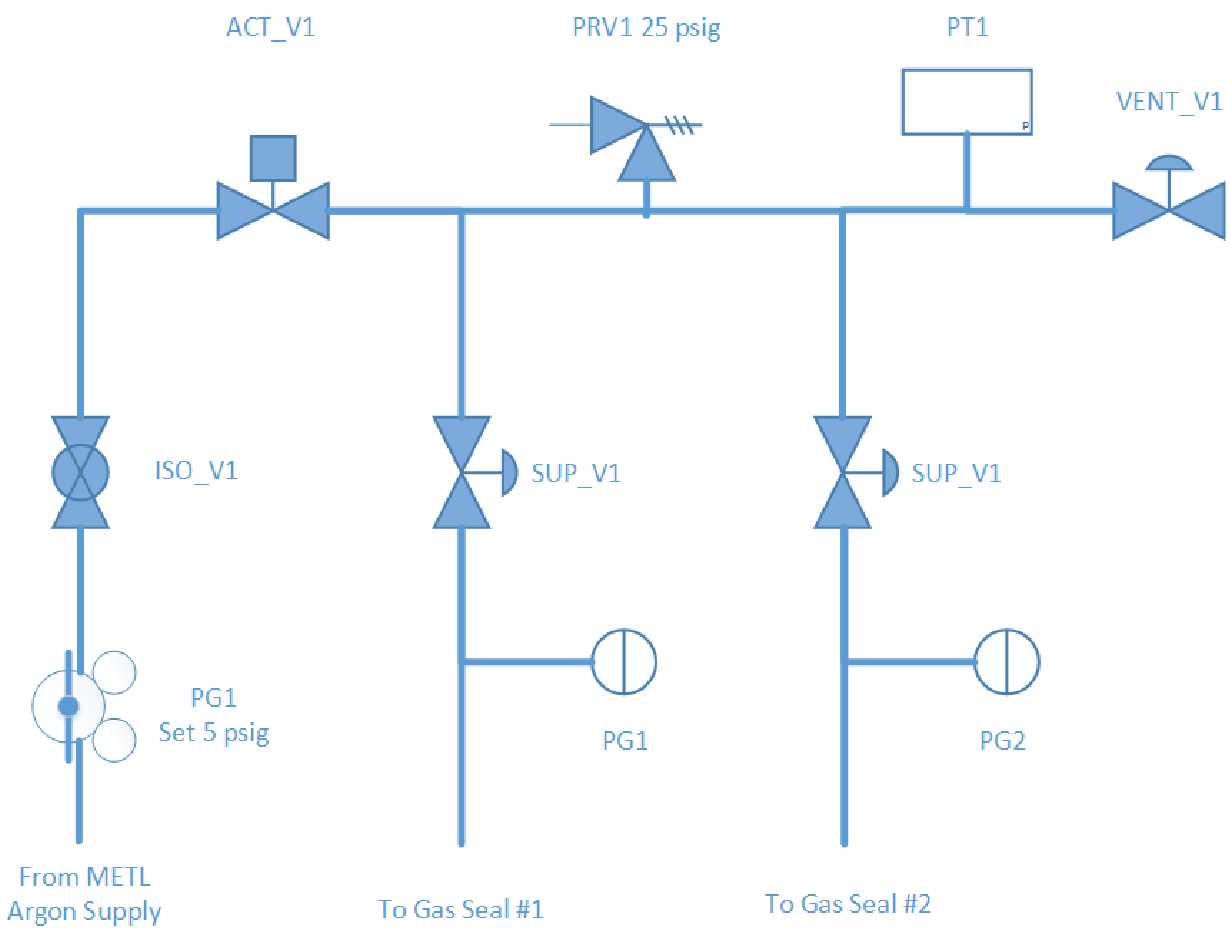

Figure 9: Gas manifold diagram.

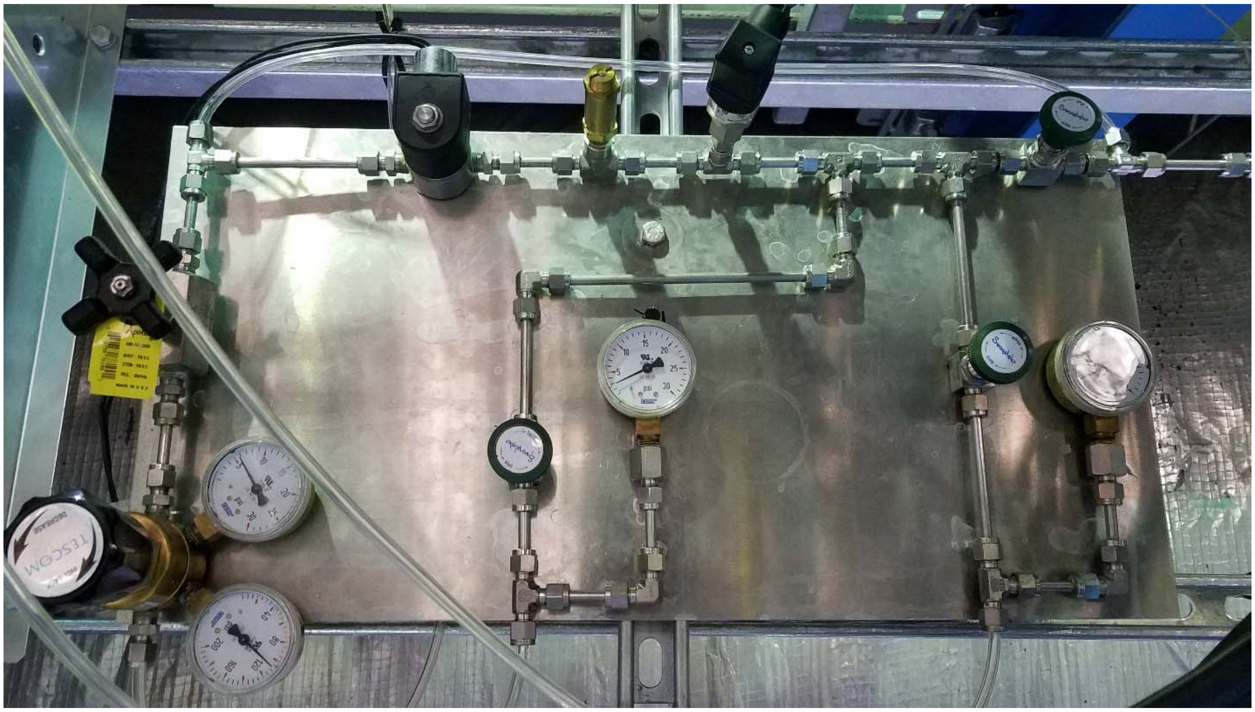

Figure 10: Dynamic shaft seal gas manifold.

After completing the installation of all the GTA's support systems, a final pre-sodium commissioning was performed. The GTA was assembled in the experimental test assembly workstation flipper and fully instrumented, as it would be during experimentation. The motor programming, dynamic seal system, temperature monitoring and control, vibration sensors, torque sensor, and remote disconnect control were all tested and proved to be in working order. Following this, the GTA was disassembled and cleaned using a Citranox solution in a heated ultrasonic bath. This minimized the contamination the GTA would introduce to METL's sodium supply. Cleaning was completed early December 2018 and the GTA was assembled and ready for installation into METL.

5. Installation of GTA into METL

In early December 2018, operation of the GTA was fully commissioned and the system was cleaned thoroughly. Following the final approval and authorization of WCD #57532.0 covering "Gear Test Assembly Experimental Operations – METL Facility – 2018-2021" the GTA could be installed in METL. The full GTA has a conservative mass of 2500 lbs. This includes the mass of both motors and upper gearboxes that are removed during installation. The GTA was rigged to the overhead crane via the 5-ton crane hook. A 3-ton chain fall was rigged between the crane hook and the GTA to allow for finer elevation control. Figure 11 shows the GTA being removed from the assembly flipper on its way to Test Vessel 1.

Figure 11: Lifting the GTA from the Experimental Test Assembly Workstation.

The GTA was moved to Test Vessel 1 and lined up with the center axis of the vessel using the overhead crane controls. Test Vessel 1 was allowed to cool to room temperature in preparation for the article installation. Test Vessel 1 had not yet seen sodium from METL, so the cover flange could be removed without concern of exposing sodium to the high bay atmosphere. Care was taken to protect the metal c-ring seal and seal surfaces during this procedure, as well as to prevent any debris from falling into the open test vessel. Once the article was aligned properly with the test vessel, the chain fall was used to lower slowly the article into place. Figure 12 and Figure 13 show the process of lowering the GTA into Test Vessel 1.

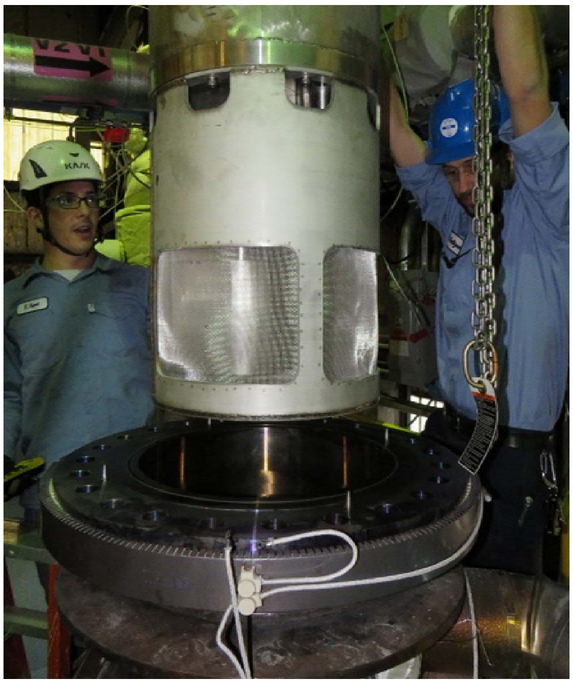

Figure 13: GTA being lowered into V1.

Figure 12: GTA Installed in V1.

The GTA was secured and sealed to Test Vessel 1 using 24 flange bolts torqued to the manufacturer's specification. Leak testing was performed to confirm the performance of the main flange seal, the dynamic shaft seals, and the instrument port seal. This was accomplished by pressurizing vessel 1 with 10 psig of helium via the sample port on the METL Valve Manifold. A helium leak detector with sniffer wand was used to probe the various seals and confirmed all three were operating satisfactorily. The GTA was again fully instrumented now that test vessel installation had been completed. A final in-vessel commissioning was performed to confirm the operation of the various supporting instrumentation. The article was insulated using Cerablanket and was prepared for heat-up. Test Vessel 1 and the GTA began the gradual heat-up and bake-out process on January 10, 2019 when the system was commanded to go to 250°C at 1.5°C/hour. After reaching the operating temperature of 250°C, Test Vessel 1 and the GTA sat for roughly 2 weeks to bake-out any moisture that would cause problems during sodium fill. On February 1, 2019, Test Vessel 1 was filled to the overflow line with sodium from METL's dump tank. This activity was accomplished using differential pressure by pressurizing the gas space in the dump tank by an amount necessary to overcome the pressure head between Test Vessel 1 and the dump tank. This procedure was tested previously when empty Test Vessel 2 was filled to the over flow line successfully in late September 2018.

24-hour manned operation started February 1, 2019 after filling Test Vessel 1 as the system now had moving sodium. Before experimental operation for the GTA could start, the sodium inventory needed to be purified using the cold trap. The IN port and OUT port of Test Vessel 1 were opened to the primary loop, and the entire sodium inventory was circulated through the cold trap continuously. This continued 24 hours a day until February 5, 2019 when experimental operations began. Figure 13 shows the GTA fully prepared for experimental operations.

Figure 14: GTA fully installed, instrumented, and insulated.

6. GTA Experimental Operations

Experimental operations began on February 5, 2019. The GTA was controlled using a workstation in the METL control room. Two programs were used to operate all the systems used on the GTA. The primary control program was a LabVIEW VI that reads every instrument on the GTA and writes to everything other than the Parker servomotors. Figure 15 shows the Control Panel of the LabVIEW VI that has several functions:

1. Temperature and State Monitor – All the temperature data, pressure data, torque data, and state machine statuses are presented as read-only indicators.
2. Plotting Tool – All the recorded data can be plotted versus time.
3. Motor Fault Monitor – Status of the two motor controllers as read-only indicators.
4. Heater Control – Read and write control for the two heater zones on the GTA.

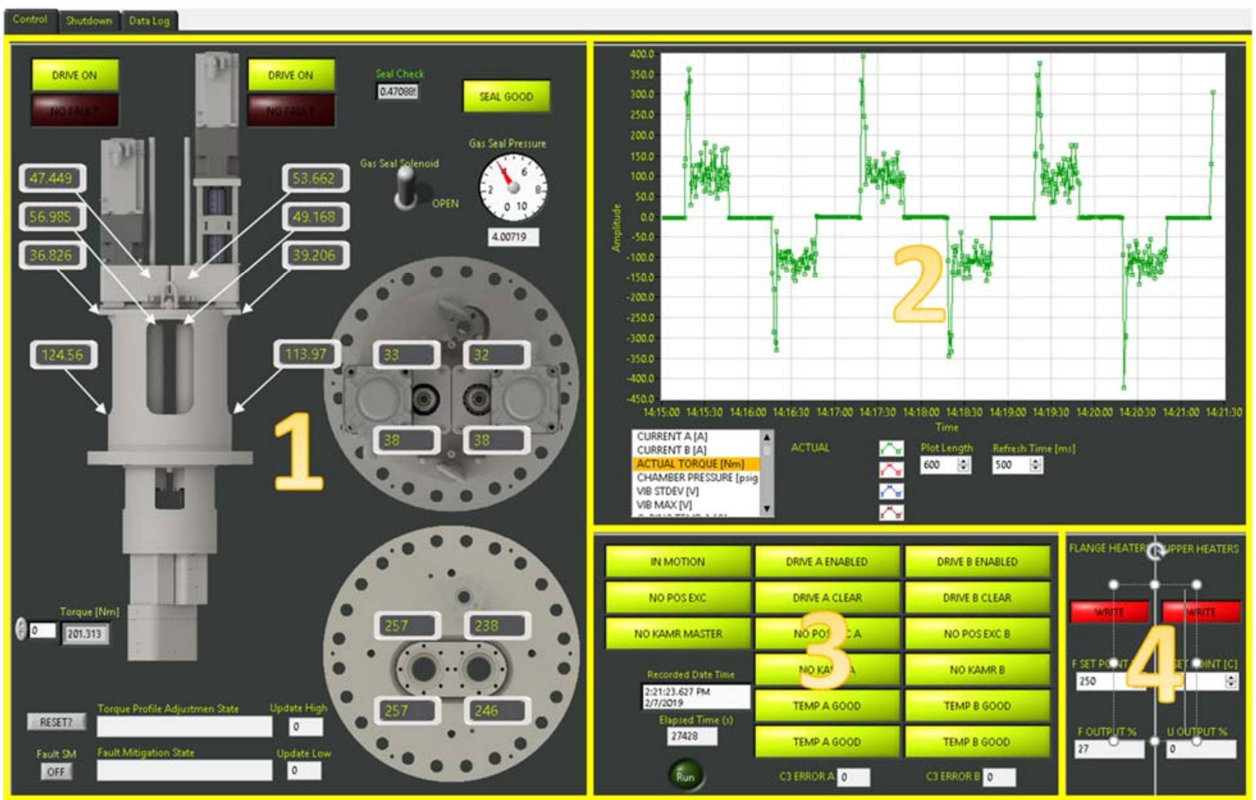

Figure 15: GTA LabVIEW Program – Control Panel.

Figure 16 shows the Vibration and Shutdown Panel of the LabVIEW VI. This presents readings from the three vibration sensor mounted on the GTA that monitor the system's health. Two sensors were out of the sodium and mounted to the upper gearboxes. The third sensor was submerged in the sodium and mounted to the test gearbox. These sensors provided the primary means of monitoring the gear and bearing health in the system. Measurements were made shortly after starting the GTA to record baseline vibration readings used to indicate normal performance. The vibration readings were continuously monitored and the motors set to trip should the local maximum or the standard deviation exceed the baseline by a factor of two. This panel also has the controls used to trip the remote SSR disconnects for the 240VAC and 480VAC.

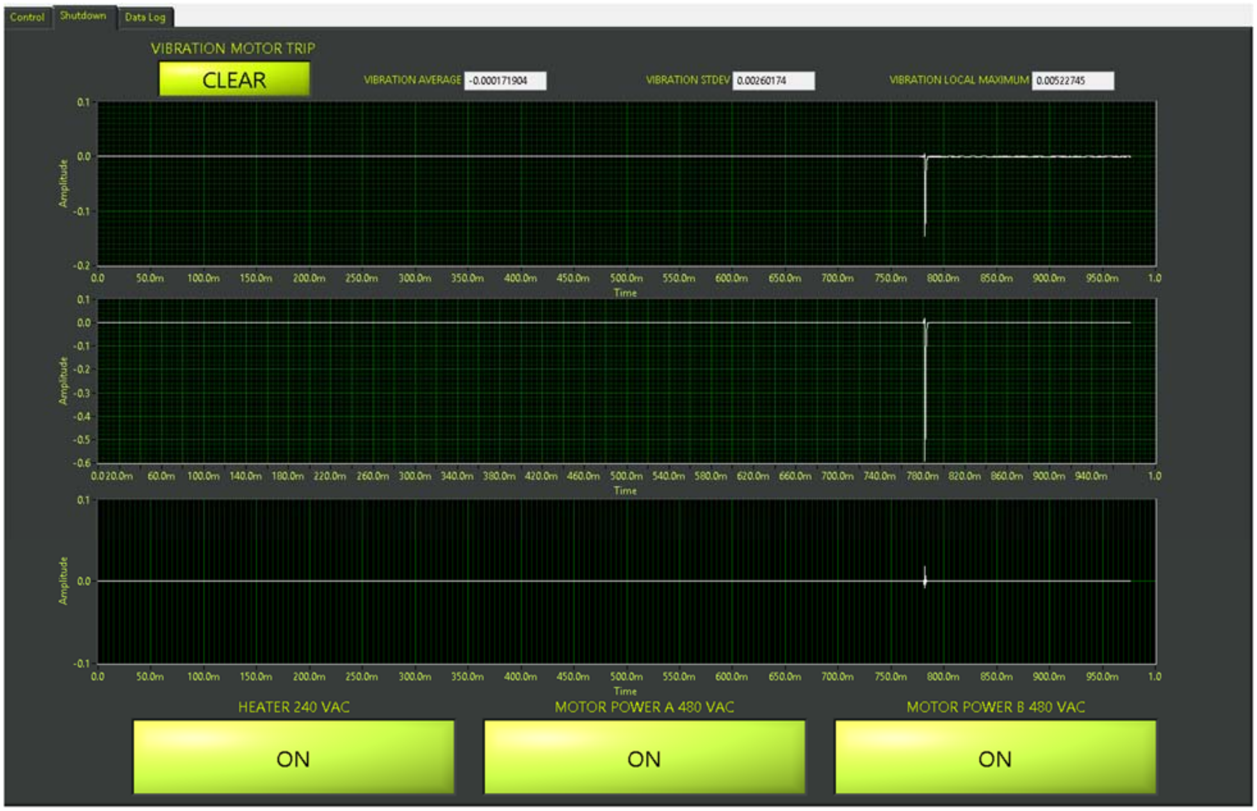

Figure 16: GTA LabVIEW Program – Vibration and Shutdown Panel.

The Parker servomotors were controlled using the ACRView software. Figure 17 shows the controls window used to operate the two servomotors. Control programs were written in the AcroBASIC language and saved in the motor controller's internal memory. Individual commands could be issued using the terminal emulator. A status panel that is more detailed than the LabVIEW copy is also shown. When the system was prepared to operate, a command to initiate the main control program was issued via the terminal emulator and the GTA began operation. A simplified description of the operations follows:

1. Motor A and Motor B power on and perform a systems check.
2. If all systems are normal (no fault flags), torque values are set for each motor
    a. Motor A in Drive at maximum allowed torque
    b. Motor B in Brake at "High Torque"
3. Motor A starts a 30-second jog in the positive direction.
4. Motor B brakes the system at "High Torque" for 2 seconds.
5. Motor B changes torque value to "Low Torque"
6. Motor A continues driving until the 30 seconds is completed.
7. Motor A and Motor B power down.
8. Repeat from Step 1, but invert direction of rotation described in Step 3.

Figure 18 displays an example of the torque data collected during normal operation.

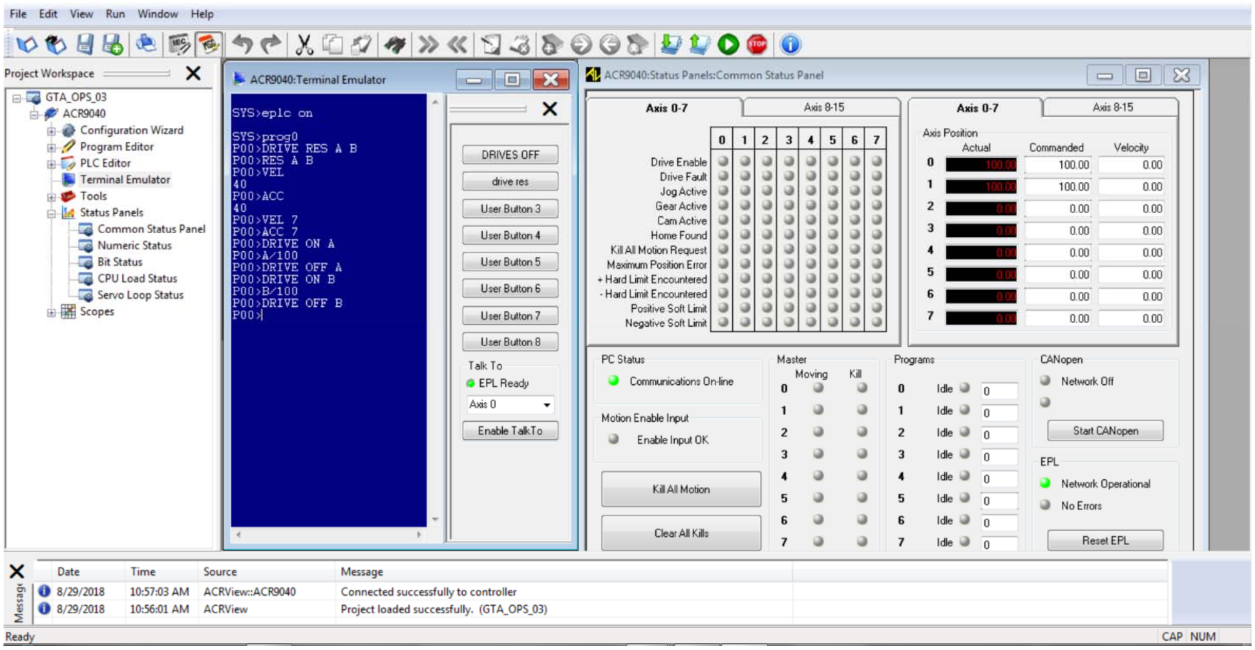

Figure 17: ACRView's Motor Control Program.

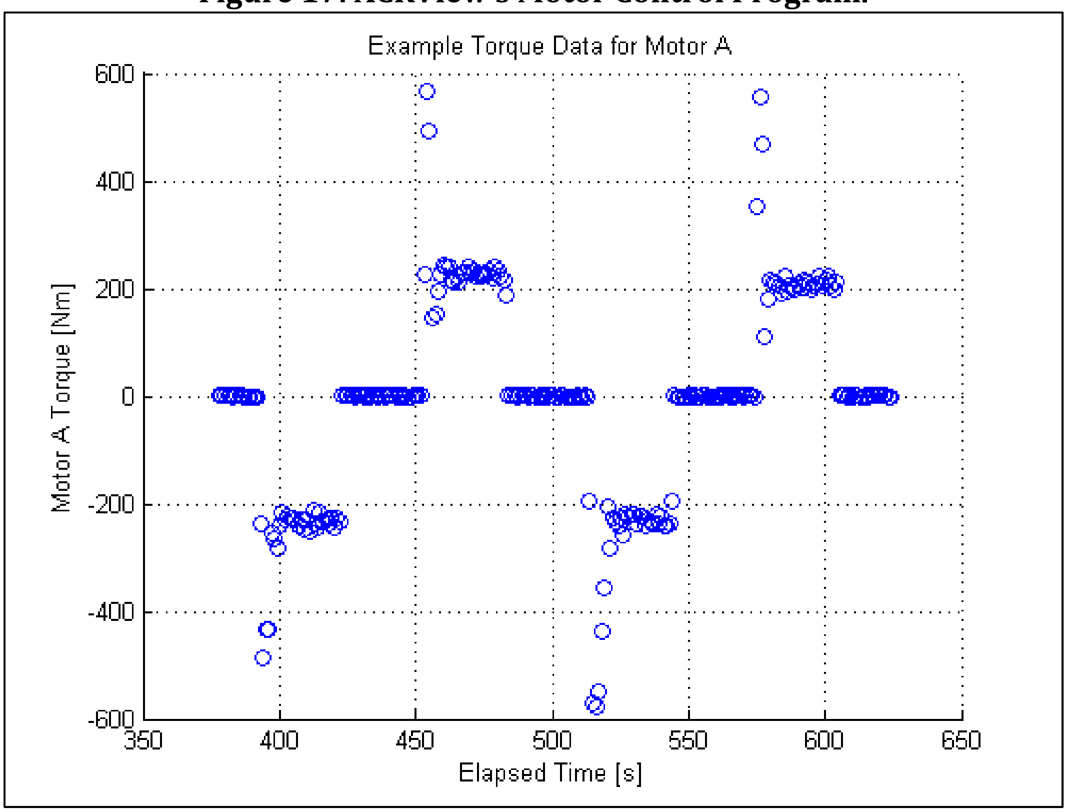

Figure 18: Example torque data collected for Motor A.

The combination of the LabVIEW VI and the ACRView programs allowed for fully automated operation of the GTA. A fault monitor state machine was programmed into the LabVIEW VI that monitors critical system parameters. The state machine monitored the seal system health, the vibration of the gearboxes, the temperature of the system, and the motor controller status. If any of these checks were out of a specified range, the motors were tripped and the operator notified. The system was programmed to always fail in a safe state so that the operator could respond in time without concern for the health of the system. From the start of experimental operations on February 5, 2019 to February 20, 2019, METL and GTA were manned with at least one operator 24/7. At the end of this period METL was put in "hot standby" with vessel 1 isolated from the loop. From February 20 until shutdown, the GTA ran during the day shift monitored by the automated system that notified an operator if a fault was detected.

7. External Gearbox Modification

The original design of the external gearboxes assumed operation of the sodium vessel at 638 degrees Celsius (1,200 degrees Fahrenheit). Analyses performed at that temperature indicated the temperature of the external gearboxes in the area of the drive shafts was 160 degrees Celsius (320 degrees Fahrenheit) due to the heat input of the thermal expansion bars that keep the external gearboxes aligned with the drive shafts that pass through the vessel cover assumed at 638 degrees Celsius. Additional heat input from the bearing operation at 350 RPM was not significant (at normal preloads) and heat generation from the shaft seals was calculated to be approximately 5 watts per shaft seal.

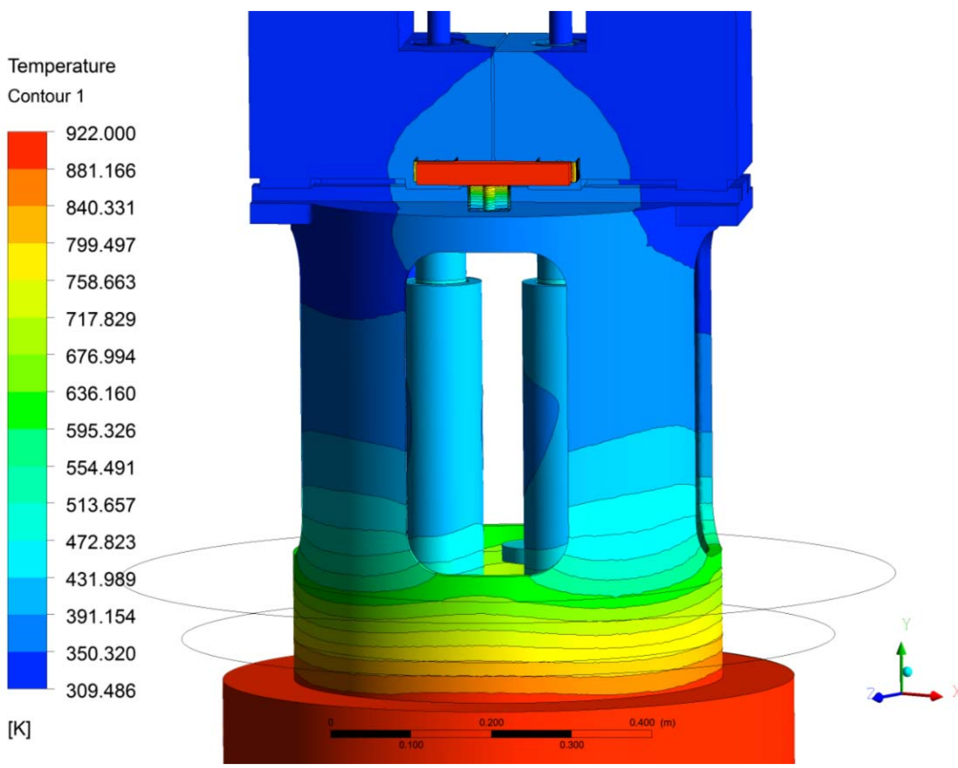

Figure 19: Temperature distribution for operation at 638°C (922K).

The use of any grease in the external gearboxes was considered problematic during the design stage for operation at a temperature of 1,200 F, so, the use of dry graphite lubricant was chosen for the high temperature operation. Dry graphite was applied during initial testing stages and worked well for the short duration tests, but required periodic cleaning in the local area around the external bearings.

As refueling temperatures are much lower (approximately 250 °C), it was decided to operate the test unit at 250 °C. The lower temperature allows the use of silicone grease to lubricate the bearings and gears in the external gearboxes.

An issue with the external gearboxes was encountered during the experimental operations. The external gearboxes were an “open” design that did not trap grease inside the gearboxes. There was a concern that over packing these gearboxes would cause them to bind up over time. A consequence of this was a reduction in lubrication from the grease and an increase in friction experienced by the bearings used in these gearboxes. After one week of continuous operation, a bearing failed in one of the upper gearboxes. This required a temporary shutdown to disassemble the upper gearboxes and replace the bearing. It was determined that the preload of the bearings in the external gearboxes was excessively high due to the omission of some shims during GTA assembly as well as inadequate lubrication which caused the early failure.

Figure 20: Inner race shows bore polishing due to excessive preload and lack of lubrication.

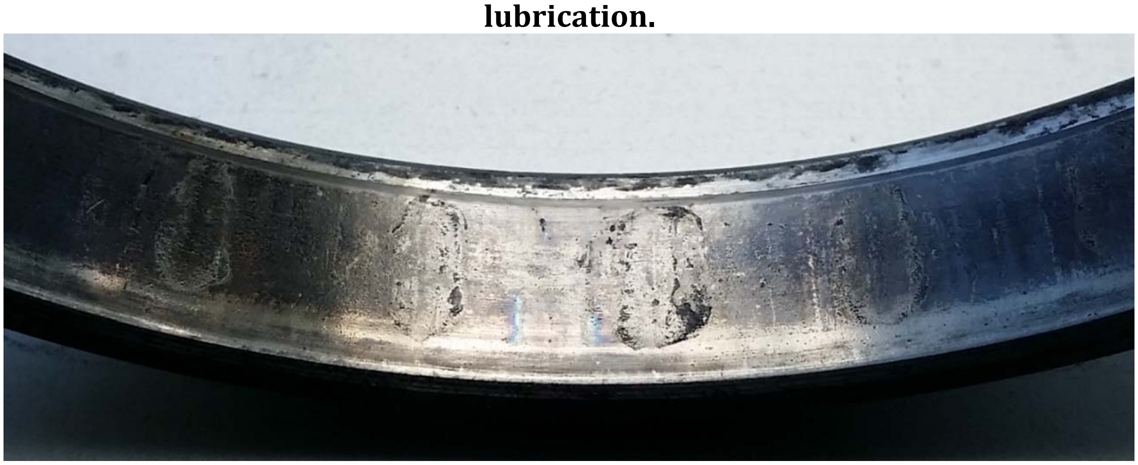

Figure 21: Outer race shows wear and deformation due to excessive preload and lack of lubrication.

Figure 22: Tapered rollers show signs of pitting due to excessive preload and lack of lubrication.

An attempt was made to provide more grease to these gearboxes when they were taken apart, but another bearing failed several days later. This reoccurring issue was temporarily managed by applying grease generously each morning. A long-term solution was made by including a bottom plate and shaft seals that closed the gearbox and installed a grease port to regularly provide lubrication. Figure 22 and Figure 23 show the modifications made to the upper gearboxes. The health of the upper gearboxes improved after installing these components along with proper shims, with no more bearing failures and a reduction in vibration readings for the remainder of the experimental operations.

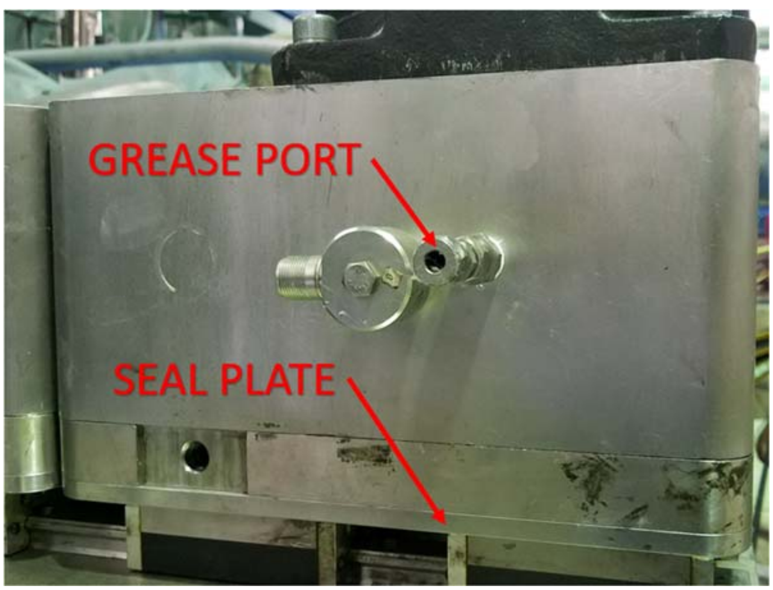

Figure 23: Modified external gearbox aimed at maintaining lubrication.

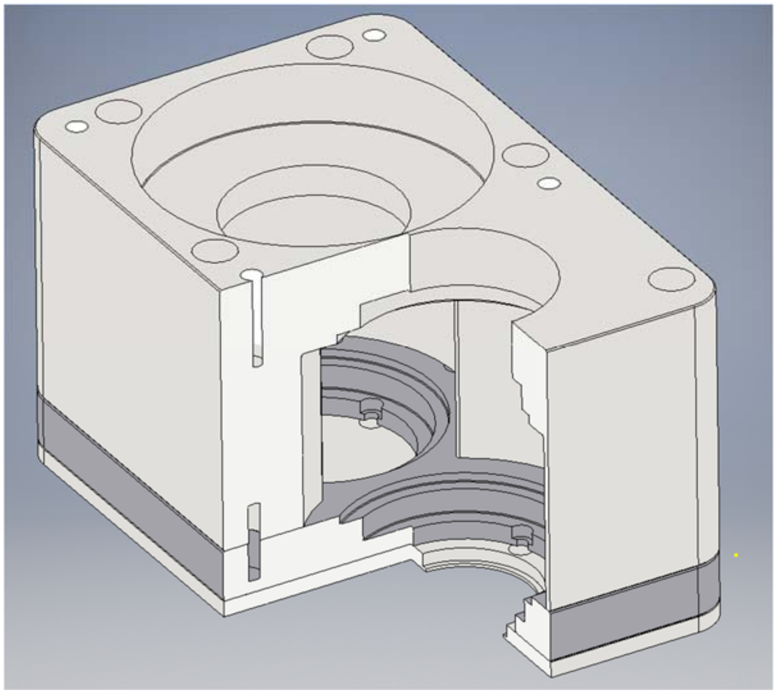

Figure 24: Cutaway of modified upper gearbox.

8. Shutdown and Removal from METL for Cleaning

On March 7, 2019 the automated system reported an over current fault coming from the motor controllers. The operator made attempts to start the system back up, but found that the shafts would not rotate in either direction. An attempt to free the shafts was made by maximizing the allowed current the motors could draw and slowly jogging them, but the shafts refused to rotate. First, the upper gearboxes were disassembled to determine if something failed there, but the gears and bearings looked healthy. The motors were tested free from the system and found to be in working order. Finally, an aluminum rod was inserted in the upper gearboxes and a large pipe wrench was used to try to turn manually the shafts, but the system was found to be seized. This indicated there was a failure on the sodium side of the GTA and that a shutdown was required. METL remained in hot standby with the GTA isolated from the loop in test vessel 1. As discussed below, GTA has operated for 19,600 cycles (equivalent to 9,800 removal and insertion cycles for a core assembly).

Now that Test Vessel 1 had seen sodium, it was important that the vessel not be exposed to any atmosphere at the risk of contaminating the sodium. The Flexicask System was designed to keep a test vessel inert when removing a test article. It consists of a two-gate system that "seals" the top of a test vessel when the flange has been removed, as well as a large glove bag that keep the test article inert while transporting the article away from the test vessel. Figure 25 shows a rendering of the Flexicask System.

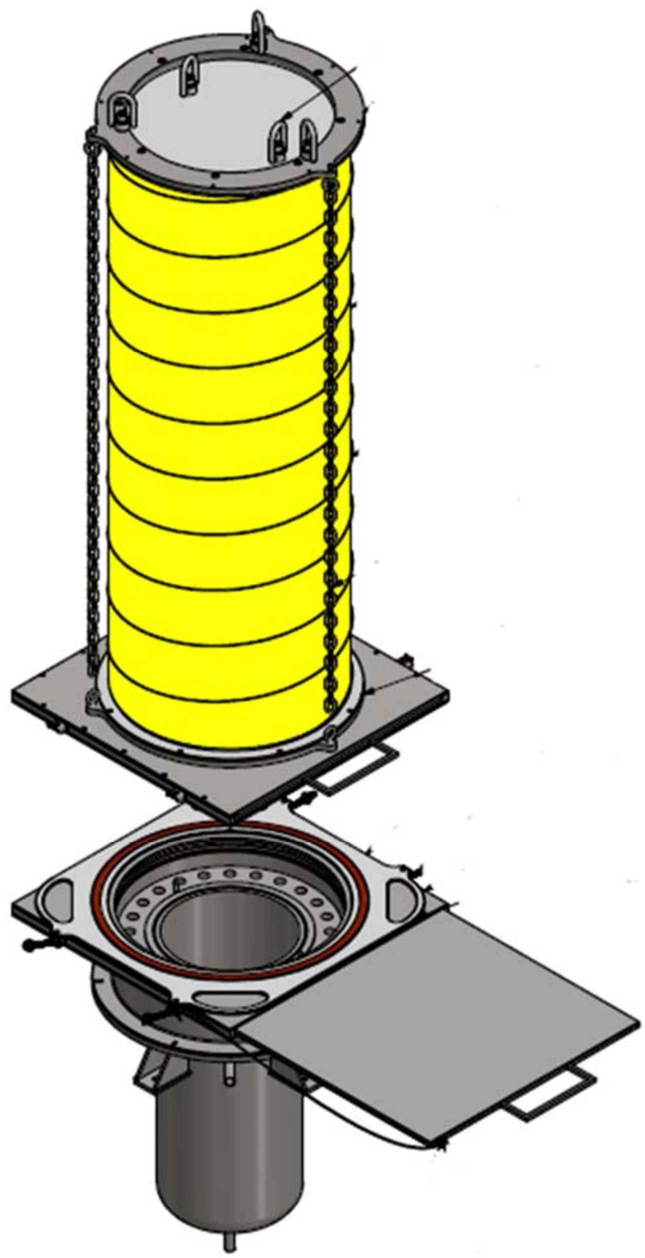

Figure 25: Isometric representation of Flexicask System.

The Flexicask had been procured and successfully tested on an unheated 18" test vessel in building 208 F-Wing prior to GTA operation. When time came to use the Flexicask on METL, a mechanical interference was discovered between the gate system and the blank flange used on test vessel 1. This required a slight redesign and additional manufacturing. The updated Flexicask was received July 18, 2019.

In the time between the GTA shutdown and receipt of the Flexicask, work on the Carbonation System was completed. The Carbonation System uses moist carbon dioxide to react passively the sodium located on the test articles rendering the sodium inert. Typically, components exposed to sodium are cleaned in the Alkali Metal Passivation Booth using dry steam, but this introduces extreme temperature from the steam as well as the sodium water interaction. If it is important to minimize additional damage to test components, the Carbonation System can be used to react sodium away at near ambient temperatures. The sodium reacts with the moist carbon dioxide to form sodium bicarbonate. A consequence of this process is that it takes a far greater amount of time than other more aggressive processes like an alcohol wash or wet vapor nitrogen processes. The Carbonation System is located on the METL Mezzanine in an uninsulated 28” test vessel equipped with a 28” to 18” Flange Adapter. The control equipment and water tank are located on the NSTF Mezzanine to keep the water away from the sodium system. Figure 26 shows a technical diagram of the Carbonation System.

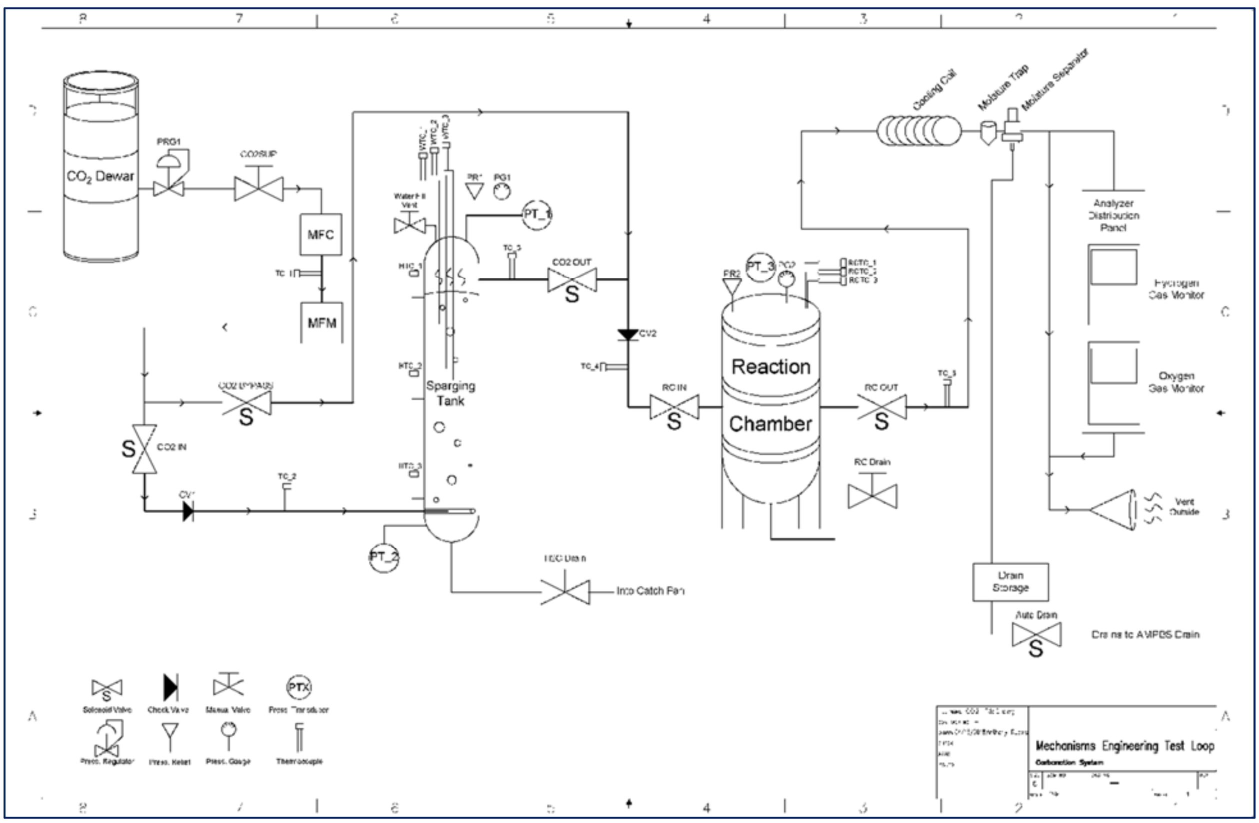

Figure 26: Carbonation System Diagram.

On August 6, 2019, the GTA was transported from Test Vessel 1 to the Carbonation System using the Flexicask. GE oxy.IQ trace oxygen detectors were used to monitor the oxygen concentrations in Test Vessel 1, the gate isolating Test Vessel 1, and the glove bag isolated the GTA. During the course of work oxygen levels remained well below 100 ppm in all three systems. A blank 18” flange was installed on Test Vessel 1 using the Flexicask, and the vessel was successfully sealed and pressurized with argon.

Figure 27: Uninsulated GTA in Test Vessel 1 with bolts removed.

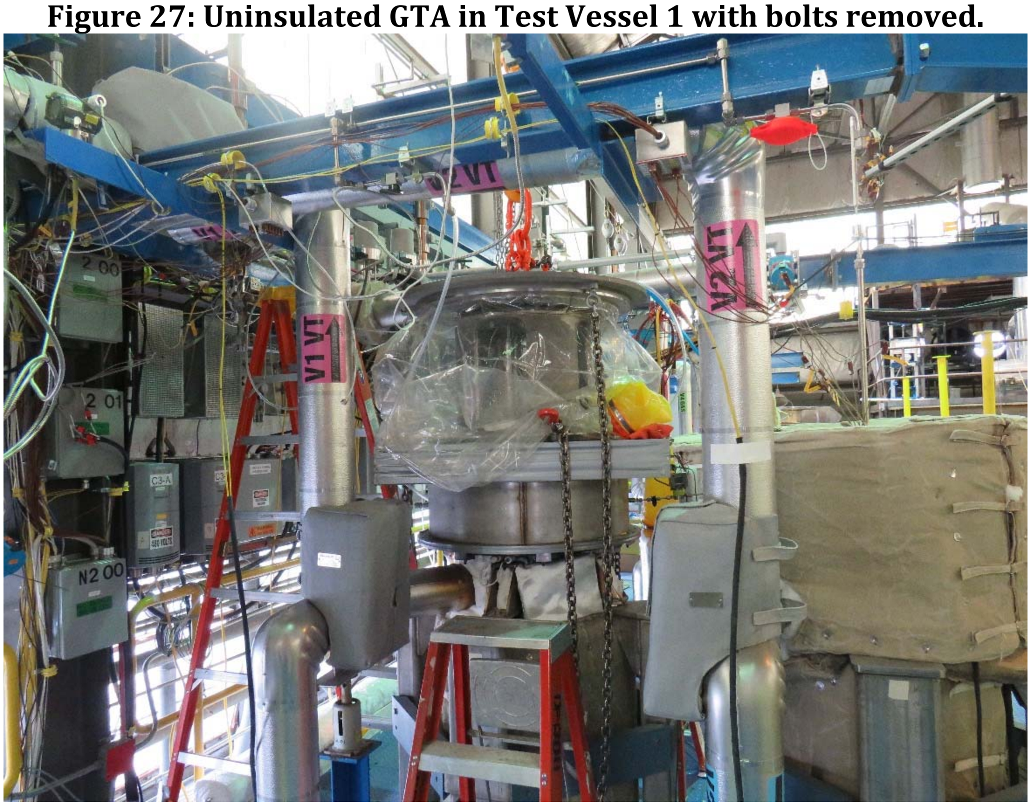

Figure 28: Flexicask installed on GTA, fully collapsed and not inerted.

Figure 29: Flexicask secured to GTA, fully collapsed and inerted with argon.

Figure 30: GTA fully removed from test vessel 1, with gates installed and still secured to each other.

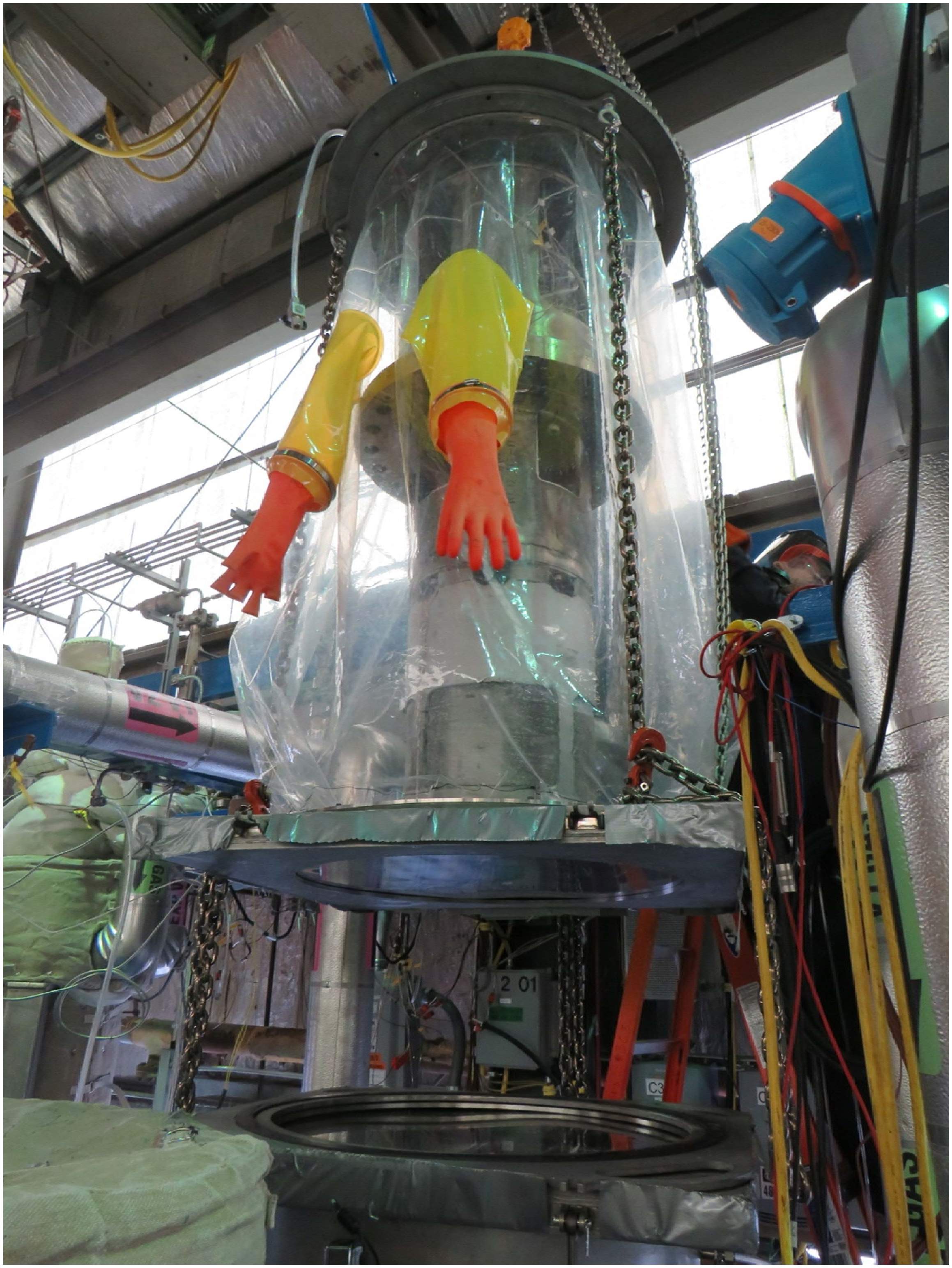

Figure 31: GTA fully removed from test vessel 1, with gates installed and separated from each other.

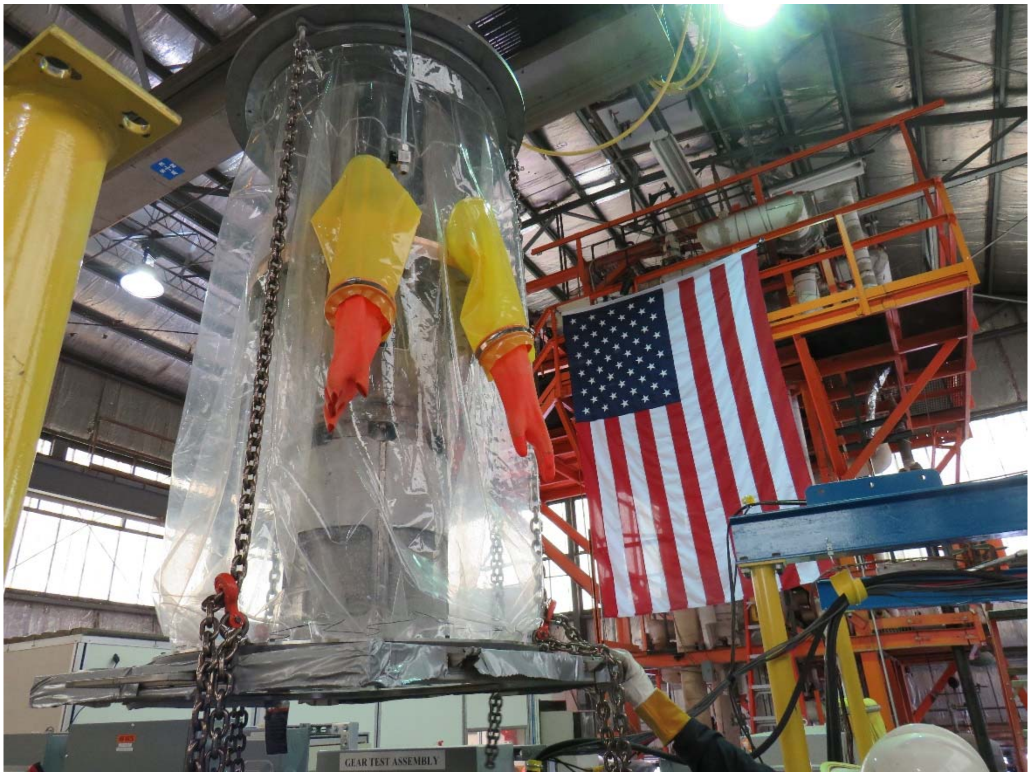

Figure 32: GTA being transported to the Carbonation System.

Figure 33: GTA installed in the Carbonation System.

The Carbonation System has been running since August 6, 2019, and the cleaning progress has been periodically checked.

Figure 34: GTA raised from Carbonation System for visual inspection.

Figure 35: Sodium bicarbonate production and expansion on GTA.

Figure 36: Sodium bicarbonate falling from GTA into catch screen.

Figure 37: Sodium bicarbonate on bottom of gearbox with catch screen removed.

9. Data Review and Analysis

The data files collected from the various run cycles was merged into a single database for analysis of the remaining estimated fatigue life of the Inconel 718 tested gears. The data indicates that approximately 19,600 loading cycles were performed before it is presumed that one of the steel bearings in the liquid sodium failed. The data is currently being arranged and analyzed to determine the amount of fatigue life remaining in the Inconel 718 gears.

The gear over-pin dimensions will be re-measured (after the 19,600 cycles of operation and sodium has been removed from the GTA) to measure and estimate the wear rate of the Inconel 718 gears operating under load in the 250 C liquid sodium. The gears will also be checked for cracking and pitting using the Eddy Current Inspection system developed at Argonne.

The measured wear rates and reduction in fatigue life for the gears will be used to calculate a quantitative lifetime reduction factor for Inconel 718 vs Inconel 718 gears operating under expected refueling loads in a high temperature liquid sodium environment. The lifetime reduction factors can be used in the industry standard (AGMA) gear design equations to determine actual lifetimes for gears manufactured from these materials operating in a high temperature liquid sodium environment for future fuel handling system design and analysis.

A separate report detailing the results of the analyses performed on the gear operational data will be issued first quarter of 2020. The report will contain wear measurement estimates that compared to the baseline pin-over measurements taken before the testing started. Estimates of gear fatigue life remaining after the first segment of testing will be provided based upon gears in normal lubricated conditions. Any cracks or pitting on the gear faces will be documented for each testing segment. The number of cycles of operation under the various loading conditions applied will be used to determine an approximate number of years of operation in a sodium fast reactor for the load spectrum fatigue life analyses.

10.Replacement In-Sodium Roller Bearings

A set of replacement tapered roller bearings manufactured from Hastelloy were designed to replace the in-sodium bearings (originally manufactured from high strength steel). These bearings should provide a significant increase in the lifetime of the internal bearings.

Additional testing data performed in the past [Reference 1] was researched for materials tested in sodium, data for low loads of pins rubbing on plates (30 to 130 psi contact pressure) tested in liquid sodium was reviewed and materials were selected based upon the new data. Although the contact pressure is much higher (35,000 psi contact pressure) in the current rounds of testing, the performance of the material is expected to be an excellent alternative.

Due to difficulties of finding a bearing manufacturer willing to make a small run of the tapered roller bearings from the selected Hastelloy material, a ball bearing made from the same materials has been designed and manufacturing drawings are currently in production. The Inconel 718 spur gear testing will continue using the high strength steel tapered roller bearings we have on hand while the new ball bearings are manufactured.

The calculated lifetime of the replacement ball bearing is lower due to the reduced contact length of the balls compared to the tapered rollers, but the use of the Hastelloy material should increase the life significantly (due to increases in strength and hardness) versus the use of the high strength steel material used in the current bearings.

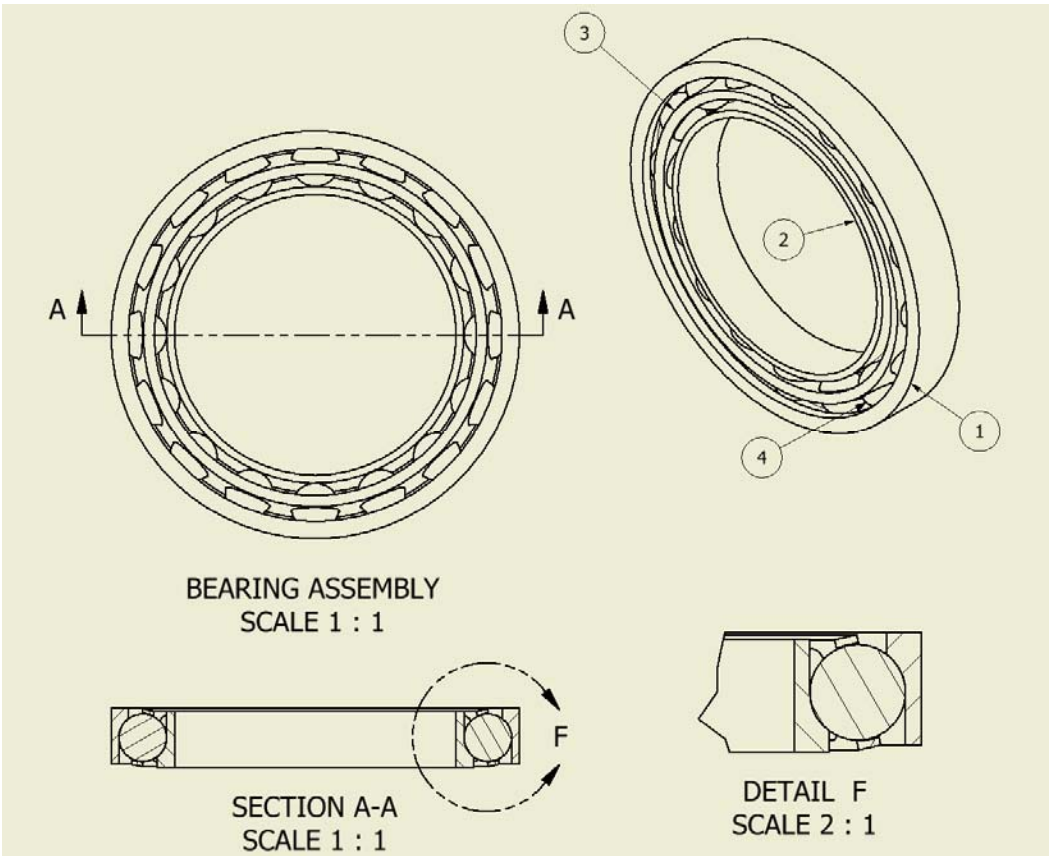

Figure 38: Replacement Hastelloy ball bearing for in-sodium use.

11.In-Sodium Gear Test Plan

A set of new gears manufactured from Hastelloy were designed for use in the second round of tests in the gear test assembly. The drawings were provided to Forest City Gear for manufacture and will be delivered 4th quarter of 2019 for testing once the Inconel 718 gear testing is completed. The material for the new gears was selected based upon increases in yield strength, hardness and fracture toughness while limiting the amount of cobalt in the alloy. Drawings were generated with inspection dimension requirements and were discussed with the production engineers at Forest City Gear. Agreed upon inspection dimensions for the over-pin measurements and tolerances will be included with the delivery of the gears.

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13.References:

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