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SR19036 Improve TRP Cutter Head Performance

William (Max) Housley

September 2020

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EXECUTIVE SUMMARY

The Target Rod Preparation (TRP) cutter head motor suffers from overheating problems during Tritium Producing Burnable Absorber Rods (TPBAR) breaching operations. The TRP cell cutter head drive motor must remain below the administrative limit of 100ºC during breaching operations. If temperatures in excess of 100ºC are reached, work must be stopped, and the motor allowed to cool. The work stoppage due to overheating of the drive motor directly and drastically lowers the efficiency of the TPBAR breaching process, reducing the production of Tritium gas. Due to the increased need for Tritium gas, the overheating problem must be addressed to improve the overall efficiency of the TPBAR breaching process.

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LIST OF ABBREVIATIONS

FY	Fiscal Year
OEM	Original Equipment Manufacturer
SRNL	Savannah River National Laboratory
TEF	Tritium Extraction Facility
TPBAR	Tritium Producing Burnable Absorber Rods
TRP	Target Rod Preparation

1.0 Introduction

The Target Rod Preparation (TRP) system is responsible for breaching Tritium Producing Burnable Absorber Rods (TPBARs). This system is contained within an inert cell within the Tritium Extraction Facility (TEF). The breaching system is a mechanical system, driven by numerous electric motors. There are several steps involved with breaching a TPBAR. Generally, one motor is responsible for driving one step of the breaching process, with some steps being more complex than others. The motor responsible for driving the TPBAR gripping and custom mechanical breaching system is a U33 model radiation hardened stepper motor constructed by Empire Magnetics. The TPBAR breaching process is executed by rotating several cutting wheels around the TPBAR while indexing the cutting wheels inward radially towards the center of the TPBAR. This mechanism functions similarly to a piping/tubing cutter. There is also a collet system responsible for holding the TPBAR in place during cutting operations. This collet is closed and opened multiple times during the cutting process and is driven by the same motor that drives the cutting process. The drive motor mentioned above was selected specifically for these operations by the Original Equipment Manufacturer (OEM) of the TRP breaching system, RTS Wright.

Currently, the TRP breaching process is inefficient due to overheating of the motor that drives the TPBAR breaching and gripping equipment. In an effort to improve the overall efficiency of the TPBAR breaching process, the TRP cutter head drive motor's parameters were analyzed. Several options to improve TPBAR breaching efficiency were explored. These options included: providing forced convective cooling over the motor housing to remove heat from the local area, replacing the single motor with a dual motor system, and replacing the motor with a larger motor.

All testing was planned and accomplished on a test stand that simulates the breaching of a TPBAR in a clean area in building 723-A (Fig 1-1). There are several variations between the testing environment in 723-A and the TRP hot cell environment.

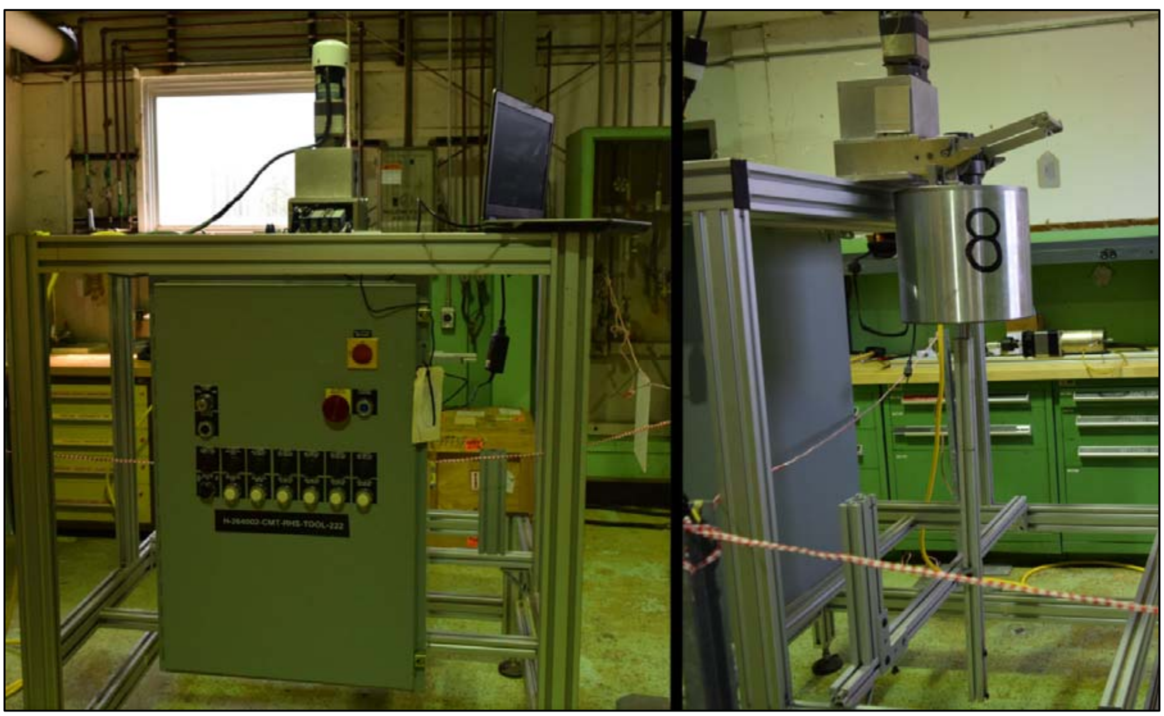

Figure 1-1. Test Stand General Setup

The test stand gives a rough representation of the TPBAR breaching process but is certainly not an exact replica of the TRP hot cell. As an example, the motor installed on the test stand is a generic industrial model motor whereas the motor installed in the TEF is a radiation hardened motor, both of which are manufactured by Empire Magnetics. The radiation hardened motor has specialty electrical components that may not reject heat as well as an industrial motor. Additionally, all breaching tests in 723-A were in open, ambient air (natural convection), whereas the TRP cell has a slight, constant, negative pressure. This negative pressure would supply a small amount of forced convection over the motor. Additionally, the TRP cell is an inert cell filled with Nitrogen, rather than typical ambient air. Ambient air is mostly made of Nitrogen so the difference in heat transfer coefficients between Nitrogen and ambient air are insignificant. Simulated debris on the outside of the mock TPBARs could not be accurately replicated during the breaching cycles in 723-A. This debris is present in the TRP hot cell and its presence could have a negative impact on the operation of the motor. There was no additional heat load added to the motor during testing. The TRP cell contains auxiliary equipment that adds heat to the cell, this equipment includes lights, cameras, vacuums, or other motors running in proximity of the cutter head drive motor.

Some of the items that add to the heat load in the TRP hot cell (Cameras, in-cell lighting) are powered for the duration of all breaching operations. Other items such as the turret drive motors, collet drive motors, and vacuum cleaner, are on intermittently throughout breaching operations. These pieces of equipment were analyzed to determine if they could be replaced with newer or more efficient equipment to reduce the overall heat load in the TRP cell.

2.0 Experimental Procedure

A series of experiments were designed to obtain baseline temperature data from the test stand cutter head drive motor.

The first set of tests included breaching TPBARs until the test stand cutter head drive motor (U33 model) overheated. There is no secondary gripper and gripper motor on the test stand, so the rod was held at a specified height while the grip/ungrip/grip sequence was executed (Fig. 2-1). Though the mock TPBAR was not moved, the drive motor was still required to be run the same amount of time and under the same load that would be required in the TRP hot cell. Temperature data was captured by attaching thermocouples directly to the test stand cutter head drive motor.

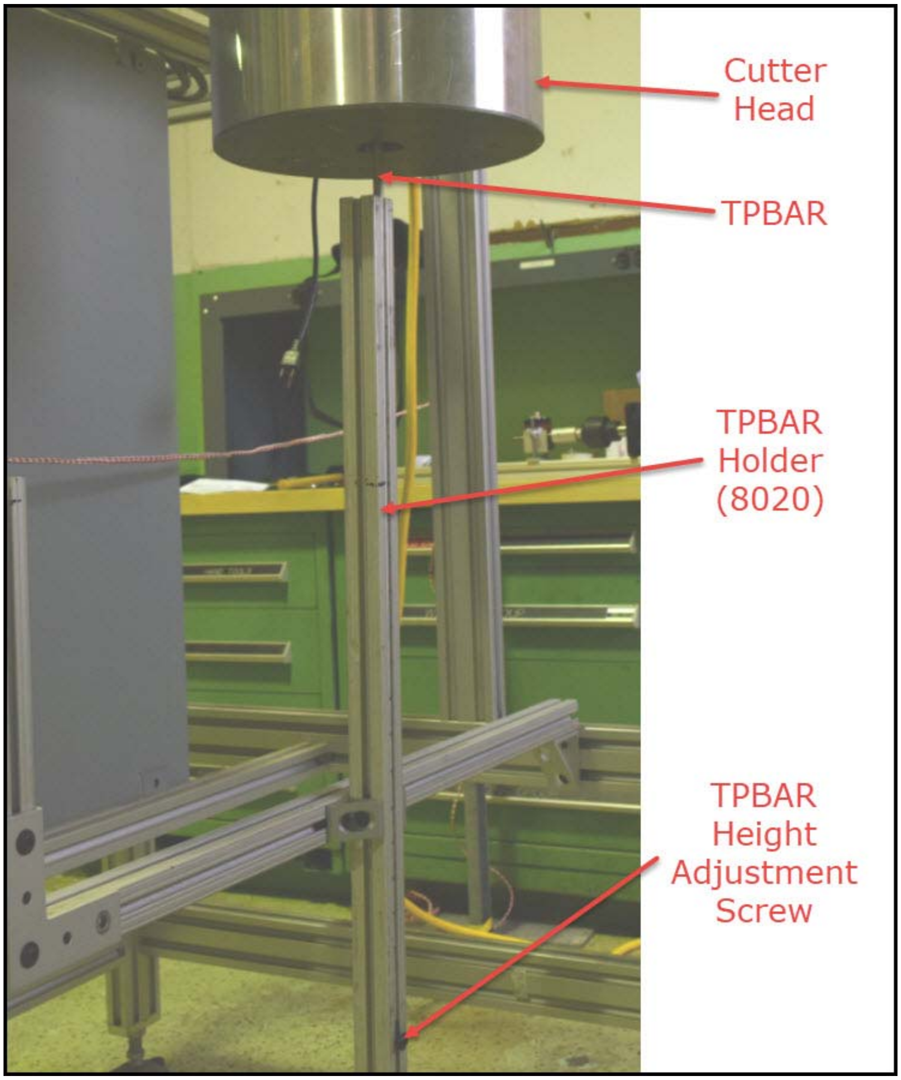

Figure 2-1. TPBAR Position

Four stick-on type thermocouples were placed 90^{o} apart on each surface of the test stand cutter head drive motor (Fig. 2-2). The associated data acquisition unit was set to capture 1 sample/second, which was believed to be more than adequate for this experiment. A higher sampling rate would lead to an unnecessary amount of data, as each complete breach cycle takes approximately 4 minutes with 6-8 breach cycles per test.

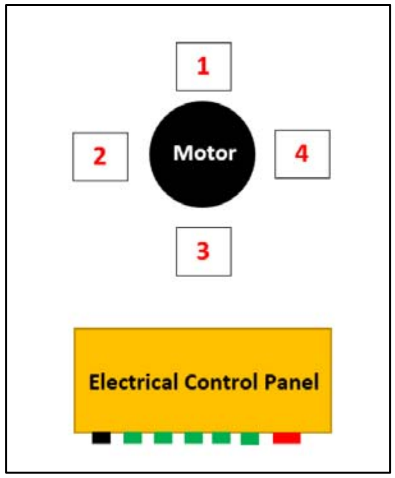

Figure 2-2. Thermocouple Layout

Concerns were expressed about the torque of the larger motor providing enough force to damage the cutter head. So, a different set of tests were developed to measure the torque produced by the larger motor to be installed on the test stand. It was decided to calculate the torque output of the currently installed motor to determine which torque limiter to purchase and install on the larger motor to prevent damage to the cutter head.

The torque testing module was set up to test the mechanical torque limiter. This was done to ensure that the amount of torque produced downstream of the mechanical limiter would not exceed the amount of torque produced by the U33 model test stand cutter head drive motor. A torque sensor was placed downstream of the mechanical torque limiter. One side of the torque sensor was held firmly in place, the other side was connected to the torque limiter and the new larger motor (U43 model) (Fig. 2-3) The larger motor was run, and the torque curves were recorded. This was done to ensure that the torque limiter functioned as specified by the vendor and that the cutter head would not be damaged by the U43 model motor.

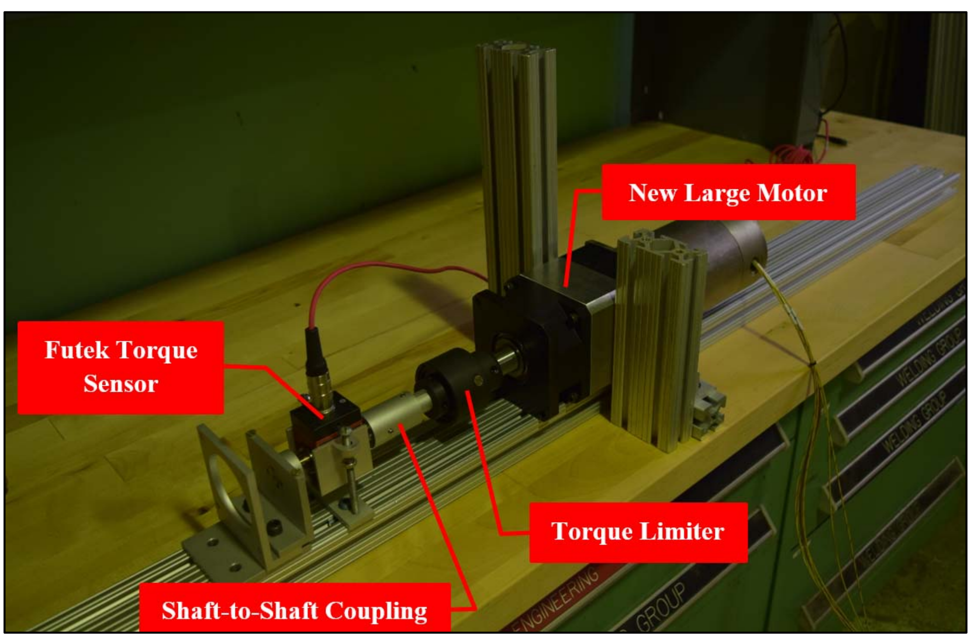

Figure 2-3. Torque testing Module

3.0 Results and Discussion

The first set of tests involved running the test stand cutter head drive motor (U33 model) until it reached approximately 100ºC. The graphs below display the data captured from 3 breaching cycle runs of the motor to 100ºC.

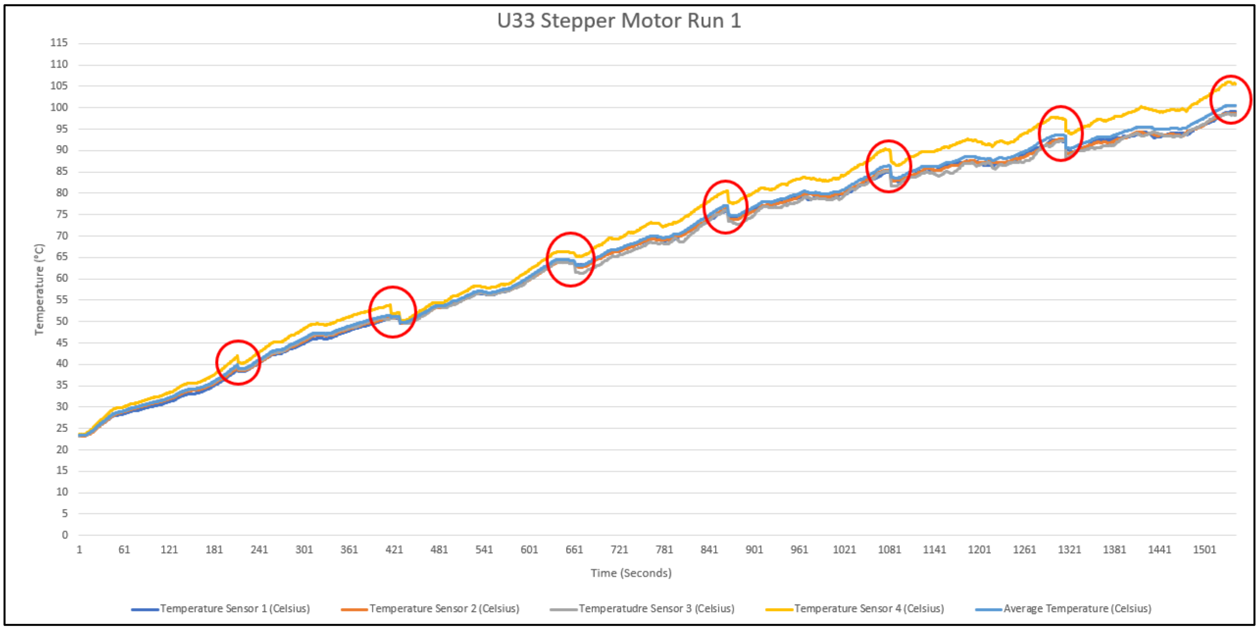

Figure 3-1. TRP Test Stand Cutter Head Drive Motor Temperature Data – Run 1

This figure shows the temperature profile of the test stand cutter head drive motor during the breaching of 7 mock TPBARs. Prior to beginning the test run, the TRP cutter head was driven to its lower and upper limits. This process is called "homing" and is required every time the TRP test stand is powered on and accounts for the slightly above room temperature starting point on all 3 runs. Each TPBAR breaching cycle takes approximately 240 seconds. This has been identified as the small spikes circled in red in the figure. The small drop off is believed to be due to moving the TPBAR to be breached to its new position, allowing the motor to cool slightly. This process also occurs in the TRP cell in the TEF but takes slightly more time to position a new TPBAR to be breached.

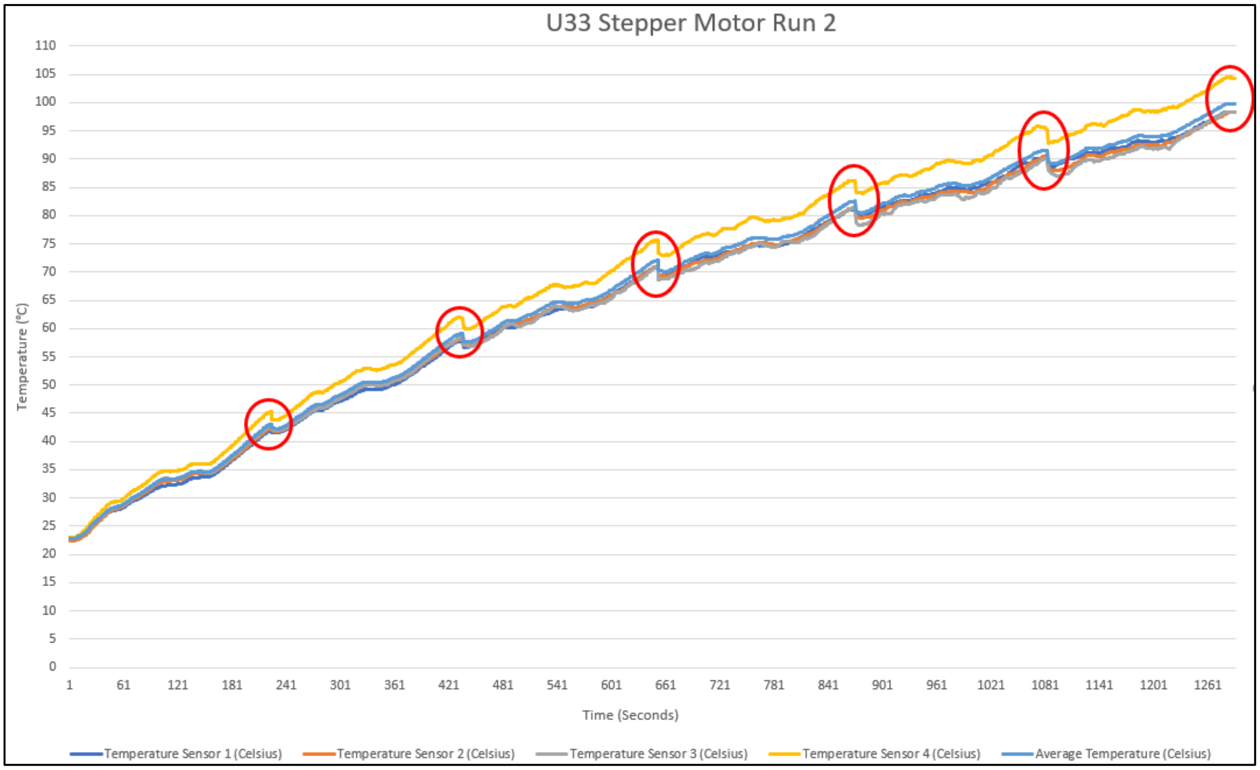

Figure 3-2. TRP Test Stand Cutter Head Drive Motor Temperature Data – Run 2

This figure shows the temperature profile of the test stand cutter head drive motor during the breaching of 6 mock TPBARs. Fewer TPBARs were able to be breached before reaching 100ºC in run 2. This run was completed 4 days after run 1 was completed, so there was adequate cooling time between runs. The reason for the decrease in number of breaches was not immediately clear during the testing.

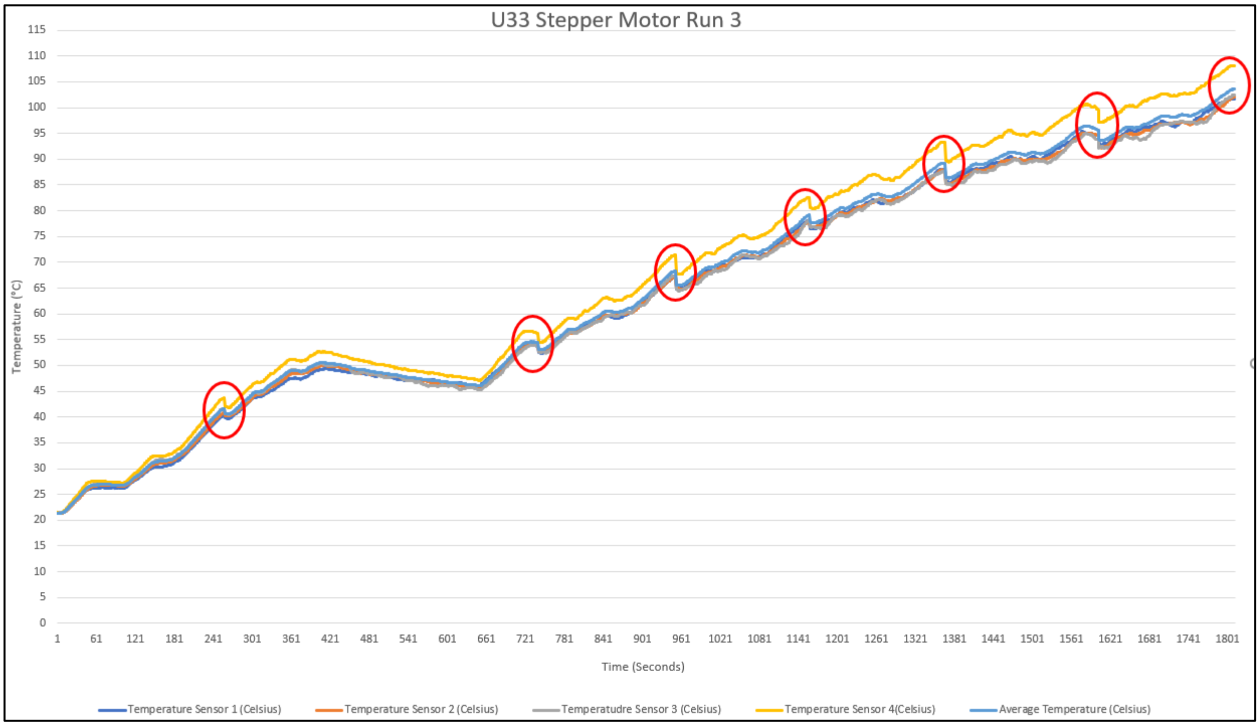

Figure 3-3. TRP Test Stand Cutter Head Drive Motor Temperature Data – Run 3

This figure shows the temperature profile of the test stand cutter head drive motor during the third and final run. A total of 8 mock TPBARs were breached during this run. There is a drop off just after the second complete breach (not identified with a red circle). The decrease in temperature was due to the failure of a heel to fully exit the cutter head. The system was stopped, and the situation was analyzed. It was found that the heel was stuck in the cutter head but could be easily removed. The heel was safely removed with the emergency stop button engaged and then cutting operations were resumed. This led to a total of 8 mock TPBARs being breached before 100ºC was reached.

Torque data was also captured using the torque testing module. This data was captured to ensure that the installation of the larger motor and torque limiter would not damage the cutter head and its internal components. The larger, U43 model motor, was tested a total of 3 times.

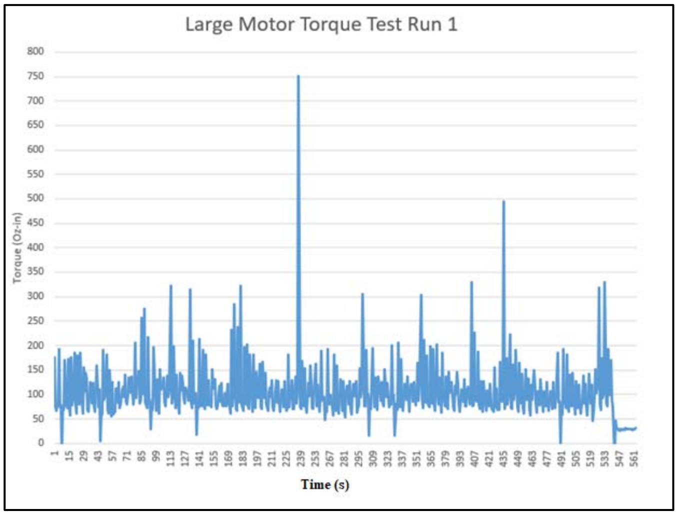

Fig. 3-4 Torque Test Run 1

Figure 3-4 shows the torque in Oz-in. experienced by the torque sensor downstream from the torque limiter for run 1 of the torque testing module.

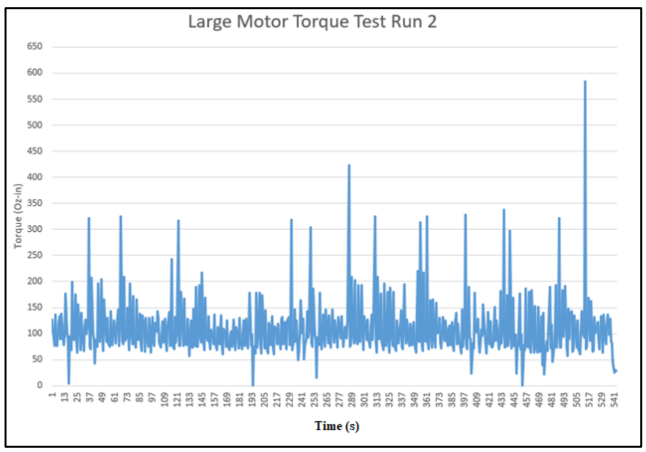

Fig. 3-5 Torque Test Run 2

Figure 3-5 shows the torque in Oz-in. experienced by the torque sensor downstream from the torque limiter for run 2 of the torque testing module.

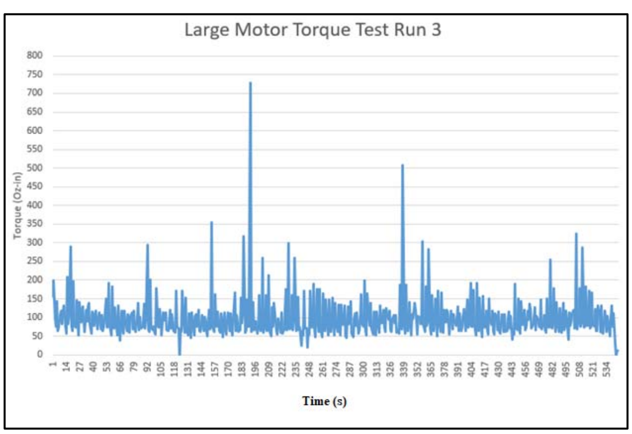

Fig. 3-6 Torque Test Run 3

Figure 3-6 shows the torque in Oz-in. experienced by the torque sensor downstream from the torque limiter for run 3 of the torque testing module. The 3 figures show the same trend, which means the torque limiter is consistent. However, the torque limiter was set to 350 Oz-in. and allowed torque values of up to 700 Oz-in.

As mentioned previously, the heat load produced by auxiliary equipment necessary to breaching operations, but not directly responsible for the breaching of TPBARs was analyzed. The turret and collet drive motors were not analyzed, because no motor was found in FY19 that could operate more efficiently or be cooled more effectively. Additionally, the turret and collet drive motor duty cycles are drastically lower than the duty cycle of the cutter head drive motor.

Currently the TRP hot cell is lit by four (4) 175W Lithonia Lighting metal halide flood lights. Each of these lights is designed to deliver approximately 13,000 lumens, giving a ratio of 74 lumens per watt. However, the metal halide light bulbs within the flood light produce light in a 360-degree arc. The design of the flood light fixture redirects as much light as possible out into the cell, typically about half of the lumens are directed into the TRP cell. Meaning the metal halide lights have a field efficiency of ~50% and are effectively providing 6,500 lumens of light to the TRP cell (37 lumens per watt effective).

LED lights have a similar lumen to watt ratio (~38-40 lumens per watt), but LEDs emit light only in a 180-degree arc. This gives LED lights a higher field efficiency as they will be able to produce the same effective number of lumens for about half of the watts of a metal halide light. This means an LED light of about 80-90W will produce the same effective number of lumens as a 175W metal halide light. It is expected that installing LED lights in place of the metal halide lights would halve the overall heat load produced by the lights in the TRP cell. These lights remain on even when the TRP cell is not in use, which would provide a significant reduction in the heat load within the TRP cell.

Additional work was executed to prepare for the return of the test stand which involved the fabrication of various adapters and a heat sink to be used with the U43 model motor. An adapter was fabricated in order to allow the larger motor to be installed on the test stand. The installation and testing of the larger motor was never completed as the larger motor arrived on site just about the time the test stand was removed from SRNL and sent to an offsite vendor. The test stand was not returned to SRNL during FY20.

4.0 Conclusions

FY19

There were no motors that are more efficient or contain internal cooling that could be easily installed in the TRP cell. Motors with internal cooling often relied on a closed or open loop water cooling system, which could not be installed in the TRP hot cell. The motor specified by the OEM was chosen to operate at optimal RPM/torque for operation of the cutter head.

Forced convective cooling provided by an electrically powered fan would be difficult due to dose within cell. Electric fans would fail rather quickly and need to be replaced. The replacement frequency of the fan would also be inconsistent and would still not wholly fix the overheating issue.

A dual motor system was not feasible due to space constraints. Both the two motors and the torque swapping system between the two motors would be very complex and quite large.

Installing a larger motor was found to be the most cost-effective and easily implemented option. A larger motor can produce the required torque while drawing less amps and in turn, generating less heat. However, the larger motor can produce torque in excess of original motor which could lead to damage to the cutter head. A mechanical torque limiter will be required if the larger motor is to be installed in the TEF facility.

The torque of the larger motor can and should also be limited in the motor control software by limiting the number of amps that can be drawn. Additionally, the mechanical torque limiter will provide a second, completely separate mechanism that will prevent over torque events and damage to the cutter head. The results of the torque limiter testing raised concern about the efficacy of the purchased torque limiters. Due to the information gathered during these tests, the installation and testing of the larger motor in FY19 was halted due to the concern that damage to the cutter head could still be possible even with the torque limiter installed.

It was found that the smaller motor overheats after about 6-8 breaching cycles in both the TRP hot cell and in building 723-A (ambient air). The smaller motor generates the most heat returning to the “home” position after a cutting operation is complete. The return to “home” causes the motor to run without stoppage for approximately 75 seconds. The motor doesn’t produce much torque in this operation, but it runs significantly longer than other steps in the cutting operation. One of the thermocouples attached to the test stand cutter head drive motor read higher than the others, implying that the heat generated in the motor is not uniform. If this is true in the motor installed in the TRP cell, it may be possible to concentrate forced convective cooling on this particular area.

FY20

A heat load analysis of the hot cell was complete to determine if any equipment could be replaced to reduce the amount of latent heat within the hot cell during cutting operations. No motors could be replaced with high efficiency motors as none were found in FY19. Most motors do not run very long in comparison to the motor driving cutting/gripping of the TPBAR. The vacuum cleaner could be replaced but would require significant design changes. Replacement of the lights would provide the greatest reduction in heat load in the cell and require the least amount of modification to the TRP cell. The lights are on 100% of the time the TRP system is operating and even when the system is not operating. The current lights are metal-halide contained in fixtures. The flaw with metal halide is that they produce light in a 360° arc and a fixture is used to reflect most of the light back into the cell. Only about half of the lumens produced by this light are seen, giving the metal-halide lights an efficiency of about 50%. Replacing the metal-halide lights with directional LEDs would reduce the amount of heat produced in the cell by approximately 40% since LEDs will only provide light in the direction they are aimed.

In FY 20, we learned a second vacuum hose exists for cleaning the floors of the TRP hot cell. It was determined that this could be used to provide some amount of forced convection over the TRP cutter head drive motor. A small fixture needed to be fabricated to hold the vacuum hose in the correct place to pull Nitrogen over the cutter head drive motor and/or attached heat sink. A heat sink that fits on the larger motor was fabricated to be used in conjunction with the forced convective flow. No testing was able to be complete in FY20 due to the removal of the test stand to an off-site vendor.

5.0 Recommendations, Path Forward or Future Work

The path forward should include testing of the larger motor with a tested torque limiter installed. The torque limiter should be tested on the torque testing module to ensure that the torque limiter will not allow spikes in torque that could damage the cutter head.

A new heat sink was fabricated in anticipation of the return of the test stand. This heat sink should be attached to the larger motor with the tested torque limiter installed and another set of breaching tests should be completed. Another set of tests should be conducted with forced convective cooling provided over the larger motor with the heat sink installed during breaching cycles. The forced convection should be produced by a shop vacuum with similar flow rate to the vacuum installed in the TRP cell.

6.0 References

Drawing AC29344A-00007
Drawing AC29344A-00008
Drawing AC29344A-00009
Drawing AC29344A-00010
Drawing AC29344A-00011
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Drawing AC29344A-00028

Drawing AC29327A-00214 E1902200003
Drawing AC29327A-000672
Drawing AC29327A-000751 Turntable Drive Motor Assy
Drawing AC29327A-000786
Drawing AC29327A-000806 Vacuum System
Drawing AC29327A-000831 In Cell Lighting Assy
Drawing AC29327A-000838 TRP Power Distribution Panel
Drawing AC29327A-000847 TRP Wiring Diagram
Drawing AC29327A-000881 Interconnection Diagram
Drawing AC29327A-000889 TRP Cable Assembly
E-EW-H-8761 Sheet 0 – TRP Electrical Block Diagram

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