Redus Engineering
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Project - Extending Operating Depth of the Minn Kota 101 Lower Unit W/O Pressure Compensation	Proj. Ref.	Pages 1 of 58	File Ref. TR-24-01

Minn Kota 101 Lower Unit W/O Pressure Compensation

Parker FlexiSeal Rotary Seal

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March 21, 2024

Rev No	Date	Description	Issued By	Checked By	Approved By
1	3/10/24	Issued as Draft	CLR/AS	AS	CLR
2	3/21/24	Added tapered to seal adapter	CLR/AS	AS	CLR

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1. EXECUTIVE SUMMARY

This report covers the testing of the Minn Kota 101 Lower unit, part no. 2886289, first to establish the maximum depth the unit can operate with off-the-shelf lip seals and again with the Parker FlexiSeal Rotary Seal part no. 0301-FC-S-187-00500-260-S-C-M.

The test was conducted in a test cell capable of achieving a pressure of 600 psig or 1,350 fsw. Test Cell pressure and temperature as well as the MK-101 motor current were logged on a PLC.

The simulated depth in the test cell was increased in 10 psi increments until the 1,000 fsw target depth was achieved.

Five test cases were evaluated, three with the stock Minn Kota 101 Lower unit and two with a modified Minn Kota 101 Lower unit that utilized a high-pressure Parker FlexiSeal Rotary Seal. Modification to the lower unit to accept the new seal requires the fabrication of a custom seal adapter part that reduces the bore to match the new lip seal. Drawings are included to fabricate the seal adapter.

Key findings were that the off-the-shelf Minn-Kota 101 lower unit could be used without pressure compensation to a depth of 300 fsw and that replacing the dual lip seals in Minn-Kota 101 lower unit with a Parker FlexiSeal Rotary Seal part no. 0301-FC-S-187-00500-260-S-C-M, the maximum depth can be increased to at least 1,000 fsw.

Utilizing this high-pressure lip seal requires a custom seal adapter to be fabricated.

2. INTRODUCTION

The goal of this project was to determine if utilizing an HP lip seal from Parker could enable the use of the Minn-Kota 101 lower unit (LU) thruster without pressure compensation down to 1,000 fsw. A test cell was modified to hold the LU with its skeg removed and provide power to the LU motor so that it could be turned on while under pressure in the test cell to simulate an operating LU at depth. As a control, the OTS Minn Kota 101 LU was tested dynamically to determine the maximum operating depth of the unit without pressure compensation.

To conduct the experiment, a test cell was utilized shown in Figures 5-6. A hydraulic power unit (HPU) was used to generate the pressure for the test with a 50:50V solution of fresh water and ethylene glycol (EG) as the media. The water:EG solution was chosen to prevent damage to the HPU and provide good heat transfer from the LU as no active temperature control was used on the test cell. The adjustable pressure relief valve for the pump was set at 500 psig which set the maximum pressure the test cell could achieve. A needle valve, in the bypass line back to the HPU reservoir, was used to adjust the pressure manually in the test cell.

Figure 1 – Minn Kota 101 Lower Unit

3. CONCLUSIONS

1) The off the shelf Minn-Kota 101 lower unit can be used without pressure compensation to a depth of 300 fsw. While there is some variablity around the onset depth for leakage past the dual lip seals, 300 fsw is a conservative value. In one case, leakage did not occur until 810 fsw.
2) By replacing the dual lip seals in the Minn-Kota 101 lower unit with a Parker FlexiSeal Rotary Seal part no. 0301-FC-S-187-00500-260-S-C-M, the maximum depth can be increased to at least 1,000 fsw. Utilizing this high pressure lip seal requires a custom seal adapter to be fabricated.
3) At a depth of 300 fsw, the current draw was 23% lower with the Parker seal than using the OEM seal. However, it should be noted that the unit was run with no prop attached in all tests. The 23% reduction represents an efficiency gain in shaft drag only, not in the motor's total current draw with a prop installed.
4) In all test cases (fresh water only) with the original seal set, even when leakage occurred, the lower unit continued to operate.
5) No mechanical failure of the LU housing was observed.

4. SETUP

3.1 Minn Kotta 101 Shaft Seal

The Minn Kota 101 shaft lip seal is designed to provide a watertight seal around the propeller shaft in the lower unit of Minn Kota trolling motors. In addition to the shaft seal, there are four other seals as shown in Figure 2, two for the thru bolts and two for the end caps. Each of these are potential leak paths. Figure 3 is a part diagram for the 4" Minn Kota 101 lower unit.

Figure 2 – Seal set for Minn-Kota 101 lower unit. MK part number 2889460

There is no available published technical information from Minn Kota on the maximum operating depth of these lower units. In the Personal Submersibles (Psub) community, these lower units have been widely used as thrusters and pressure compensated pneumatically or hydraulically. Pressure compensation in the Psub community has historically been an issue with failures seen using both techniques. The goal of the study is to measure, in a controlled test, the depth at which the OTS seal system fails to establish a control point against which to compare the performance of a lip seal that is designed for higher differential pressures.

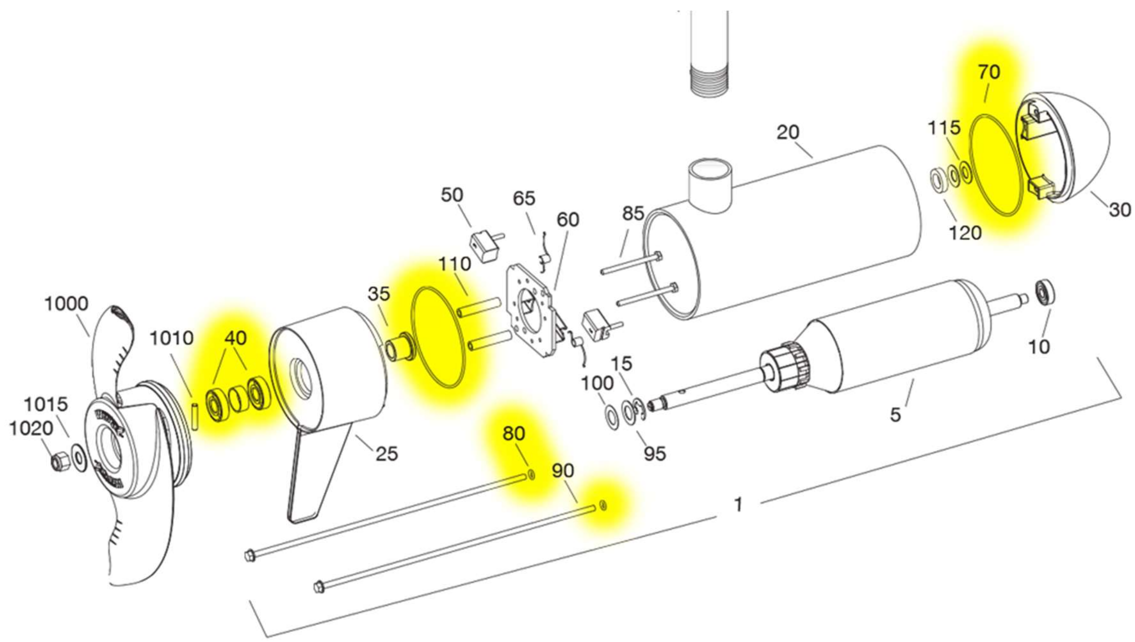


Figure 3 – Part diagram for the 4" Minn Kota 101 lower unit

3.2 Selection of New Seal

The FlexiSeal Rotary Shaft seals made by Parker can be ordered in a huge number of configurations. There are so many possible combinations of attributes, that these seals must be made to order rather than stocked, with a lead time of about three months. Below are the configuration choices we made to optimize the seal for application in a submersible thruster.

The part number is **0301-FC-S-187-00500-260-S-C-M**, which breaks down as follows:

0301 → The base PTFE material is graphite filled. This choice of filler material lowers the coefficient of friction.

FC → FlexiSeal (product family) with an o-ring between seal and gland centered on its outside face.

S → The lip geometry chosen is the "Scraper," which was selected because it is designed to prevent foreign objects such as grains of sand from getting under the lip.

187 → Dimensional attribute. Half the difference between the shaft diameter and the bore diameter is 0.187" .

00500 → Dimensional attribute. The seal is for a 0.5" diameter shaft.

260 → Dimensional attribute. The seal height is 0.260" .

S → The spring material is stainless steel.

C → The spring is a "canted coil" spring. This type is recommended for friction-sensitive applications.

M → The spring has a medium load range (tension.) This is a choice that seeks a compromise between friction, sealing ability, and wear.

3.3 Fabrication of the Seal Adapter

The selected seal has an OD of 7/8" and the Minn Kota brushed end cap has a seal gland OD of 1 -1/8". These "round numbers" mean that a 6061 aluminum tube is readily available in a matching size. The tubing does need to be turned on a lathe for a more exact fit, but the machining effort is minimal.

In order to achieve a precise interference fit with the Minn Kota endcap, the adapter was first machined to a few thousandths of an inch from the target dimensions, and then finished by hand with emery tape, test fitting the two parts and sanding iteratively.

One challenge is that the Minn Kota brushed-end caps seem to come in two different finishes. It is possible these are salt versus fresh water versions of the product. The black ones appear to be anodized inside the gland, which means that their dimensions are precise. But the white endcaps are powder coated, which gives them a rougher surface and uncertain diameter. The test was conducted using a white endcap. The final fit between insert and endcap was done by lightly sanding the powder coat inside the gland with a Dremel tool and flap disc. The goal was to have sufficient interference that finger pressure alone would not push the insert to the bottom of the gland, but that only very light taps with a mallet would do so. See Appendix D for drawings of the seal adapter. See Figures 11-12 for pictures of the seal adapter.

Figure 4 – Parker FlexiSeal Rotary Seal (0301FCS180700500260SCM)

3.4 Test Cell Setup

The purpose of the test cell was to enclose the MK-101 lower unit in a pressure vessel that was instrumented to measure the pressure and temperature in the cell as well as the current to the motor while slowly increasing pressure to determine the onset of leakage though the shaft seal. The intent of the test was to first test the maximum depth the OTS MK-101 can withstand without pressure compensation and then to repeat with a high pressure Parker shaft lip seal. All test cases were with the MK-101 rotating at approximately 1,500 RPM. The maximum pressure for the test sequence was set at 500 psig with a pressure relief valve and also with PLC ladder logic. A hydraulic power unit (HPU) was used to develop the pressure. All tests (Cases 1-5) were performed a drip tube connected to the MK-101 motor housing that passed through the wall of the test cell enabling a visual detection of the first drops of liquid coming from the motor. The test cell is shown in Figure 5.

As seen in Figure 6, a 3,000 psig pressure transmitter was calibrated and wired into the Automation Direct 205 series Programable Logic Controller (PLC) analog input card. While it would have been better to use a 0-600 psig pressure transmitter, using the existing transmitter was a concession to cost. A 600 psig bourdon pressure gauge was also installed to display a manual pressure measurement. The PLC hardware as well as the I/O for the test is shown in Appendix A. A positive displacement pump in the HPU was used to develop the pressure. An RTD was installed in the test cell to measure the temperature. A vernier needle valve was used in the bypass line back to the HPU reservoir to manually regulate cell pressure by bypassing flow to the cell. The minimum pressure in the cell was 8 psig with the HPU running.

For Cases 1 - 5, the test cell was configured with the drip tube as seen in Figure 5. Figures 6 shows the process flow diagram the cell. In Appendix D, the last drawing is the wiring diagram for the test cell.

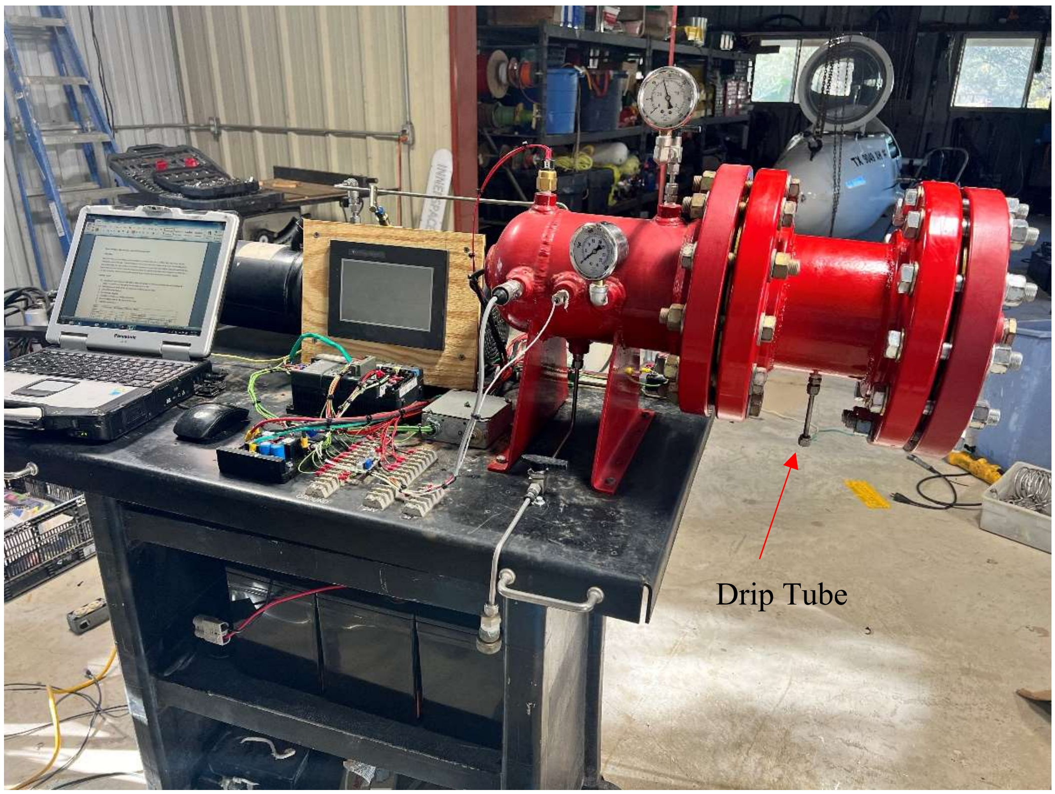


Figure 5 – Test Cell with MK 101 lower unit installed with drip tube

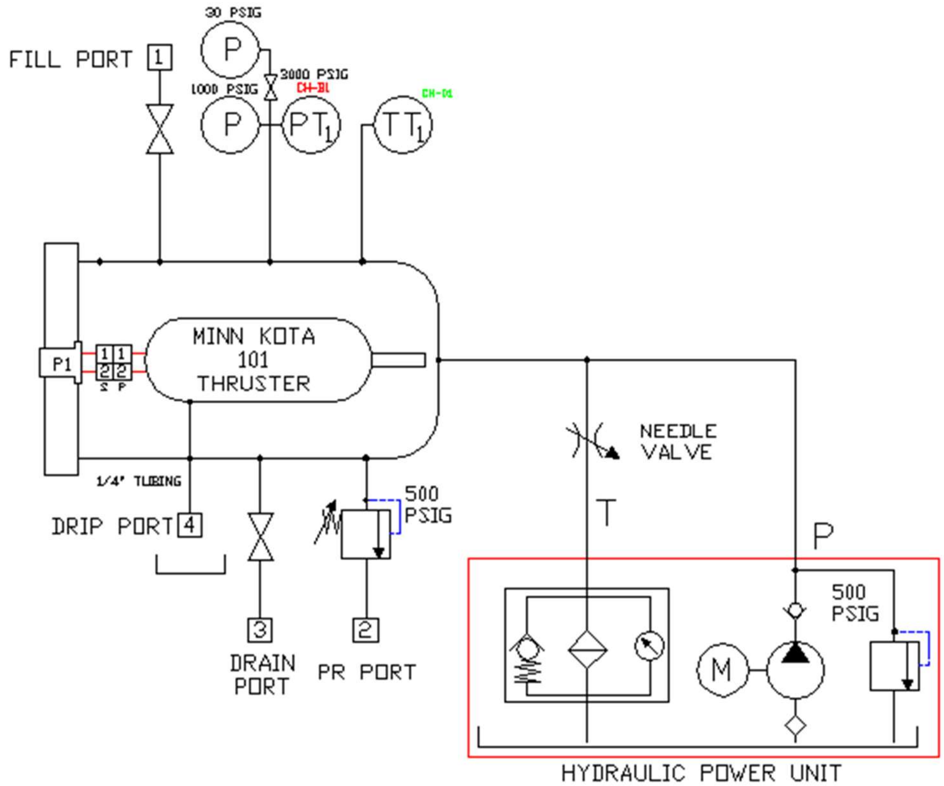


Figure 6 – Setups for Pressure Cases 2-6, Drip Tube

A 50:50V solution was made of ethylene glycol and fresh water. The cell was manually filled with this solution for each test case. The intent of the solution was to provide a fluid that would enable good heat transfer from the motor to the cell wall and then to the environment as temperature was not controlled for the test. A set of Subconn inline connectors was used to connect the motor to a wet cable that was connected to an electrical penetrator through the cell wall.

The wiring diagram for the Minn-Kota 101 motor is shown in Figure 7. For this test, three Vestwoods 12.8V 100Ah LiFePO4 (VC12100Plus) batteries were connected in series for a nominal 36V. The Minn Kota motor controller is shown in Figure 8. The potentiometer on the controller was used to manually set the motor speed to its maximum value in the forward direction.

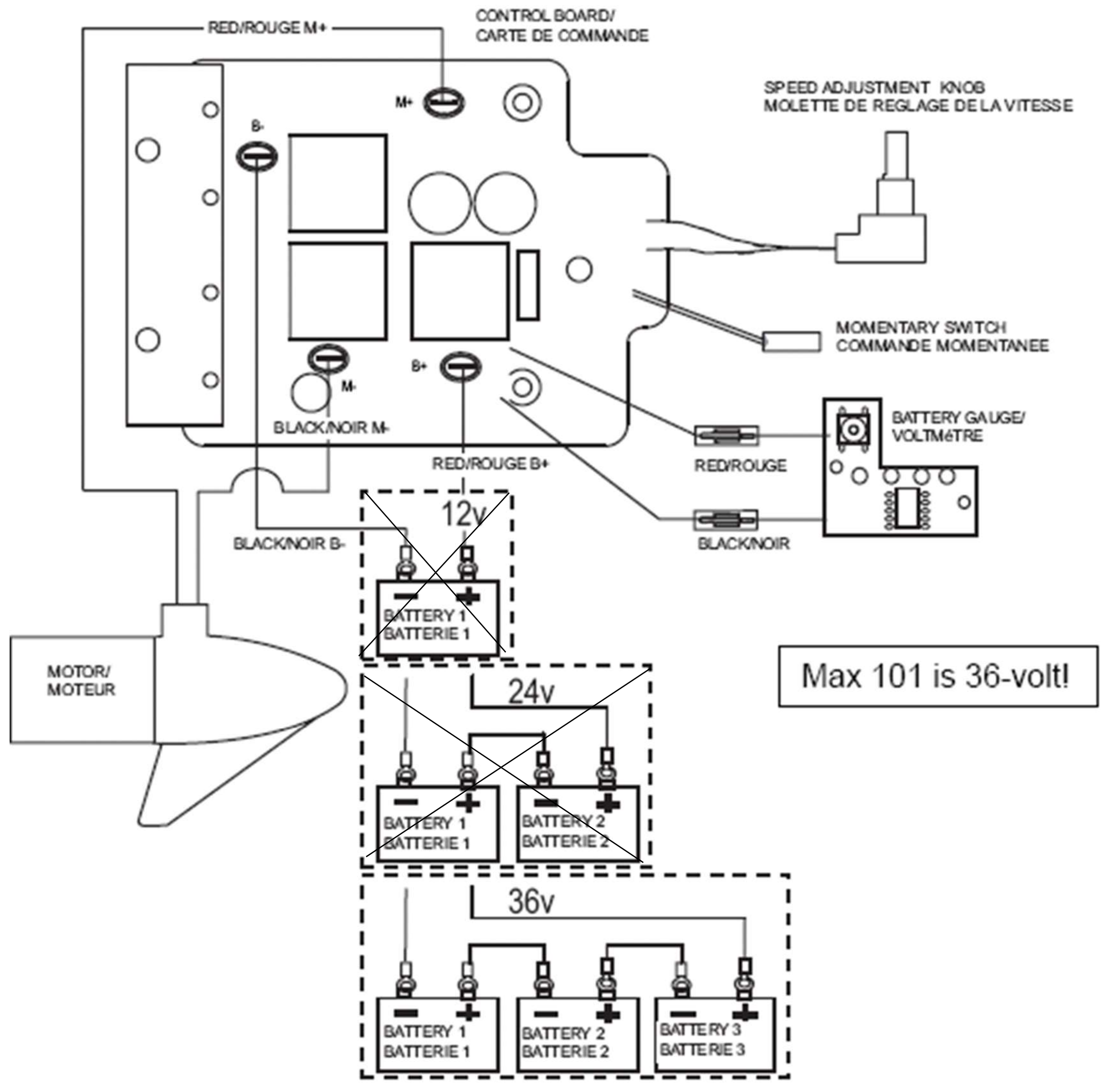


Figure 7 – Wiring Diagram for MK-101 using the 2774037 control board

Figure 8 – Minn Kota 24/36V Motor Controller, 2774037

Figure 9 – MK-101 in test cell Connection between MK-101 and Drip Tube

The interface to the PLC was an AutomationDirect EA9-T7CL-R touch screen monitor as seen in Figure 10. Displayed were the cell pressure, associated depth assuming saltwater density of 64/cu-ft, cell temperature, battery voltage and current to the motor. An indicator light which showed the state of the 10 psig overpressure switch was also displayed. The over-pressure switch and its indicator are legacy implementations on an earlier version of the test cell and are not used for the five test cases. There were three alarms programed into the PLC ladder logic, Alarm 1 was a HP alarm, Alarm 2 was a low voltage alarm on the battery bank and Alarm 3 was a high current alarm. The MK-101 typically could see a max current of 46A with a propellor. In this case, a value of 5A was set for this alarm as no prop was installed on increased current would only be caused by increased torque due to added pressure on shaft lip seal.

Figure 10 – HMI Home Screen - AutomationDirect C-More EA9-T7CL-R

Figures 11 and 12 show the custom seal adapter with external dash 022 O-rings installed. See drawings AS-CLR 01 and AS-CLR 02 in Appendix D for details of the Seal Adapter.


Figure 11 – Minn-Kota 101 Lower Unit Seal Adapter – horizontal view


Figure 12 – Minn-Kota 101 Lower Unit Seal Adapter – vertical view

5. DISCUSSION OF RESULTS

Table 1 shows the cases that have been evaluated. Cases 1, 2 and 5 are with the original Minn Kota 101 Lower Unit dual lips-seals installed. Case 3 and 4 are with the high pressure Parker FlexiSeal Rotary Seal. Each case used a drip tube connected to the body of LU that enables a precise determination of the onset of leakage into the LU. Each of these cases is discussed in the sections below.

Table 1 – Test Cases

No.	Case Description	Section
1	Original Lip Seals, Leakage Onset Depth & Flowrate	5.1
2	Original Lip seals, Leakage Onset Depth	5.2
3	Parker FlexiSeal Rotary Seal, Break-In	5.3
4	Parker FlexiSeal Rotary Seal, Leakage Depth	5.4
5	Repeat Original Lip Seals , Leakage Onset Depth	5.5

For each of these cases, the same LU was use with the exception of the brushed-end assembly. Two brushed-end assemblies were used, one that contained the OTS seals and the other the Parker seal. The same armature was used for all cases.

5.1 Case 1 - Original Lip Seals, Leakage Depth & Flowrate

Case 1 was developed to determine the onset depth for the leakage and the leakage flowrate. This was done by drilling and taping a hole in the bottom of the cylindrical section of the LU body near the bow end cap. This port location corresponds with one of the thru bolt slots between the permanent magnets. If any fluid penetrates the LU, it would immediately drain down and out through the drip port shown in Figure 5. To determine leakage flow rate, the drop count and time period over the count was taken manually. This gave the drops per minute (dpm). A measurement was made of the volume of a typical drop to get the flow rate.

Table 2 – Case 1, Test Date, Start and End Times and Elapsed Time

Test Date	2/24/2024
Start Time	17:24
End Time	20:56
Elapsed Time (hrs)	3.53
Elapsed Time (min)	212.00
Chamber Fluid(V:V)	(50:50) Water:Ethylene glycol

Case 1 pressure in the test cell and depth are shown is Figure 13. At an elapsed time of 38.3 minutes, the first drop appeared. At his point, the pressure in the cell was 80.3 psig. which corresponds to a depth of 180.3 fsw.

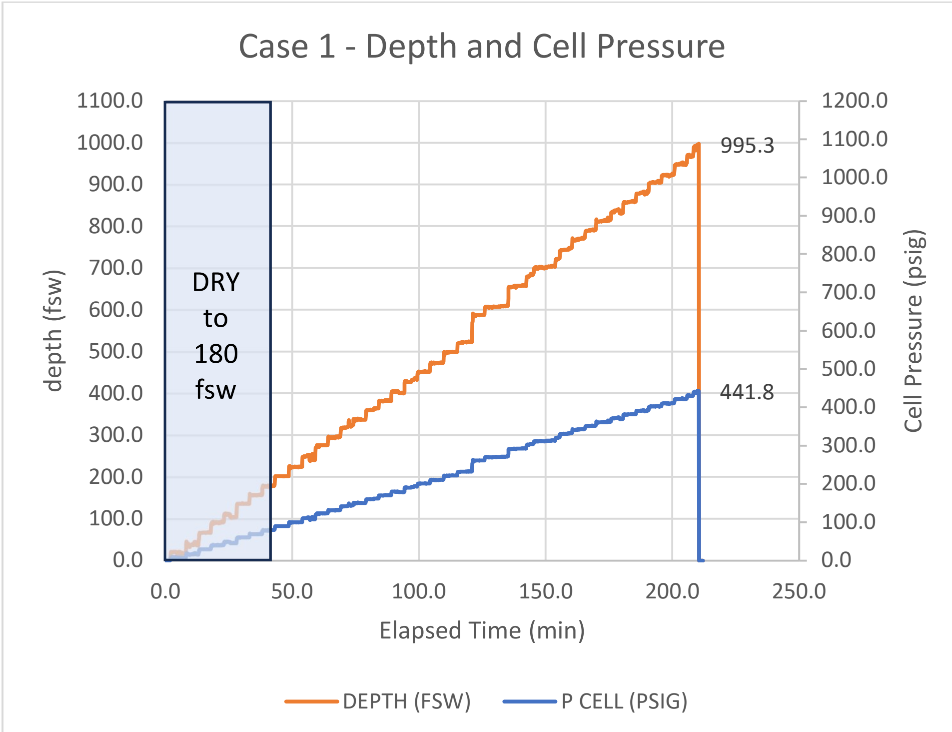


Figure 13 – Case 1, Depth and Cell Pressure

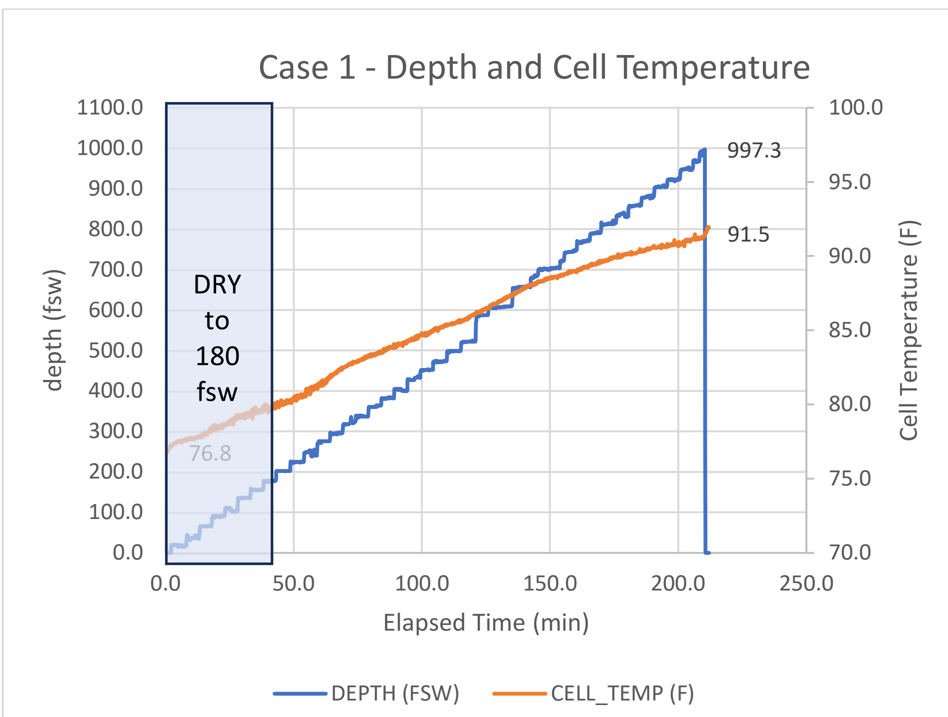


Figure 14 – Case 1, Depth and Cell Temperature

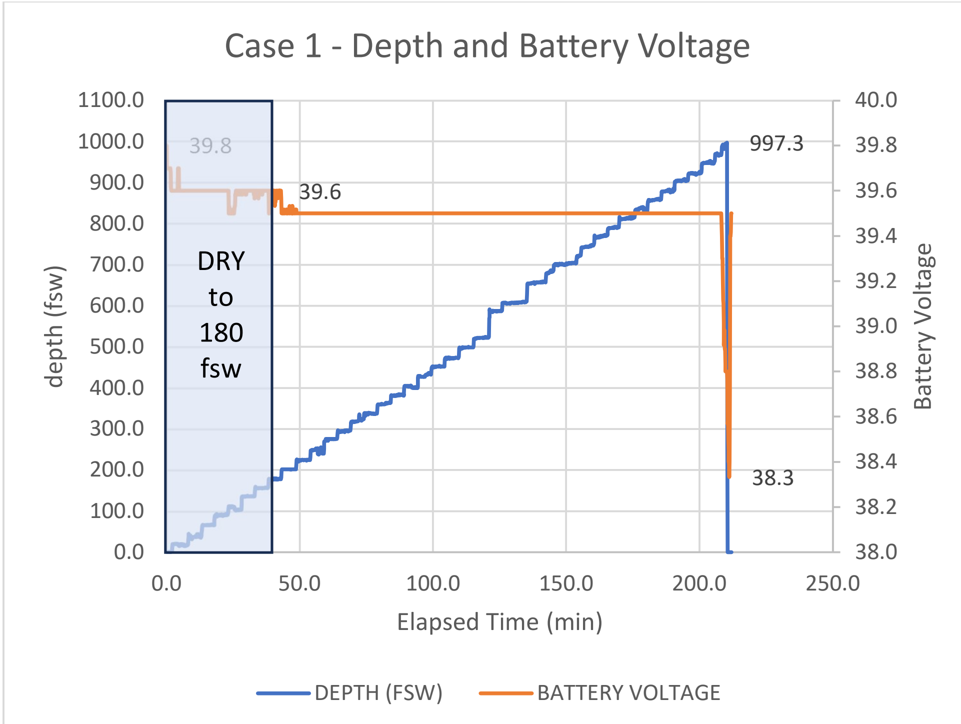


Figure 15 – Case 1, Depth and Battery Voltage

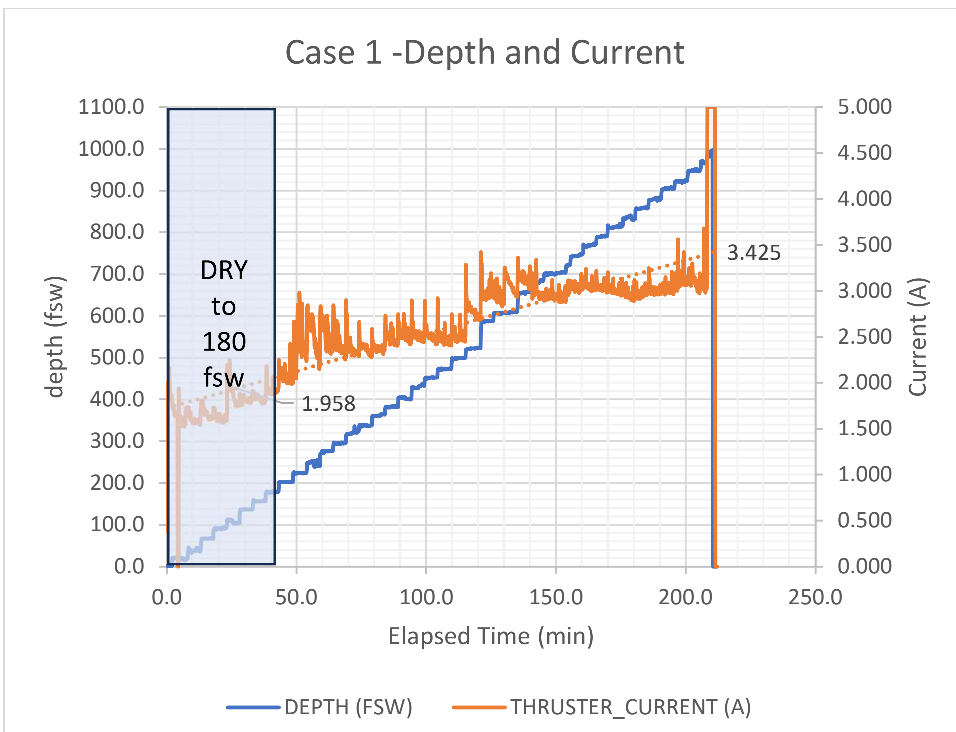


Figure 16 – Case 1, Depth and Current in Minn Kota-101 motor

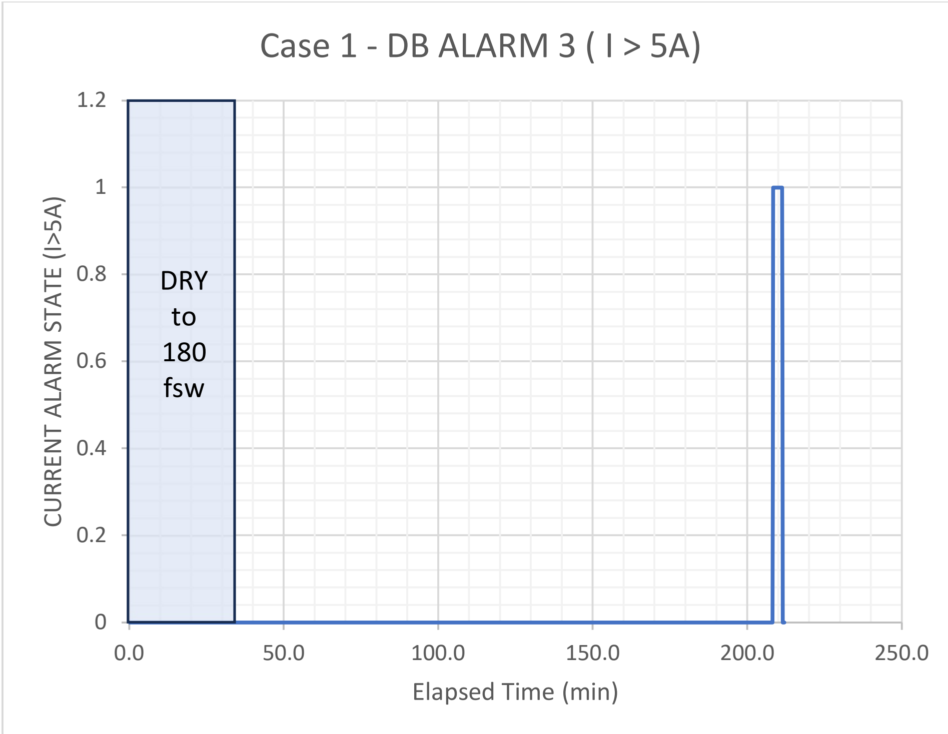


Figure 17 – Case 1, Alarm 2 (I > 5A)

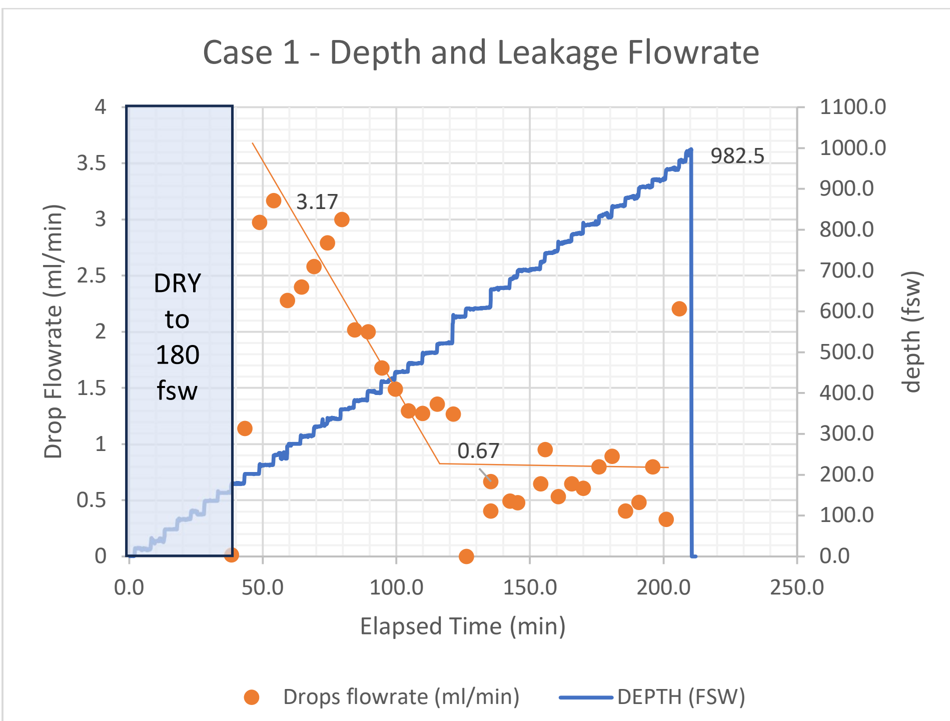


Figure 18 – Case 1, Drop flowrate (ml/min) and depth (fsw)

Key Findings from Case 1

1) OTS MK-101 with the stock seals reached the onset of dripping at 180 fsw (80.3 psig). This occurred at an elaspsed time of 38.3 minutes.
2) Leakage flowrate dropped off as pressure increased.
3) Seal failed at 990 fsw as signified by a large flow rate at sn elapsed time of 208.5 mintues.
4) MK-101 continued to operate throughout.
5) Current increased linearly with pressure.
6) On post inspection, there was no obvious damaged parts. Dual lip seals were intact but cardboard spacer was soaked.
7) RTD worked correctly so no changes necessary for next tests.
8) At an elapsed time of 124.5 minutes, measured 132 drops that had a volume of 1 TSP (5ml) over 4 minutes, 1 sec. At this elapsed time the drop flow rate was calculated as 1.25 ml/min.
9) Volume of a single drop was calculated as 0.038 ml.
10) Flowrate of drip ranged from 3.17 ml/min to 0.67 ml/min.

5.2 Case 2 - Original Lip seals, Leakage Onset Depth

It was determined that a series of three more test be run sequentially to get a better value for the leakage onset depth.

Table 3 – Case 2, Test Date, Start and End Times and Elapsed Time

Test Date	2/26/2024
Start Time	13:14
End Time	17:46
Elapsed Time (hrs)	4.54
Elapsed Time (min)	272.20
Chamber Fluid(V:V)	(50:50) Water:Ethylene glycol

Case 2 test cell pressure and depth are shown is Figure 19. At an elapsed time of 81.4 minutes, the first drop appeared from drip tube. At his point, the pressure in the cell was 161 psig which corresponds to a depth of 361 fsw. See Table 4 and Figure 23 for leakage onset depths for each of the three runs.

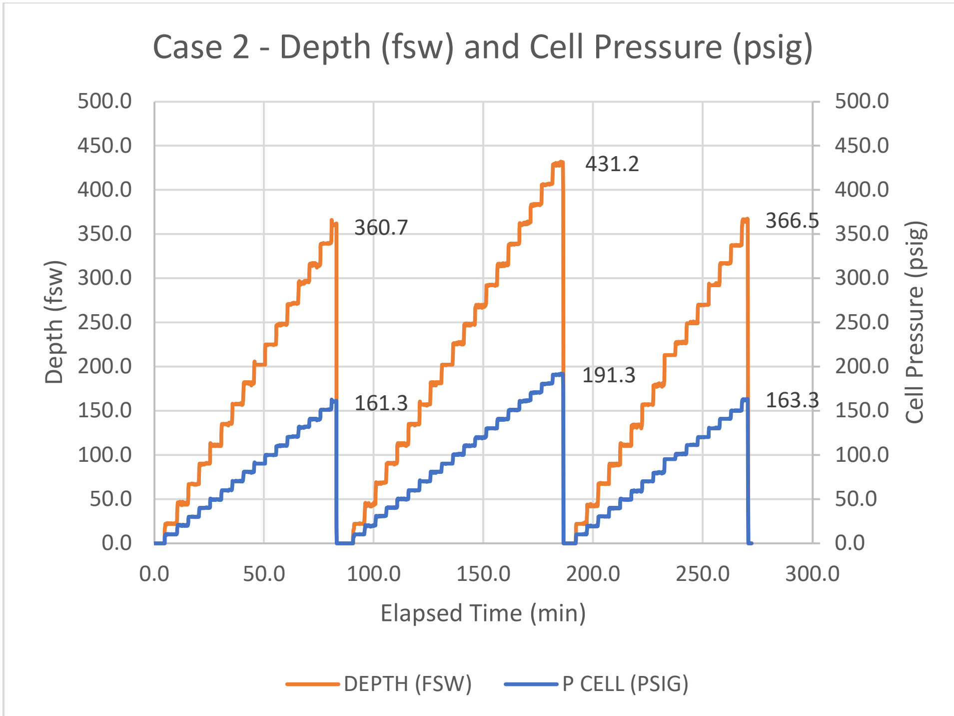


Figure 19 – Case 2, Depth (fsw) and Cell Pressure (psig)

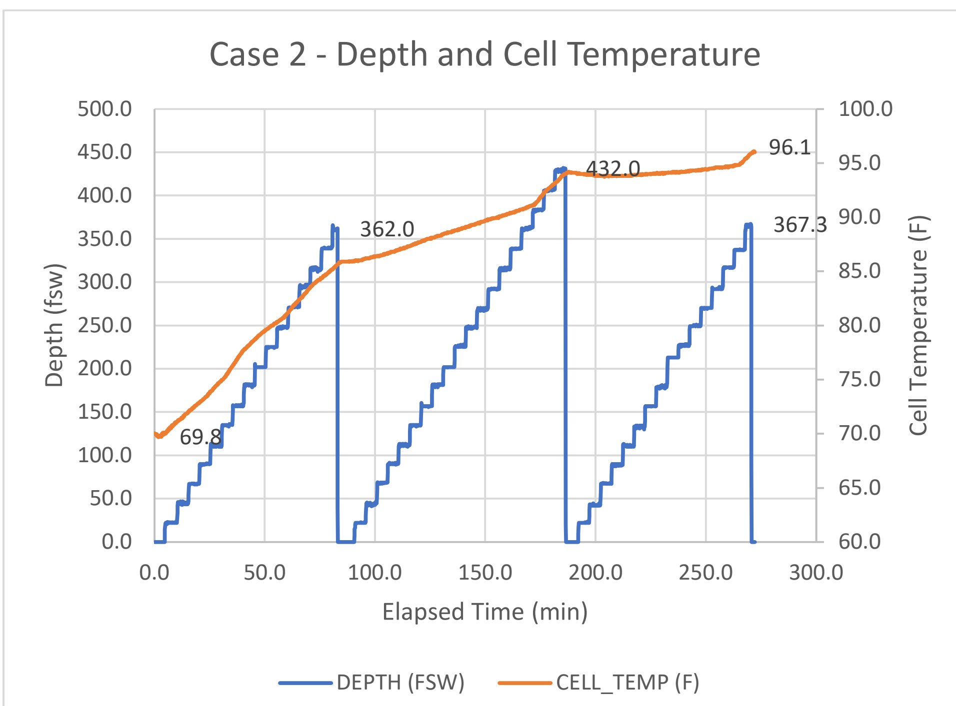


Figure 20 – Case 2, Depth (fsw) and Cell Temperature (F)

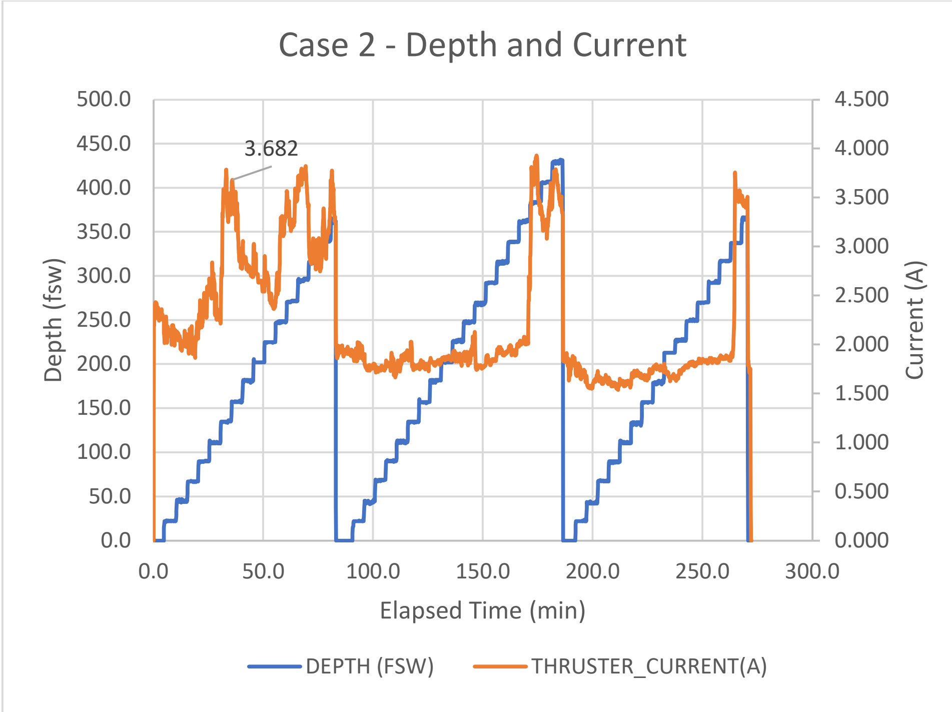


Figure 21 – Case 2, Depth (fsw) and Current (A

While current for Case 2 varied initially for run 1, lined out for runs 2 and 3 around 2 amps.

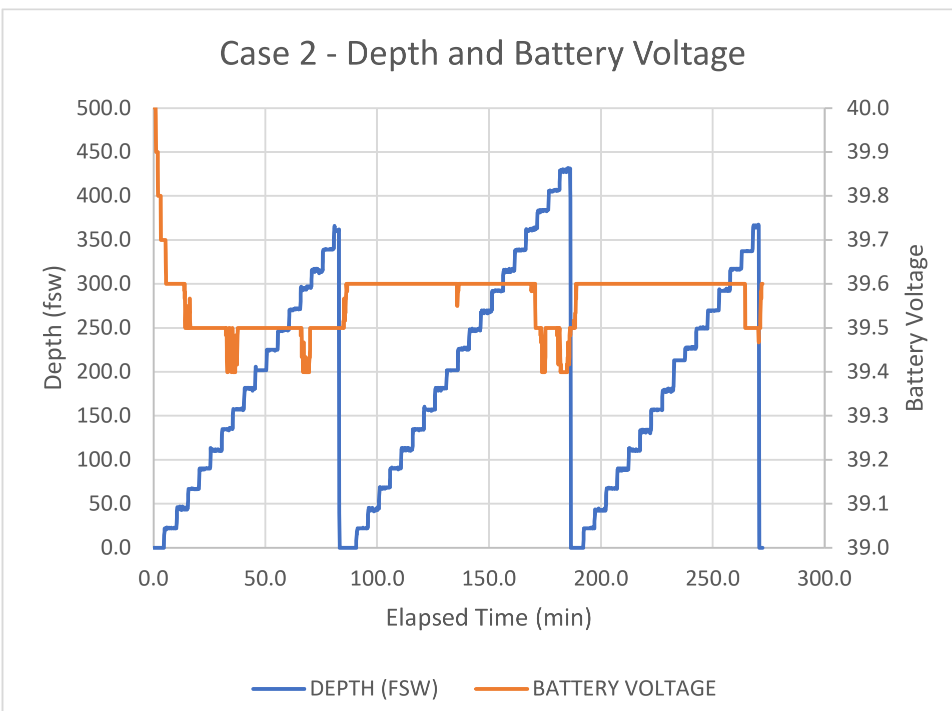


Figure 22 – Case 2, Depth and Battery Voltage

Table 4 – Case 2, Results for Onset of Leakage			
Test	Elapsed Time (min)	P (psig)	Depth (fsw)
1	81.4	161	361
2	184.9	191	430
3	268.9	162	364

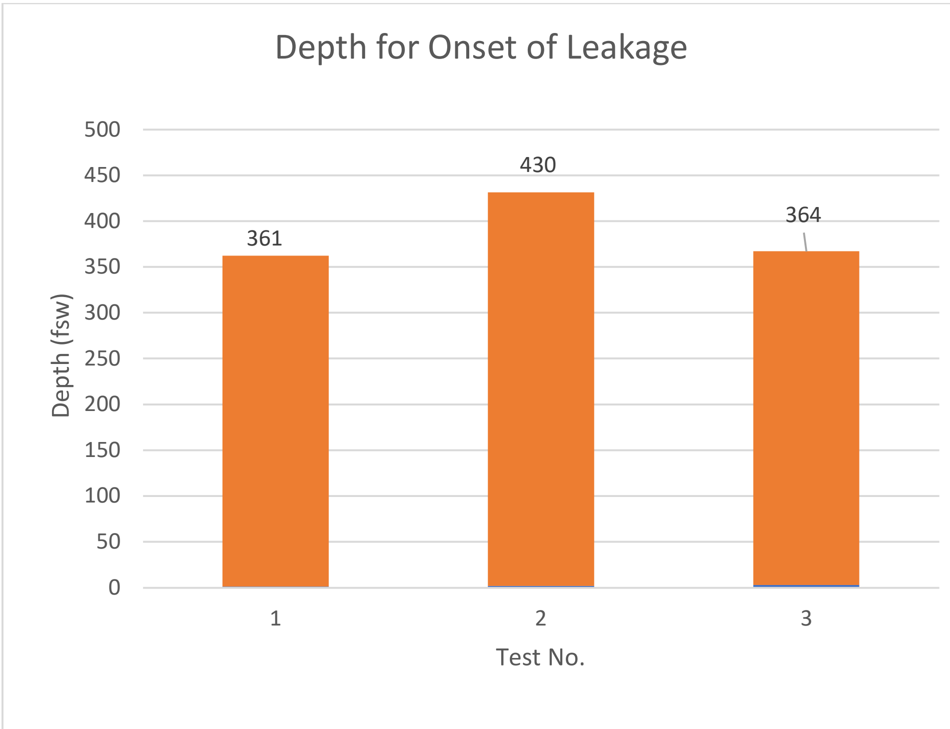


Figure 23 – Case 2, Depth for Onset of Leakage

<u>Key Findings from Case 2</u>

1) For the original MK-101 LU lip seals,the depths measured for the onset of leakage were 361, 430 and 364 fsw respectivley for runs 1, 2 and 3.
2) Maximum depth before leakage is higher (361 fsw) than the 180 fsw measured for Case 1. In Case 1, the LU flooded at 990 fsw as signified by a large flow rate at elapsed time of 208.5 mintues. This could have damaged the seal even though no obvious damage was observed.
3) In the minutes prior to the onset of dripping, current spiked to 3.5 A from a flat current base line of approximaly 1.8 A.
4) The average current to the motor over the three runs was 2.393 A at 300 fsw.
5) MK-101 continued to operate throughout.

5.3 Case 3 - Parker FlexiSeal Rotary Seal, Break-In

This set of three runs was the first with the new Parker FlexiSeal Rotary Seal.

Prior to the tests, the Minn-Kota 101 brushed-end assembly was processed to accept the new seal as follows:

1. Brush plate assembly (9-738-004) was removed
2. Large flange bearing (144-017) was removed
3. Stock lip seals and spacer (seal kit 2889460) were removed
4. Armature thread was wrapped with tape to prevent seal damage
5. Light coat of grease was applied to armature shaft
6. Seal Adapter with O-rings was greased and pressed in (interference fit)
7. Lower unit reassembled after grease applied to all O-rings
8. Lower unit was pressured tested for leaks with 5 psig using Oatey all-purpose leak detector (#30209)
9. Lower unit was connected to a Minn Kota 24/36v Control Board Assembly (2774037, Old Part Number(s): 2184007, 2184017, 2184027) and 36 volt battery to confirm that motor was operating

The test period is shown in Table 5 for Case 3.

Table 5 – Case 3, Test Date, Start and End Times and Elapsed Time

Test Date	3/4/2024
Start Time	12:08
End Time	16:35
Elapsed Time (hrs)	4.45
Elapsed Time (min)	267.00
Chamber Fluid(V:V)	(50:50) Water:Ethylene glycol

Case 3 test cell pressure and depth are shown in Figure 24. Run 1, at an elapsed time of 61 minutes, observed 8 drops over 5 minutes or 1.6 drops/min out the drip tube. At his point, the pressure in the cell was 240.5 psig which corresponds to a depth of 541 fsw. The HPU was then turned off and the cell pressure returned to zero.

For run 2 at an elapsed time of 117 minutes, observed 6 drops over 5 minutes or 1.2 drops/min out the drip tube. At his point, the pressure in the cell was 201.0 psig. which corresponds to a depth of 452 fsw. The HPU was again turned off and the cell pressure returned to zero.

For run 3 at an elapsed time of 248 minutes, terminated run with <u>no observed drips out the drip tube</u>. At his point, the pressure in the cell was 463.0 psig. which corresponds to a depth of 1041 fsw.

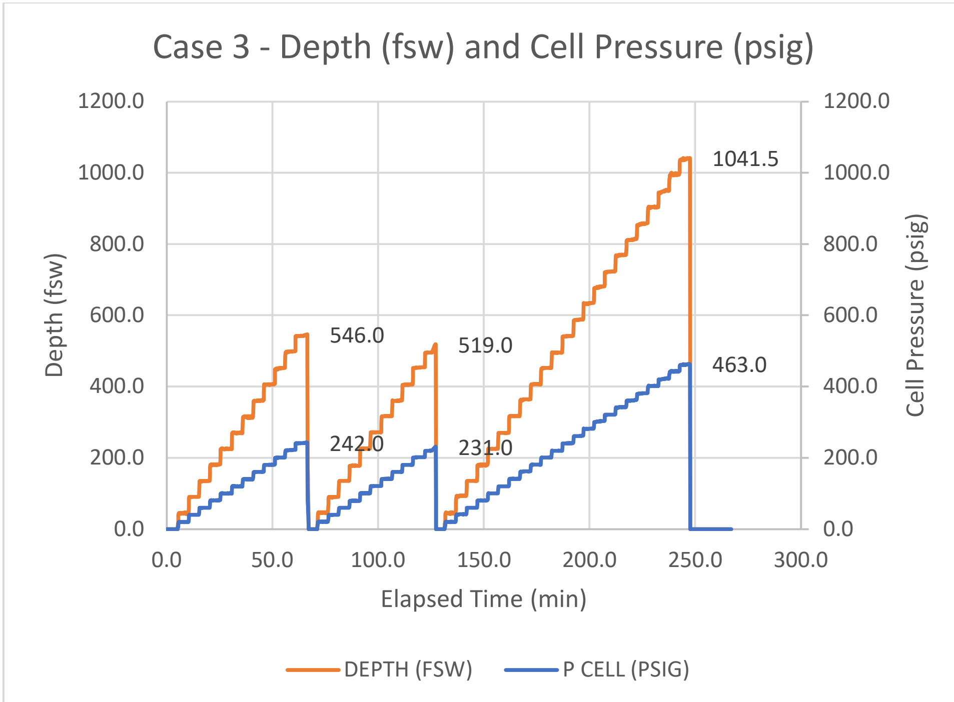


Figure 24 – Case 3, Depth (fsw) and Cell Pressure (psig)

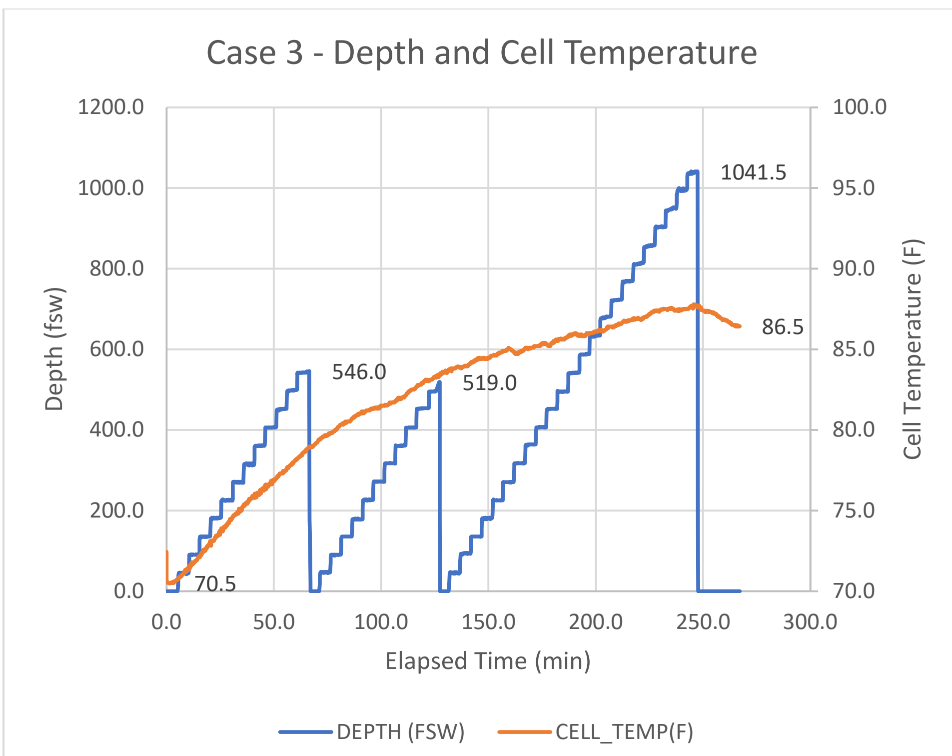


Figure 25 – Case 3, Depth and Cell Temperature

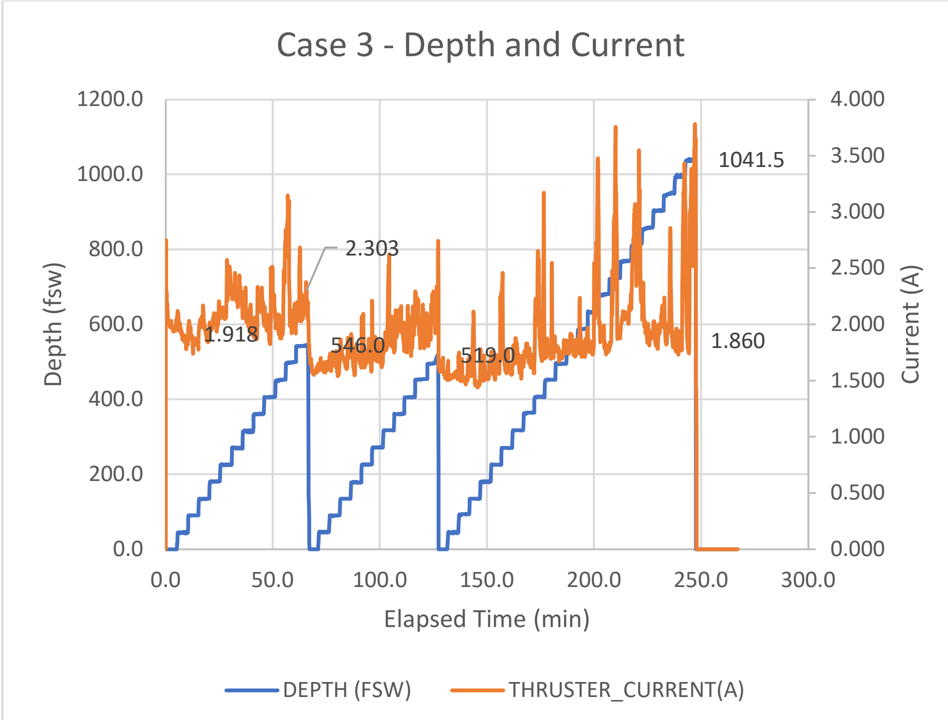


Figure 26 – Case 3, Depth and Current

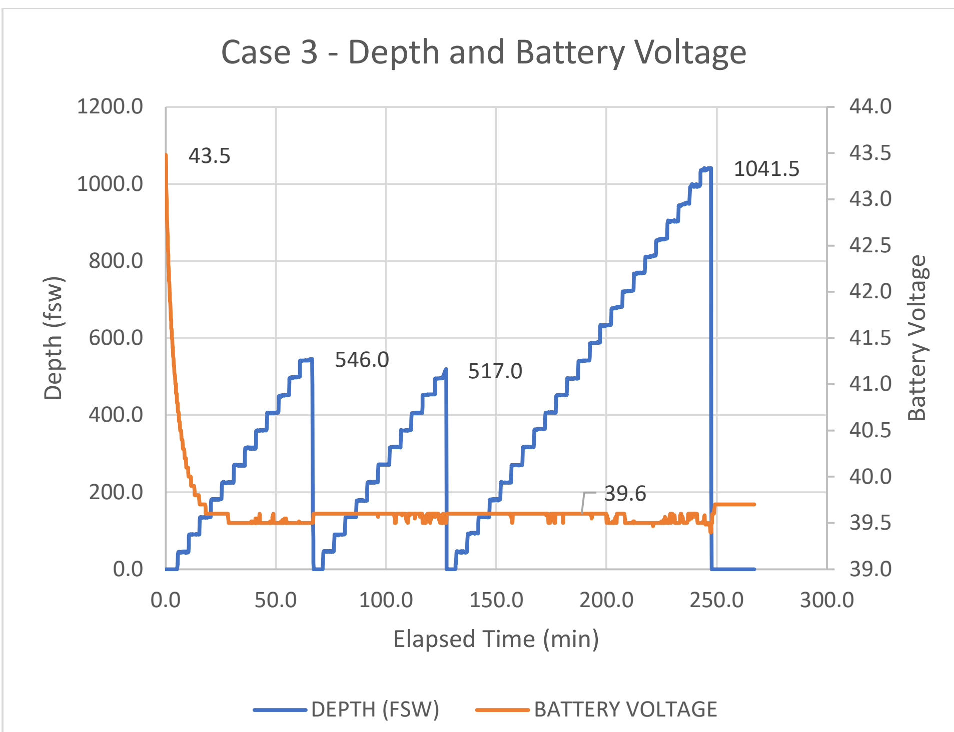


Figure 27 – Case 3, Depth and Battery Voltage

Table 6 – Case 3, Results for Onset of Leakage			
Test	Elapsed Time (min)	P (psig)	Depth (fsw)
1	61.0	241	541
2	116.6	201	452
3*	247.5	463	1042

* Depth is not leakage onset but maximum test depth

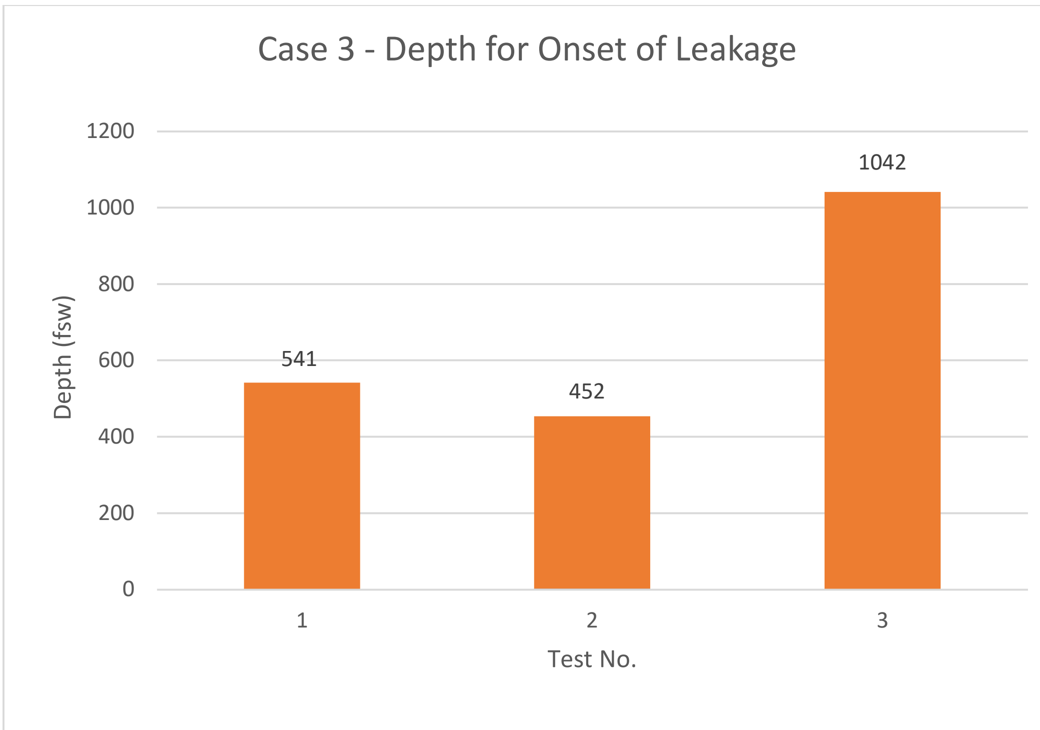


Figure 28 – Case 3, Depth for Onset of Leakage

Key Findings from Case 3

1) Run 1, at elasped time of 61 minutes observed 8 drops over 5 minutes, 1.6 dpm. Depth was 541 fsw
2) Run 2, at elasped time of 117 minutes observed 6 drops over 5 minutes, 1.2 dpm. Depth was 452 fsw.
3) Run 3, at elasped time of 248 minutes reached depth 1041 fsw , turned off HPUMK-101 continued to operate throughout.
4) MK-101 continued to operate throughout.
5) Break-in of the lip seal occurred after 2 hours and 7 minutes
6) The average current to motor over the three runs was 1.844 A at 300 fsw

5.4 Case 4 - Parker FlexiSeal Rotary Seal, Leakage Depth

Case 3 was the first test sequence with the new Parker lip seal after the Swagelok ¼ NPT fitting used to attached the drain port was machined flush with the interior of the MK-101 body. See Figure 29 that shows this fitting prior to machining flush.

Figure 29 – Swagelok Fitting, Part #: SS-400-1-4 before machining flush

A concern from Case 3 was that this fitting was protruding into LU and blocking fluid from exiting the LU until fluid built up to a level to overflow the top of the fitting. A bench test of the LU installed at an angle of 3 degrees from horizontal confirmed that 14 ml of fluid must accumulate before dripping would occur out the tube. After machining this fitting flush, only 1 ml of fluid into the LH would initiate dripping.

Rotary seals can improve their function during an initial "break-in" period, as the seal surface polishes the surface of the shaft. Parker product literature describes the phenomenon, yet does not quantify it. Case 3 tests consisted of three cycles, with the third showing markedly improved performance. We interpret the experimental results as showing that the seal break-in occurred over a 2 hour period as seen by a small leakage rate that developed at approximately 500 fsw. The last Case 3 run did not see this leakage and the seal went to depth of 1,035 fsw with no leakage.

Based on the Case 3 results, Case 4 was developed to see if this initial break-in period was complete as demonstrated by three runs with no leakage.

The Case 4 date and test period are shown in Table 7.

Table 7 – Case 4, Test Date, Start and End Times and Elapsed Time

Test Date	3/5/2024
Start Time	7:33
End Time	13:38
Elapsed Time (hrs)	6.09
Elapsed Time (min)	365.30
Chamber Fluid(V:V)	(50:50) Water:Ethylene glycol

Case 4 test cell pressure and depth are shown in Figure 30. The goal of the test was to see if the seal could operate at a depth of 1,000 fsw without leakage. The maximum pressure reached during the test was 465 psig. See Figures 31-33 for cell temperature, motor current and battery voltage respectively.

See Table 8 for the maximum depth achieved for each of the Case 4 runs.

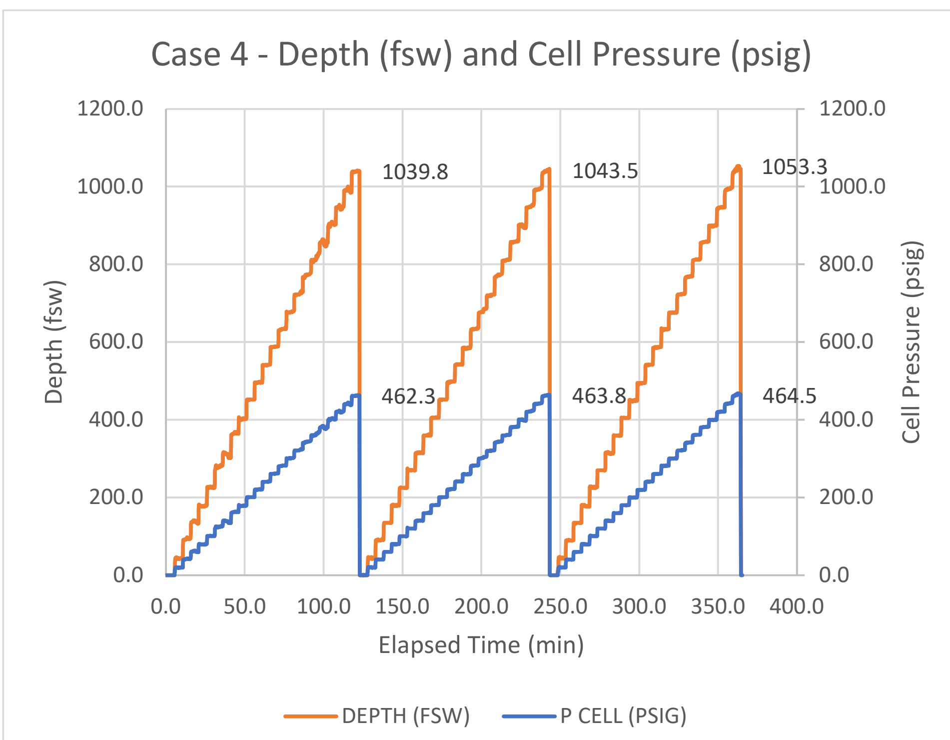


Figure 30 – Case 4, Depth (fsw) and Cell Pressure (psig)

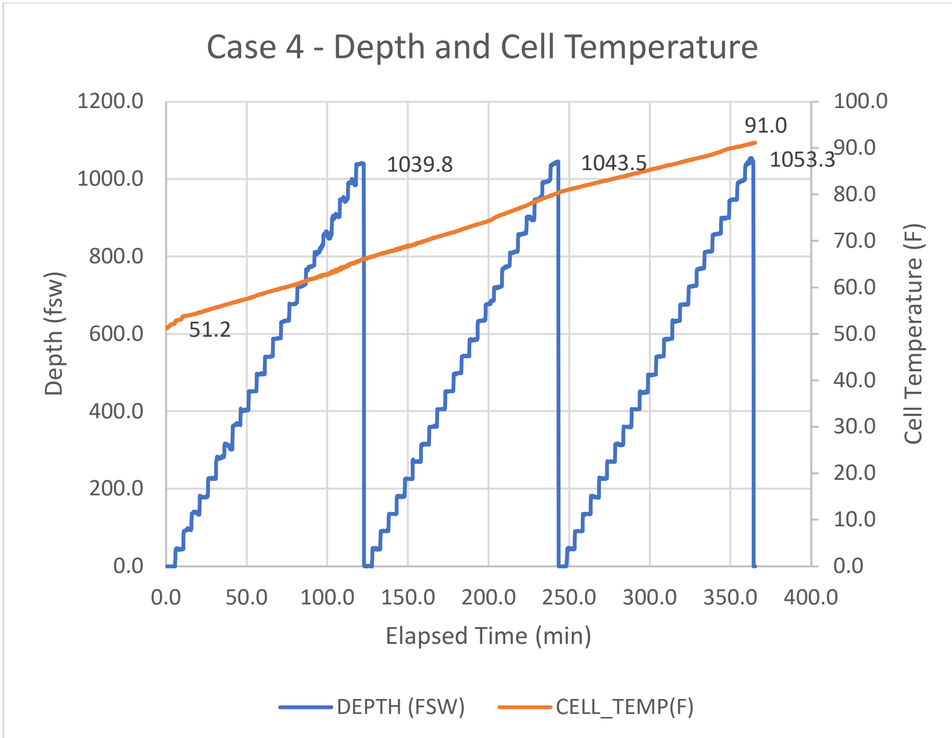


Figure 31 – Case 4, Depth (fsw) and Cell Temperature (F)

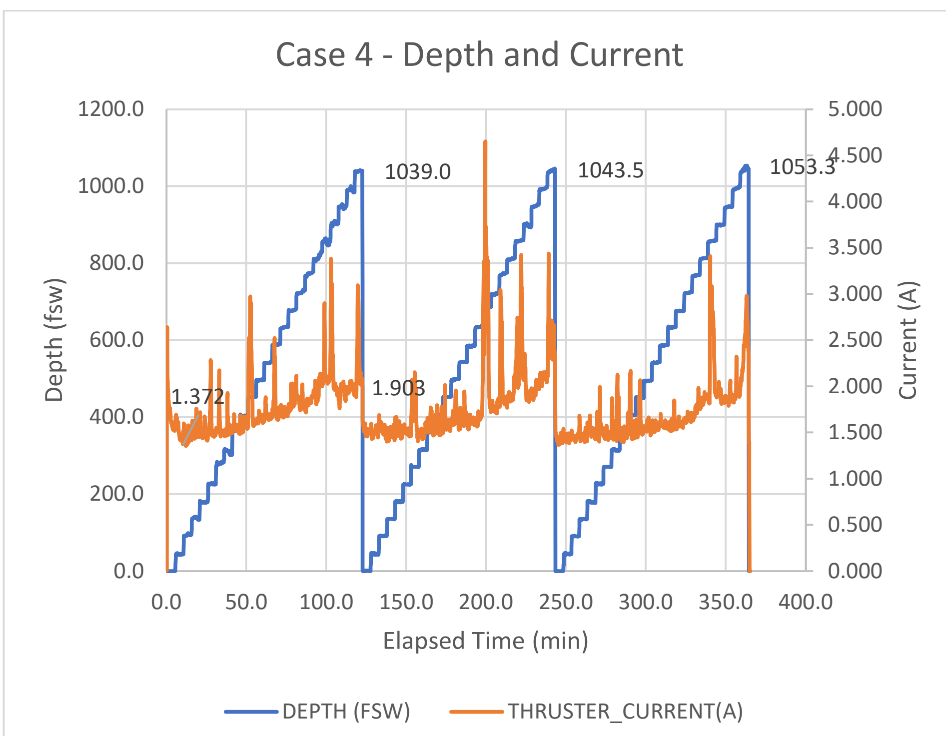


Figure 32 – Case 4, Depth (fsw) and Current (A)

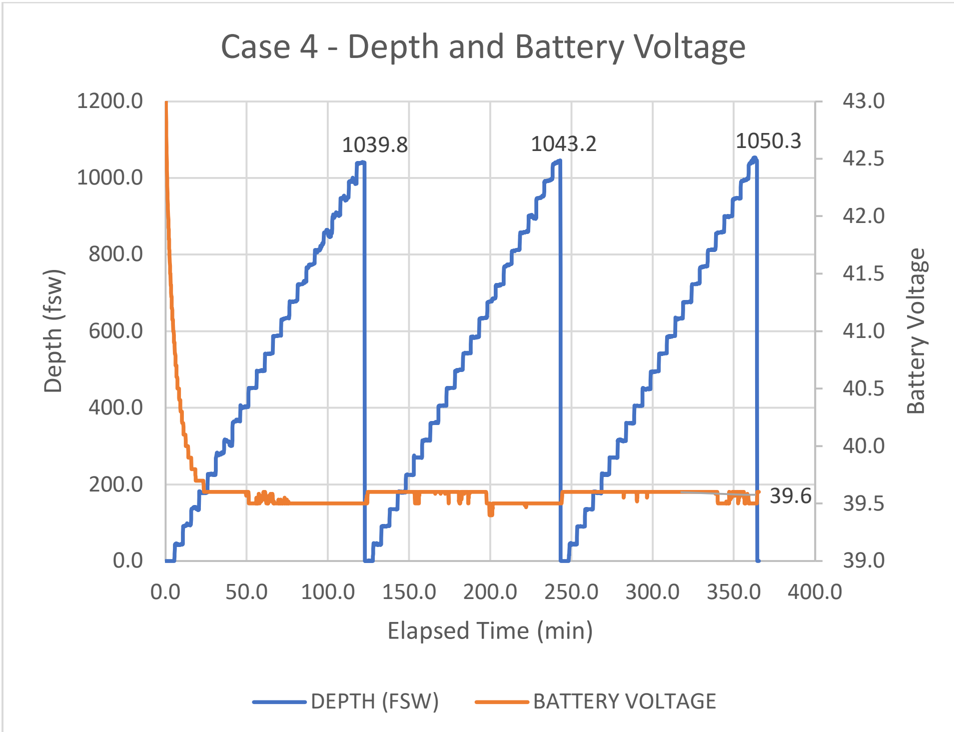


Figure 33 – Case 4, Depth and Battery Voltage

Table 8 – Case 4, Results Maximum Pressure and Depth

Test	Elapsed Time (min)	P (psig)	Depth (fsw)
1	122.6	462	1040
2	243.2	464	1044
3	364.3	465	1045

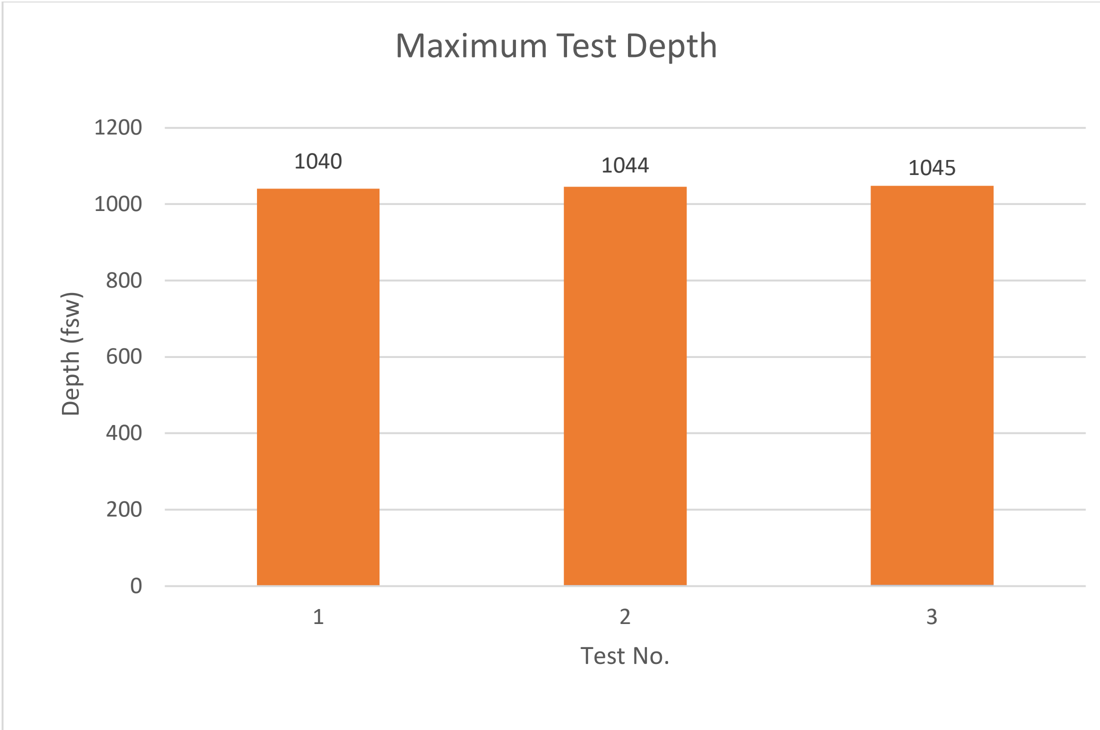


Figure 34 – Case 4, Maximum Test Depth

Key Findings from Case 4

1) With the new Parker HP seal, no leakage was obseved in these three test runs
2) The maximum test depths were each over 1,040 fsw
3) Except for momentary current spikes, the current increased linearly from 1.45A to 1.9 amps
4) MK-101 continued to operate throughout.
5) Operating the Minn-Kota 101 Lower Unit with the Parker FlexiSeal Rotary Seal, model no. 0301FCS180700500260SCM enabled this unit to operater to over 1,000 fsw without pressure compensation.

5.5 Case 5 – Repeat Original Lip Seals, Leakage Onset Depth

For the original Minn Kota 101 lower unit seal-set, in Case 1, the leakage onset depth was measured as 180 fsw and in Case 3, 361, 430 and 364 fsw. To try and reduce the uncertainty, three additional runs were made for Case 5.

The Case 5 date and test period are shown in Table 9.

Table 9 – Case 5, Test Date, Start and End Times and Elapsed Time

Test Date	3/6/2024
Start Time	14:20
End Time	18:45
Elapsed Time (hrs)	4.41
Elapsed Time (min)	264.80
Chamber Fluid(V:V)	(50:50) Water:Ethylene glycol

.

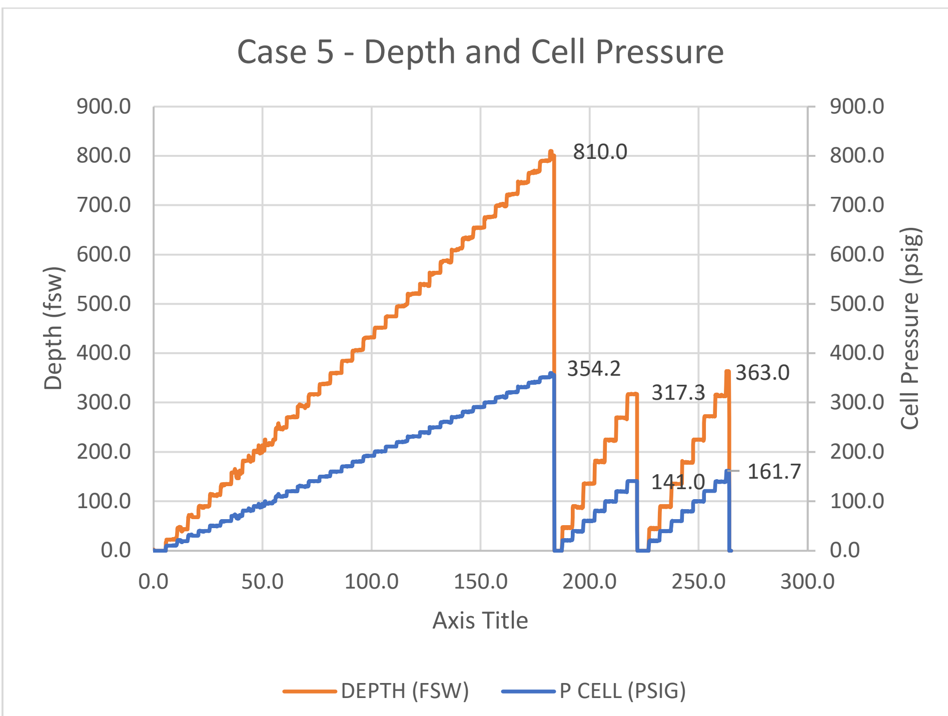


Figure 35 – Case 5, Depth (fsw) and Current (A)

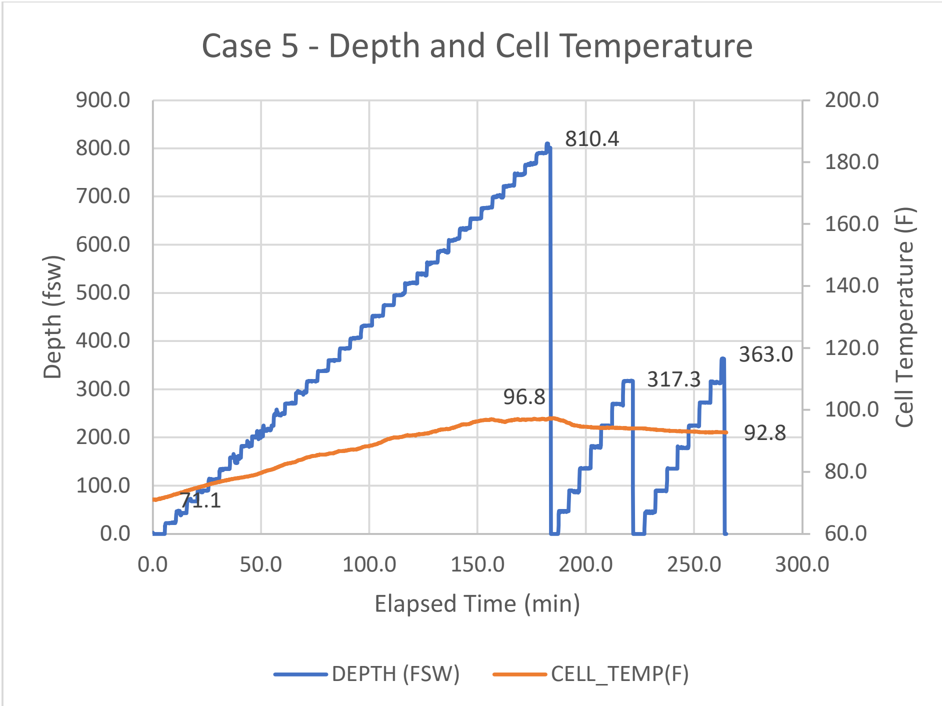


Figure 36 – Case 5, Depth (fsw) and Cell Temperature (F)

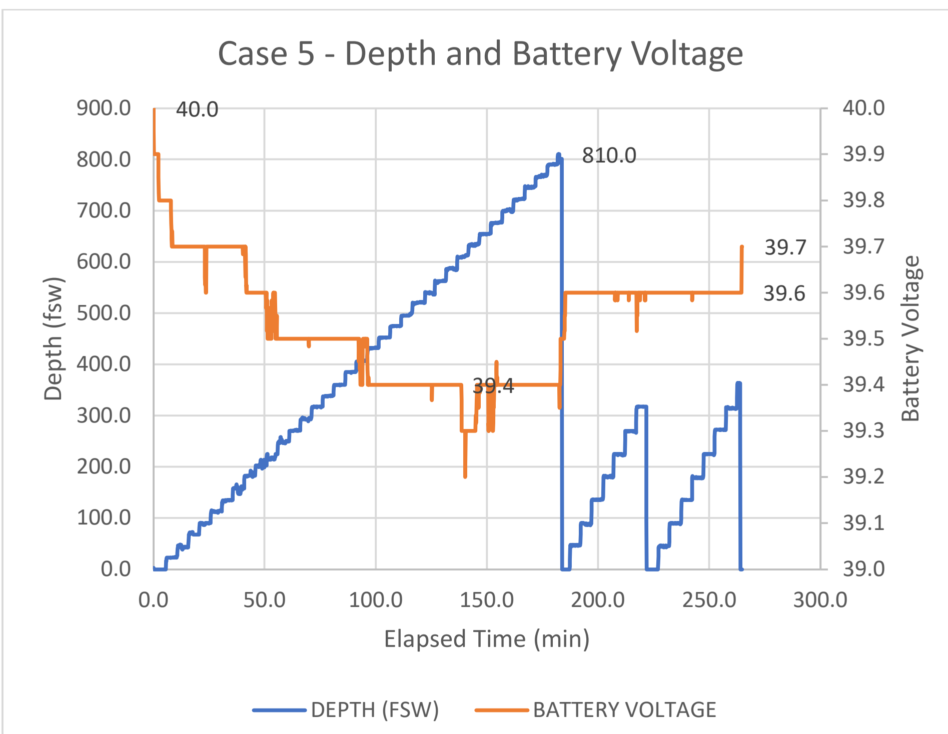


Figure 37 – Case 5, Depth and Battery Voltage

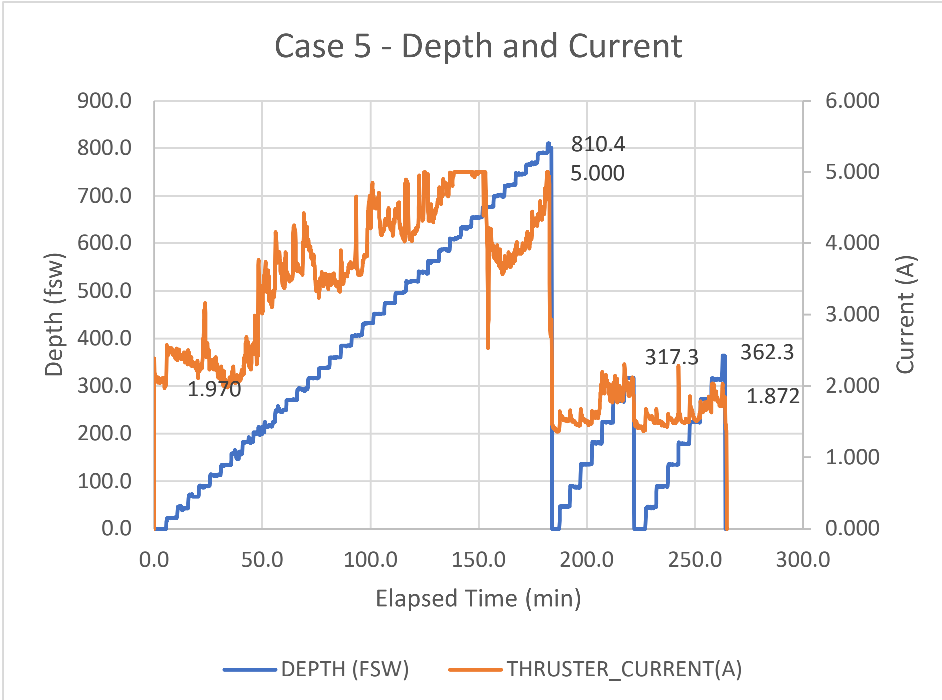


Figure 38 – Case 5, Depth (fsw) and Current (A)

Table 10 Case 5 – Results for Onset of Leakage			
Test	Elapsed Time (min)	P (psig)	Depth (fsw)
1*	182.6	360	810
2	217.5	141	317
3	262.7	160	360

* Full stream flow out drip tube at failure

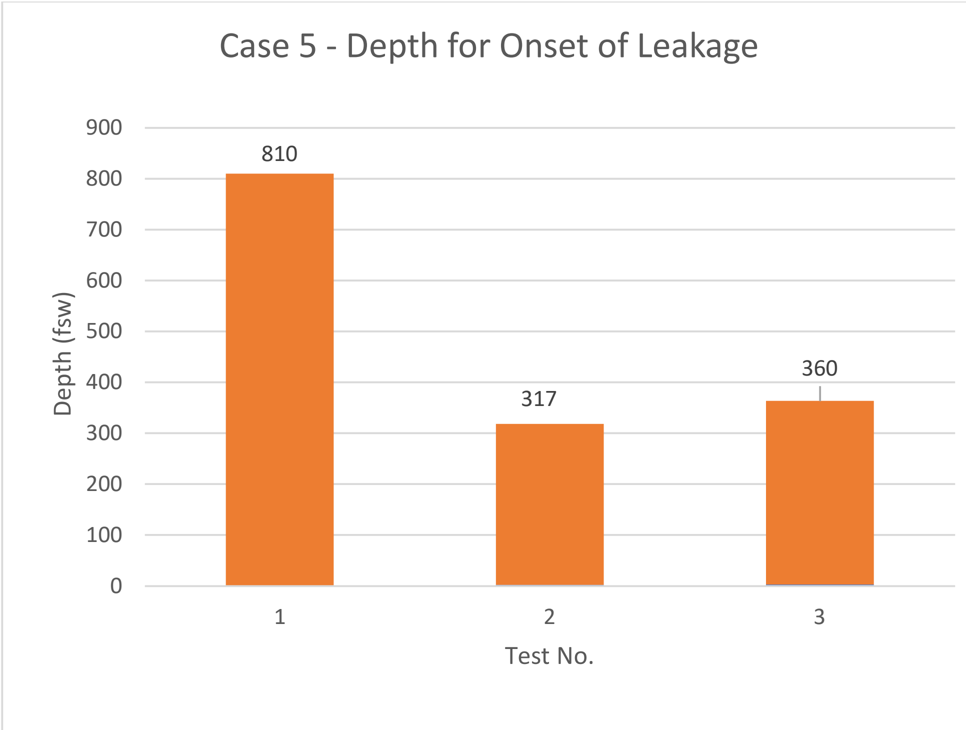


Figure 39 – Case 5, Depth for Onset of Leakage

Key Findings from Case 5

1) Run 1, at elapsed time of 183 minutes observed seal failure high flow rate. Depth was 810 fsw.
2) Run 2, at elapsed time of 218 minutes observed high drippage rate. Depth was 317 fsw.
3) Run 3, at elapsed time of 263 minutes observed high leakage rate. Depth was 360 fsw.
4) MK-101 continued to operate throughout.

6. FUTURE WORK

Single Lip Seal

For those interested in using the MK 101 lower unit as part of a thruster unit without pressure compensation for shallow diving boats such as the K-250, there is an interest in determining if using a single original lip seal rather than the dual set with spacer would enable the LU to operate at deeper depths. A future test might be to repeat Case 2 with a single lip seal.

2,000 fsw Test Case

The maximum depth tested for the Parker FlexiSeal Rotary Seal (0301-FC-S-187-00500-260-S-C-M) was 1,000 fsw. The test cell can be modified to reach a depth of 2,000 fsw. A further test might be to repeat Case 4 with this 2,000 fsw target to see if this depth is possible. The test cell maximum pressure is 2,000 psig, as set by a pressure relief valve, so 2,000 fsw is easily generated.

Corrosion Mitigation

The seal adapter design for this project is made of 6061-T6 aluminum. As such, there is a concern about how well it will hold up to corrosion in seawater. Future work could be to identify the best way to mitigate this corrosion concern. Possibilities include hard anodizing the seal adapter or installation of a sacrificial anode nut like the propeller nut that was supplied on all saltwater Minn-Kota 101 LU’s before October 2019.

Replace Cardboard Spacer

The original seal set for the MK 101 uses a cardboard spacer between lip seals. This keeps the other seal from affecting the flexing of the inner seal. As the design pressure for the factory LU was much lower than the pressures reached in these tests, a possible improvement would be to replace the cardboard spacer with an identical spacer made of 6061-T6 aluminum tubing. The calculated axial force on the cardboard spacer is 355 lbf at 1,000 fsw so there is quite a force trying to collapse this cardboard spacer at depth.

Appendix A – PLC I/O and Hardware

Programmable Logic Controller I/O

2/20/2024

I/O	Description	Type	Slot	Address	Status	Alarm Associated
Alarms						
1	High pressure in test cell > 500 psig					
2	Low Battery voltage < 36VDC					
3	High current to motor, > 5 Amps					
Inputs	Description	Type	Slot	Address	Status	Alarm Associated
CH-B1	PT1 TEST CELL PRESSURE (PSIG)	Analog	0	V2000-V2001	Installed	Alarm-1, High pressure in test cell, > 500 psig
CH-B2	CURRENTLY NOT USED	Analog	0	V2002-V2003		
CH-B3	CURRENTLY NOT USED	Analog	0	V2004-V2005		
CH-B4	VOLTAGE OF BATTERY	Analog	0	V2006-V2007	Installed	Alarm-2, Low voltage to LED < 36VDC
CH-B5	CURRENT TO THRUSTER (AMPS)	Analog	0	V2010-V2011	Installed	Alarm-3, High Motor Current, > 5 Amps
CH-B6	CURRENTLY NOT USED	Analog	0	V2012-V2013		
CH-B7	CURRENTLY NOT USED	Analog	0	V2014-V2015		
CH-B8	CURRENTLY NOT USED	Analog	0	V2016-V2017		
CH-B9	CURRENTLY NOT USED	Analog	0	V2020-V2021		
CH-B10	CURRENTLY NOT USED	Analog	0	V2022-V2023		
CH-B11	CURRENTLY NOT USED	Analog	0	V2024-V2025		
CH-B12	CURRENTLY NOT USED	Analog	0	V2026-V2027		
CH-C1	THRUSTER OVER PRESSURE SWITCH (OP)	Digital	1	X40	Installed	Pressure >10 psig (both visible and audible alarm)
CH-C2	CURRENTLY NOT USED	Digital	1	X41		
CH-C3	CURRENTLY NOT USED	Digital	1	X42		
CH-C4	CURRENTLY NOT USED	Digital	1	X43		
CH-C5	HPU CONTACTOR	Digital	1	Y40	Installed	
CH-C6	CURRENTLY NOT USED	Digital	1	Y41		
CH-C7	CURRENTLY NOT USED	Digital	1	Y42		
CH-C8	CURRENTLY NOT USED	Digital	1	Y43		
CH-D1	TT1 - CELL TEMPERATURE (F)	Analog	2	V2040	Installed	
CH-D2	CURRENTLY NOT USED	Analog	2	V2044		
CH-D3	CURRENTLY NOT USED	Analog	2	V2042		
CH-D4	CURRENTLY NOT USED	Analog	2	V2046		

PLC Modules

Slot	Name	Module	Points	Address	Description
-1	A	D2-260-1	NA	NA	CPU 30.4K WORDS W/1 RS232 & 1 RS232/422/485 PORT
0	B	F2-08AD-2	16	X0-X17	8 Channel Analog Input Voltage 12-Bit Res.
1	C	D2-08CDR	8	X20-X27	Combo 4 PT 24VDC Input and 4 PT Relay Output
2	D	F2-04RTD	32	X30-X47	4 Channel RTD, 0.1 Deg C Resolution

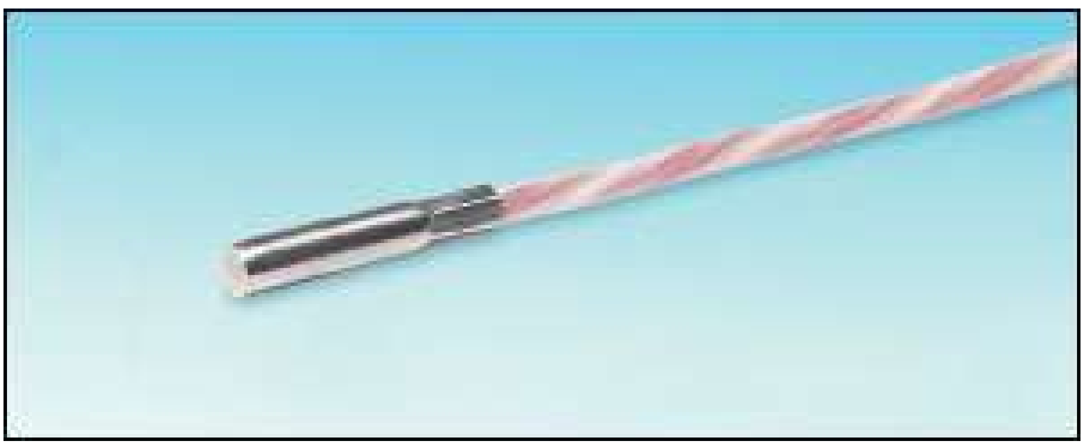
D2-04B-1 DL205 BASE 4-SLOT REQ 110/220VAC PWR W/300mA 24VDC AUX P/S

HMI EA9-T8CL

Appendix B – Transmitter Specifications

Item	Description
Application	High Pressure Transmitter
Manufacturer	TE Connectivity Measurement Specialties
Mfg. Model No.	M5231-000005-03KPG
Digi-Key Part Number	223-1726-ND
Description	TRANSDUCER 0.5-4.5VDC 3000PSI
Pressure Type	Vented Gauge
Operating Pressure	3000 PSI (20684.27kPa)
Type	Analog Voltage
Output	0.5 V ~ 4.5 V
Accuracy	±0.25%
Voltage - Supply	4.75V ~ 5.25V
Port Size	Male - 1/4" (6.35mm) NPT
Features	Temperature Compensated
Termination Style	Cable
Maximum Pressure	6000PSI (41368.54kPa)
Operating Temperature	-40°C ~ 125°C
Package / Case	Cylinder
Datasheet	M5200 Industrial Pressure Transducer (te.com)

Item	Description
Application	Test Chamber Temperature RTD
Manufacturer	DC Direct
Mfg. Model No.	314-140 Small Budget RTD Sensor
Description	100 ohm RTD element, Alpha = 0.00385, Class B
Temperature Range	-58ºF to +390ºF (-50°C to +200°C)
Probe Diameter	1/4″
Probe Length	1.18" long
Termination Style	3 wire configurations
Sheath	316 Stainless Steel
Extension Leads:	72" long, 24 AWG stranded PFA insulated cores with silicone rubber
Wire Color Code	3 wire - 2 colored red and 1 colored white
Datasheet	TC Direct for Temperature Sensing, Measurement and Control



Appendix C – PLC Ladder Logic

3/1/2024	MK-101 PROJECT 2024	260	minn-kota thruster test

Path: c:\users\public\documents\directsoft6\projects\minn-kota thruster test.prj
Save Date: 02/24/24 15:15:47
Creation Date: 02/16/24 10:06:03
PLC Type: 260
Class ID: DirectLogic 205 Series
Link Name: 260 KSeq

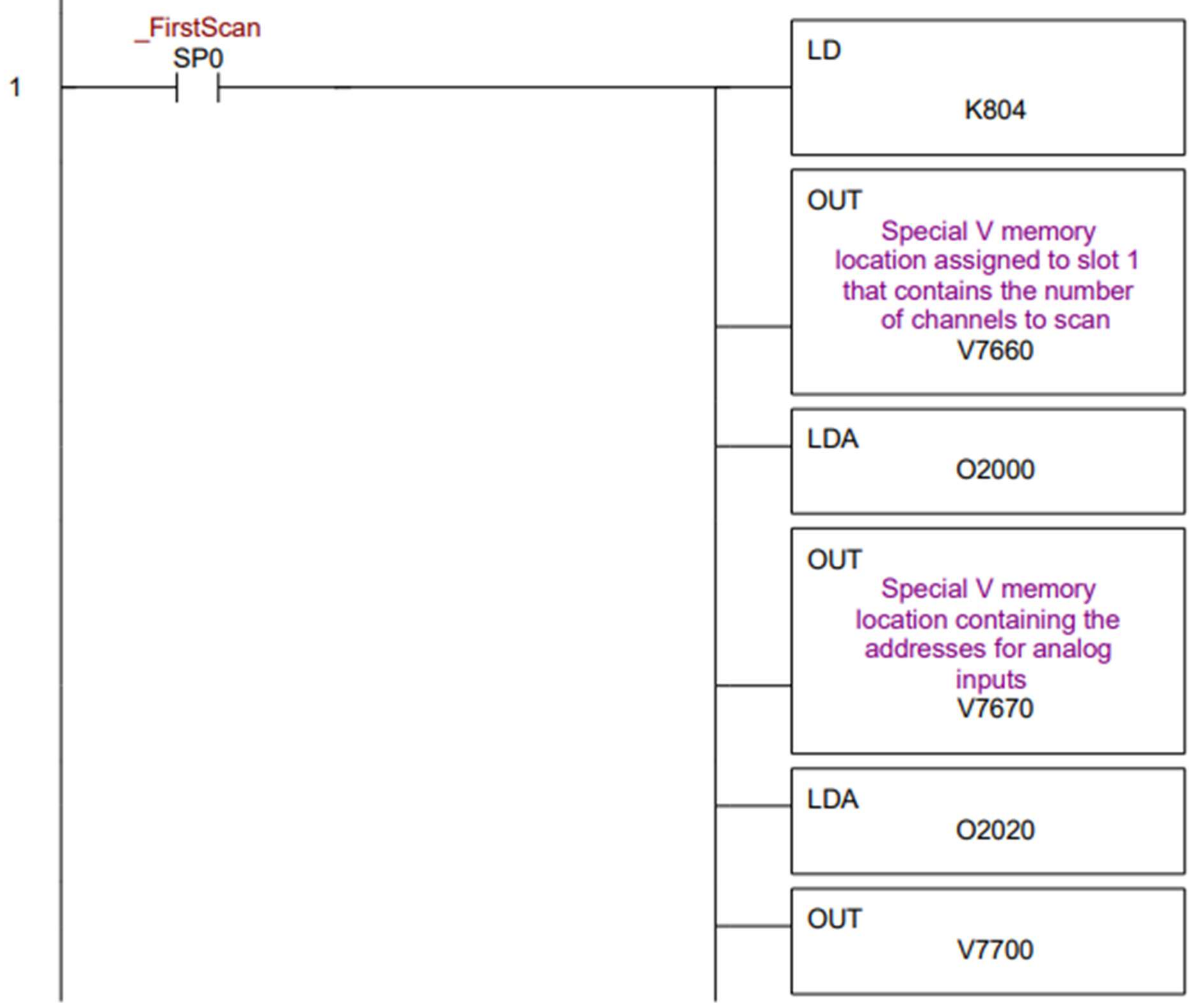
MINN-KOTA 101 PROJECT TEST CELL

MINN KOTA 101 One Atm Test

This rung specifies the number and location of V memory addresses into which the analog input signal from F2-8AD4DA-2 module in slot 0, just to right of CPU, will be stored.
Channels are:

CHB1 V2000 PT1 Cell Pressure, psig (0-5 VDC)
CHB2 V2002 Currently not used
CHB3 V2004 Currently not used
CHB4 V2006 Voltage to thruster (0-10 VDC)
CHB5 V2010 Current to thruster, A (0-10 VDC)
CHB6 V2012 Currently not used
CHB7 V2014 Currently not used
CHB8 V2016 Currently not used

CHB9 V2020 -V2021 Currently not used
CHB10 V2022 -V2023 MK moter controller signal (0-5 VDC)



LD
K1

OUT
0-10V I/O
IO Range
V36410

This rung documents the number and location of V memory addresses into which the analog input signal from F2-04RTD module in slot 2 will be stored. Channels are:

CHD1 V2040 TT1 Cell Temperature, F
CHD2 V2042 Currently not used
CHD3 V2044 Currently not used
CHD4 V2046 Currently not used

Note that for D2-08CDR the address are
X40 First Input Relay Thruster Overpressure Switch
X41 Second Input Relay Currently not used
X42 Third Input Relay Currently not used
X43 Fourth Input Relay Currently not used
Y40 First output Relay HPU Contactor
Y41 Second output Relay Currently not used
Y42 Third output Relay Currently not used
Y43 Fourth output Relay Currently not used

_FirstScan
SP0

2

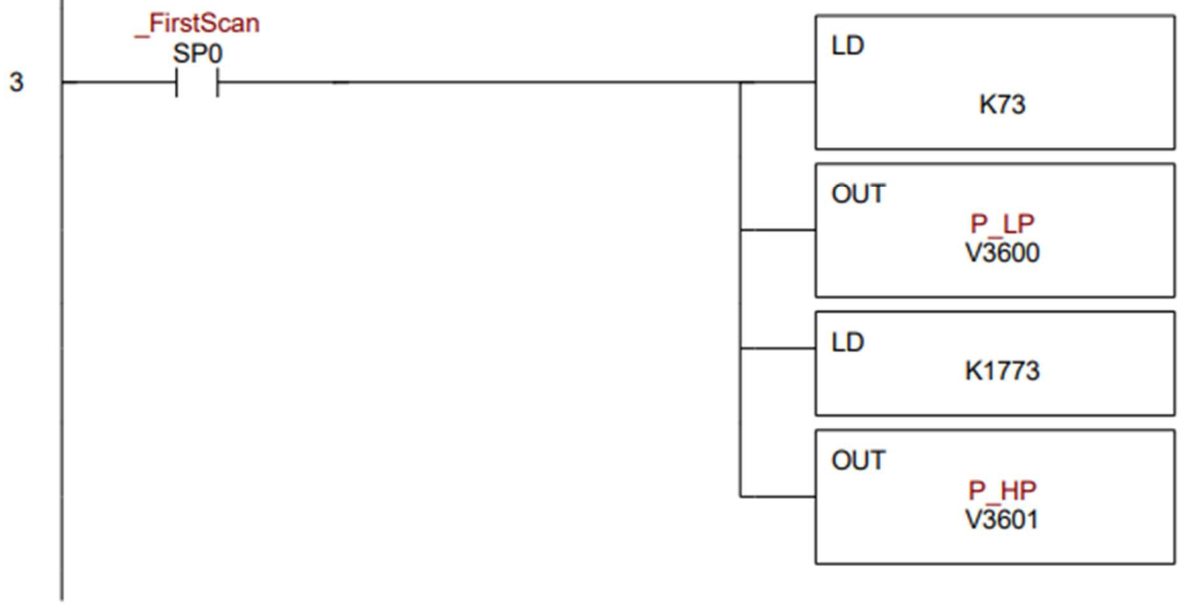
LD
K0

The rung sets up cell pressure sensor processing. This sets the low pressure and HP readings.

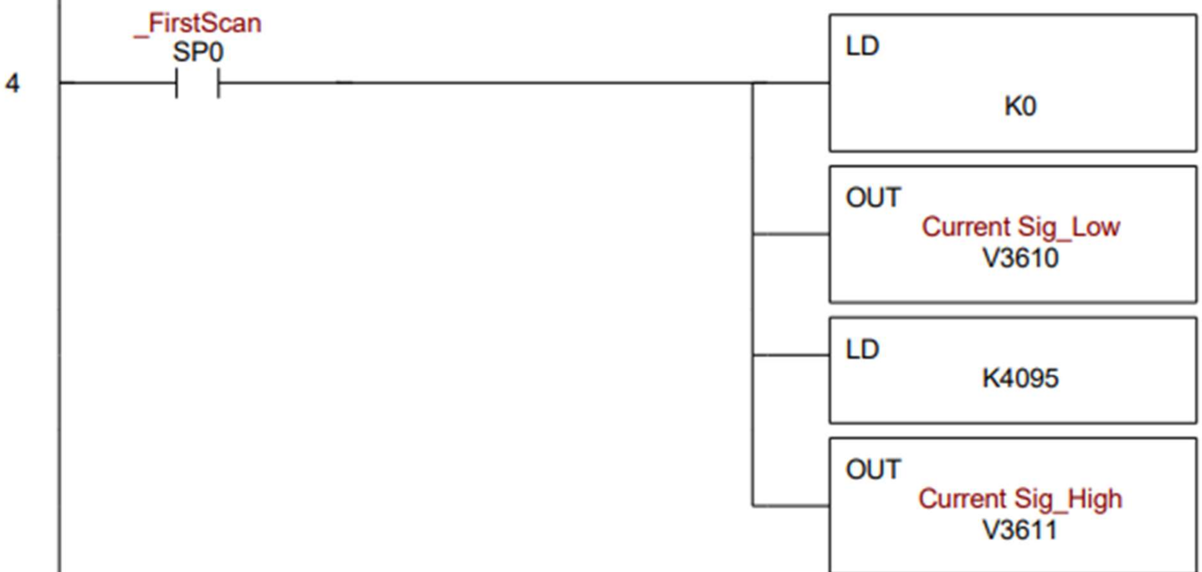
P_LP V3600 0 psig BCD K74
P_HP V3601 3000 psig BCD K1773

P= (V-0.174)/(4.329-0.174)*3000

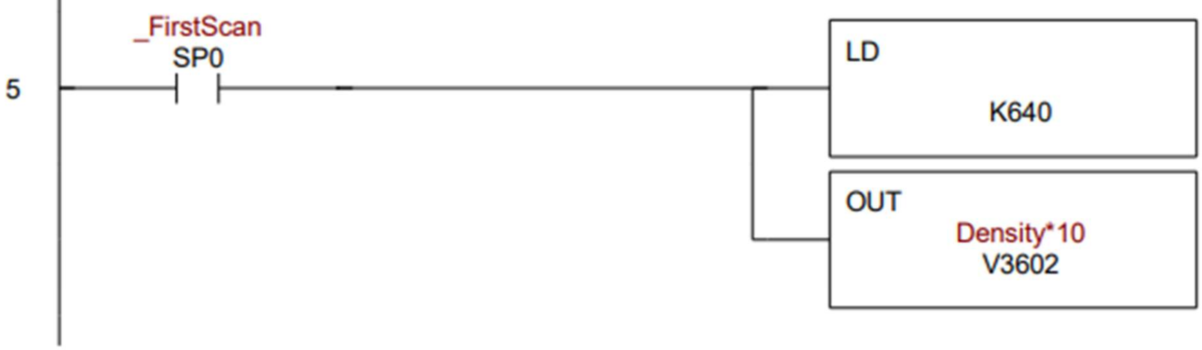
P=(V2000-P_LP)/(P_H P - P_LP)*K3000



The rung sets up motor current sensor processing. This sets the low current and the high current signal readings.



This rung sets water density for water depth calculation during startup.



This rung resets the HPU overpressure bit. When an cell overpressure event happens, then the Reset bit is set. To turn on the HPU, the HPU power switch must be on and the Reset bit must be in reset state. This keeps the HPU from cycling on and off around the high pressure limit.

RESET bit C500

C500 set, HPU will not operate
C500 reset, HPU can operate if HPU switch is on.

6 _FirstScan SP0 —| |— HPU RESET C500 (RST)

This rung scales temperature by factor of 10

V2040 Cell temperature in degrees F x 10.

V2040=V2040*10

7 _On SP1 —| |—

Math - BCD
MATHBCD IB-521
Cell Temp*10
Result (WORD) V2040
Expression V2040

This rung converts the signal for motor current, ranging from 0-4095, into Amps*100.
Sensor range is 0 to 5A

V2010 = Moter current signal (0-4095)
V3610 = Current signal minimum value (0-4095)
V3611 = Current signal maximum (0-4095)
V3010 = Current A*100

V3010=(V2010-V3610)*K500/(V3611-V3610)

8 _On SP1 —| |—

Math - BCD
MATHBCD IB-521
Current A*100
Result (WORD) V3010
Expression ((V2010 - V3610) * K500) / (V3611 - V3610)

This rung converts the signal for battery voltage ranging from 0-4095, into V. Sensor range is 0 to 50VDC Scales by factor 0f 10

V2006 = Battery voltage signal (0=0 V and 4095=50V)
V3020 = Voltage V

V3020=V2006*K50*K10/K4095

9 _On SP1

Math - BCD
MATHBCD IB-521
Battery Voltage
Result (WORD) V3020
Expression (V2006 * K500) / K4095

This rung converts the signal for cell pressure, rangeing from 0-4095, into psig. Sensor range is 0 to 500 psig. A

V2000 = Cell pressure singnal (0-4095)
V3600 = Pressure signal minimum value (0-4095)
V3601 = Pressure signal maximum (0-4095)
V3000 = Cel pressure psig

V3000=(V2000-V3600)*K3000/(V3601-V3600)

P_LP V3600 0 psig BCD K100
P_HP V3601 3000 psig BCD K1773

P= (V-0.243)/(4.329-0.243)*3000

V3000=(V2000-P_LP)/(P_H P - P_LP)*K3000

10 _On SP1 Cell Pres_Sig V2000 ≥ K73

Math - BCD
MATHBCD IB-521
Cell_P_psig
Result (WORD) V3000
Expression ((V2000 - V3600) * K3000) / (V3601 - V3600)

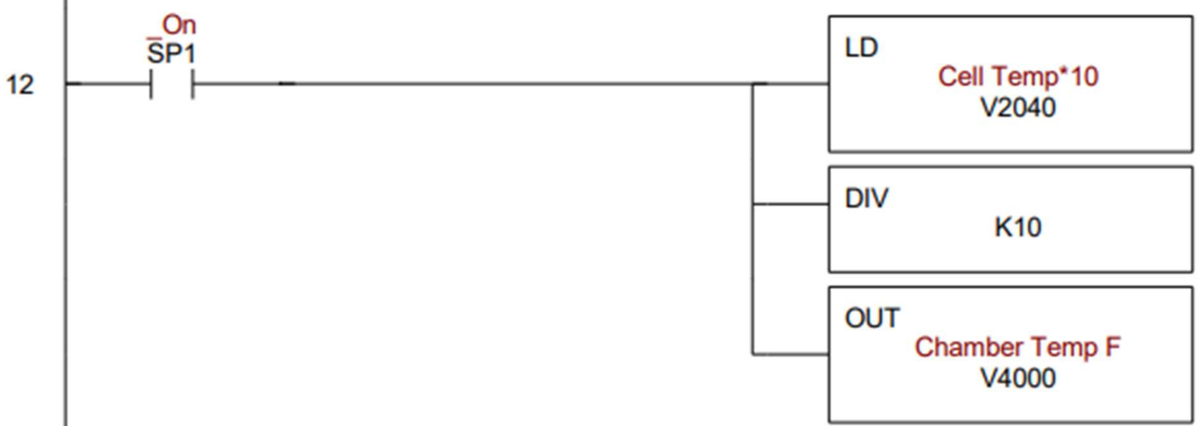
This rung calculates the equvalent water depth using the chamber pressure and the density.

V3000 = Cell pressure psig
V3602 = Water density * 10 (0-4095)

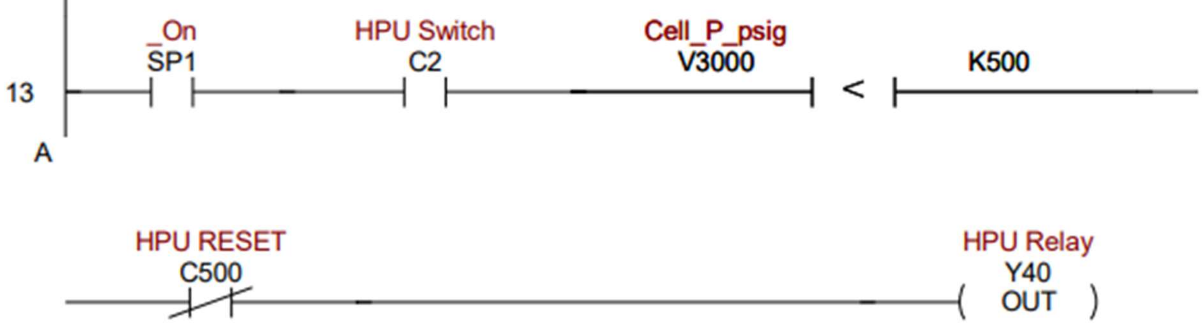
V3001=V3000 *K14400/V3602

11 _On SP1

Math - BCD
MATHBCD IB-521
Depth -FSW
Result (WORD) V3001
Expression (V3000 * K1440) / V3602



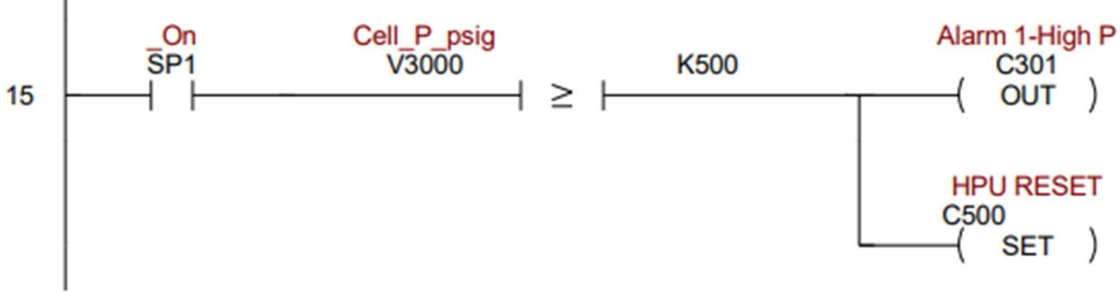
This rung turns on the HPU relay if the HPU switch is on on the operator screen and cell pressure is less than 500 psig .

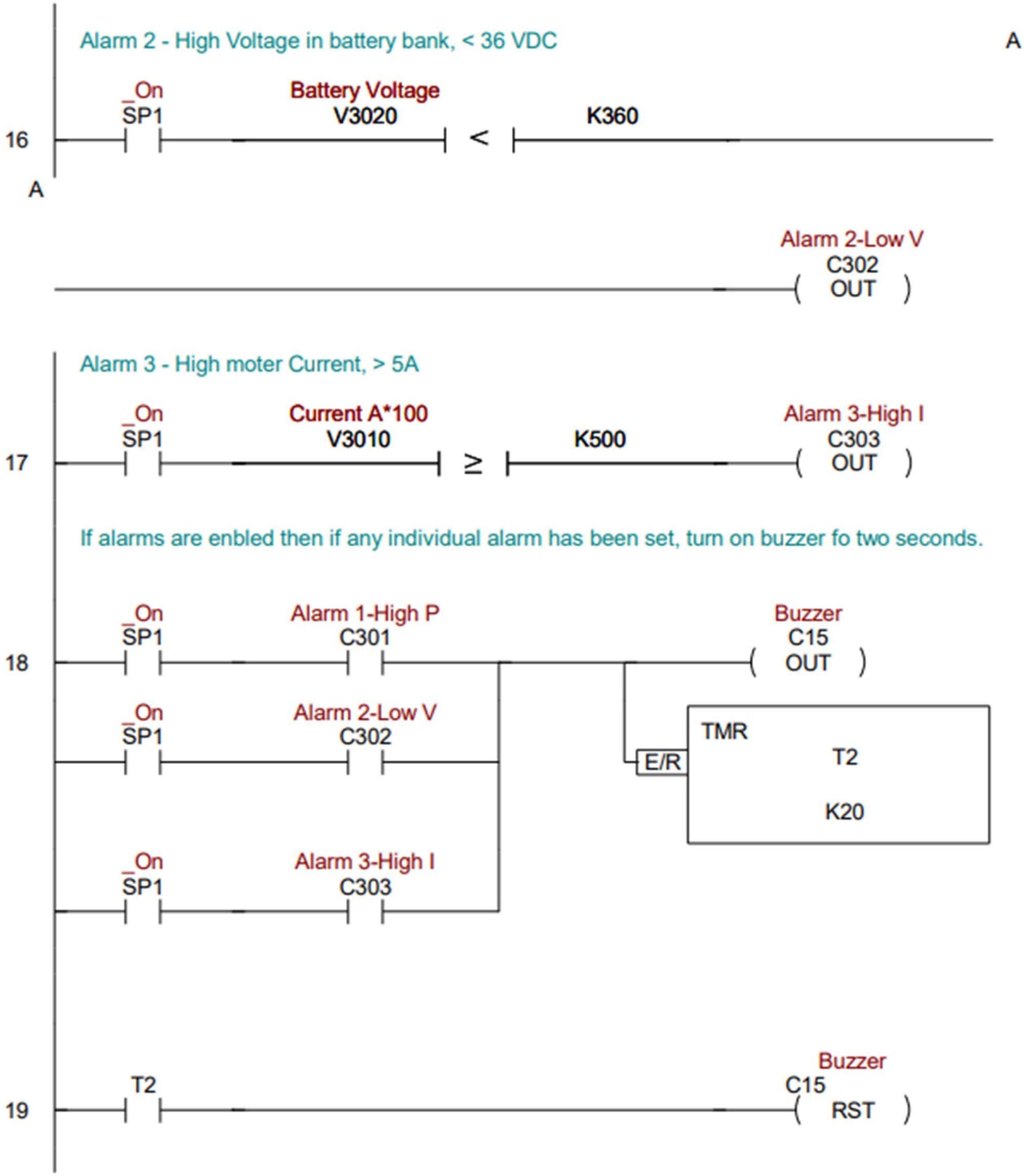


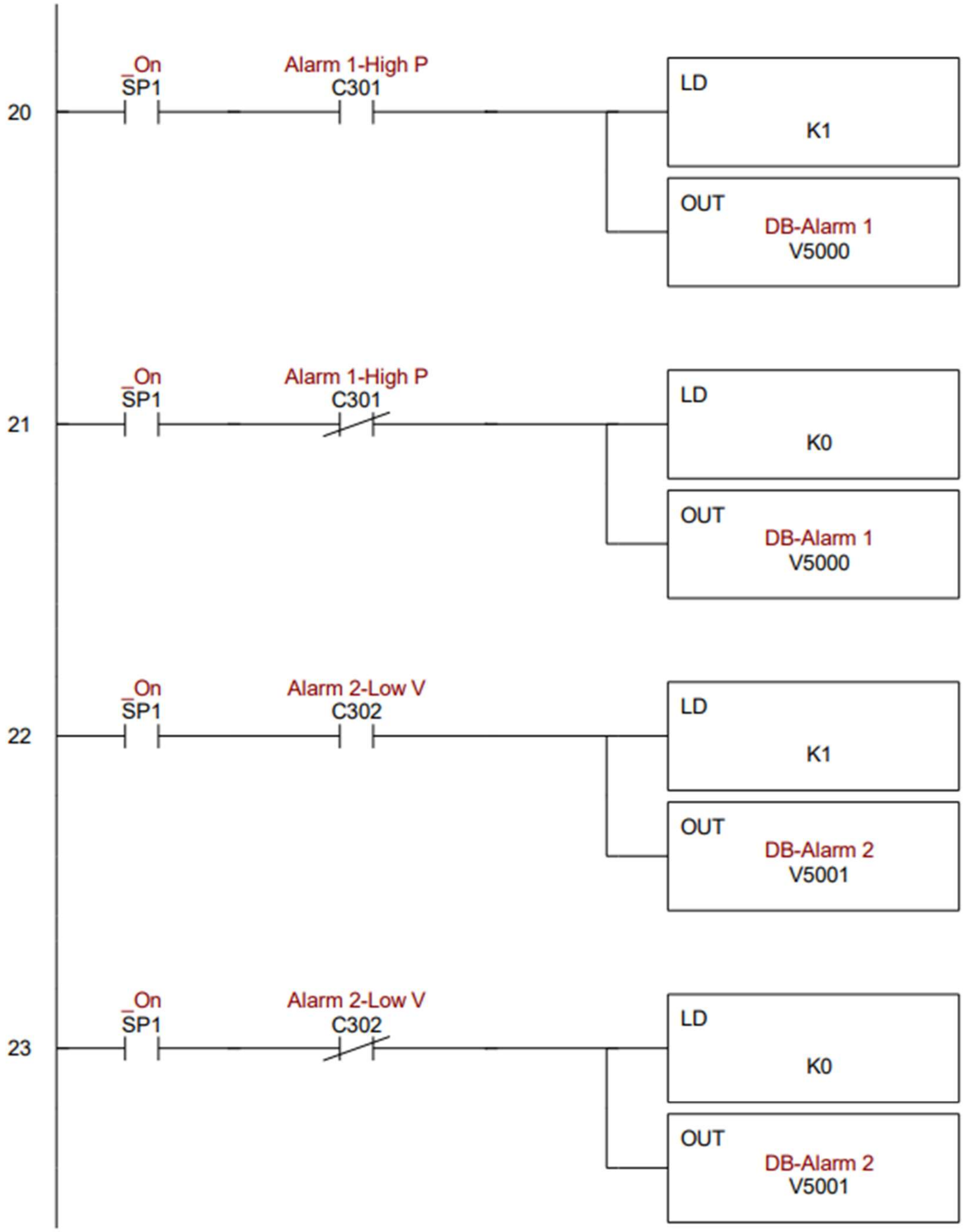
This rung test to see if the thruster overpressure switch has been closed due to exceeding 10 psig. If so, it triggers a OP event.

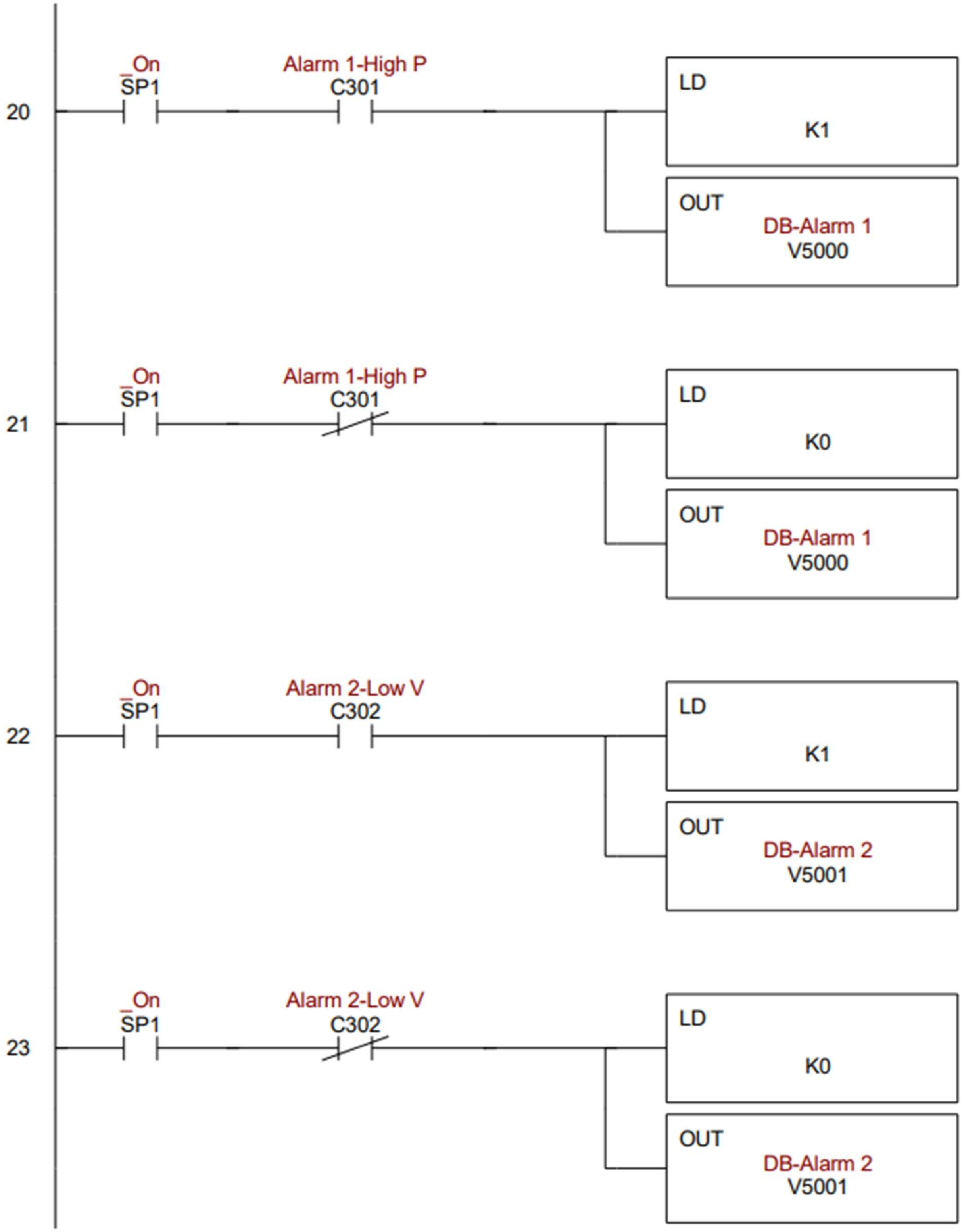
The following six rungs text for alarm conditions and set discreet flags that are used to sound an alarm buzzer.

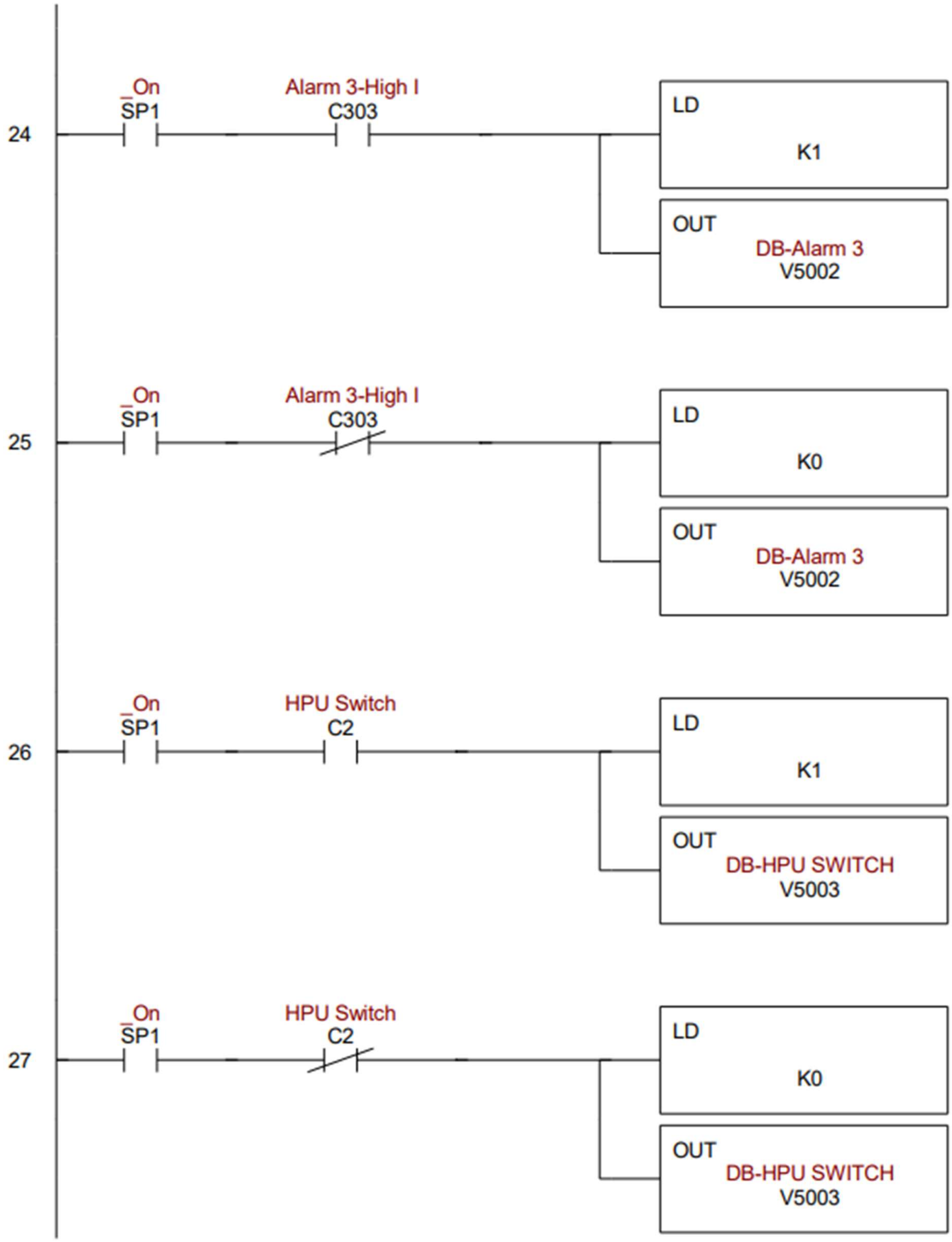
Alarm 1 - High Pressure in Test Cell, >500 psig

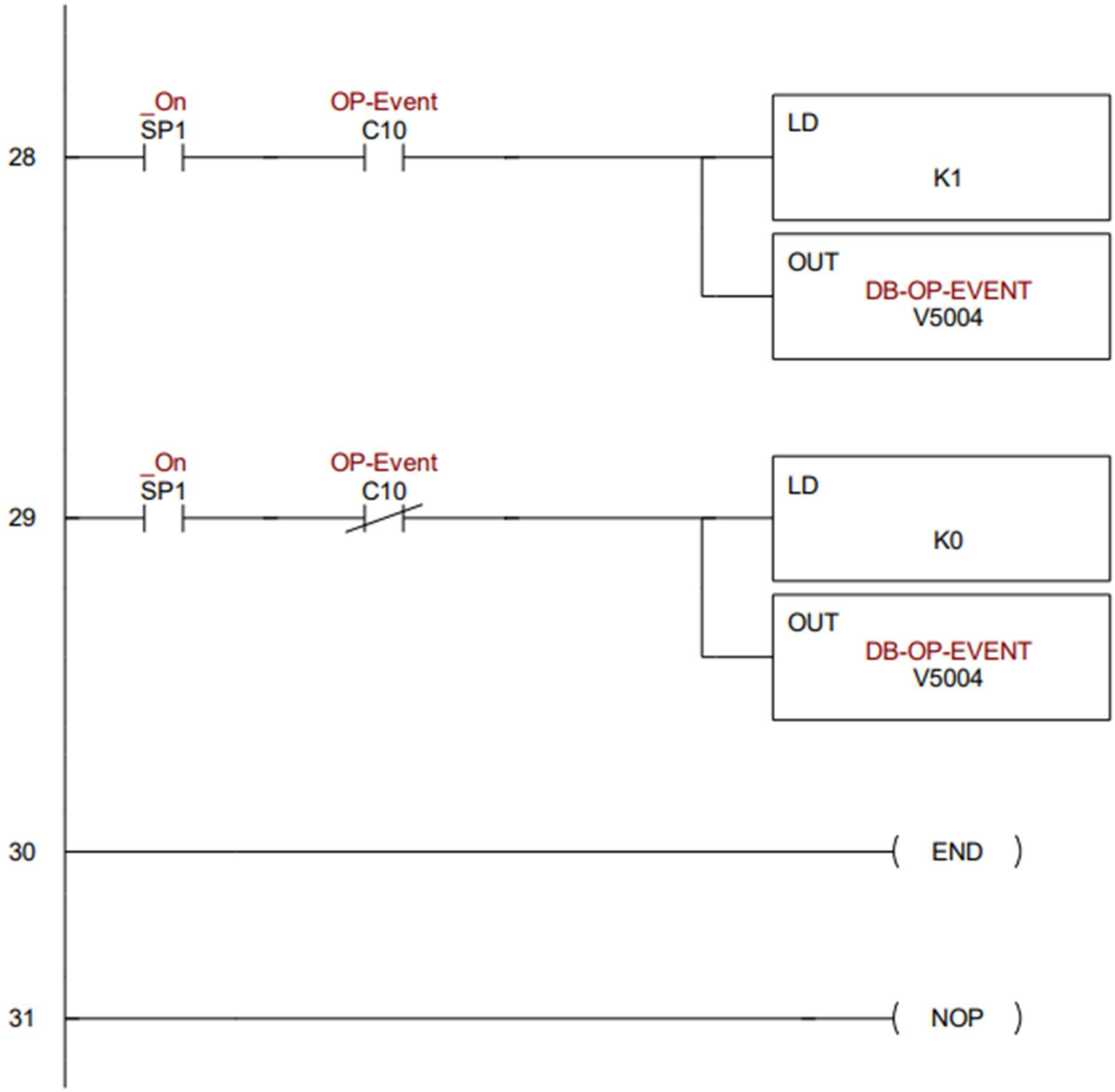



Alarm 2 - High Voltage in battery bank, < 36 VDC
A
_On
SP1
Battery Voltage
V3020
<
K360
16
A
Alarm 2-Low V
C302
OUT
Alarm 3 - High moter Current, > 5A
_On
SP1
Current A*100
V3010
≥
K500
Alarm 3-High I
C303
OUT
17
If alarms are enbled then if any individual alarm has been set, turn on buzzer fo two seconds.
_On
SP1
Alarm 1-High P
C301
Buzzer
C15
OUT
18
_On
SP1
Alarm 2-Low V
C302
E/R
TMR
T2
K20
_On
SP1
Alarm 3-High I
C303
T2
Buzzer
C15
RST
19


20
_On
SP1
Alarm 1-High P
C301
LD
K1
OUT
DB-Alarm 1
V5000
21
_On
SP1
Alarm 1-High P
C301
LD
K0
OUT
DB-Alarm 1
V5000
22
_On
SP1
Alarm 2-Low V
C302
LD
K1
OUT
DB-Alarm 2
V5001
23
_On
SP1
Alarm 2-Low V
C302
LD
K0
OUT
DB-Alarm 2
V5001

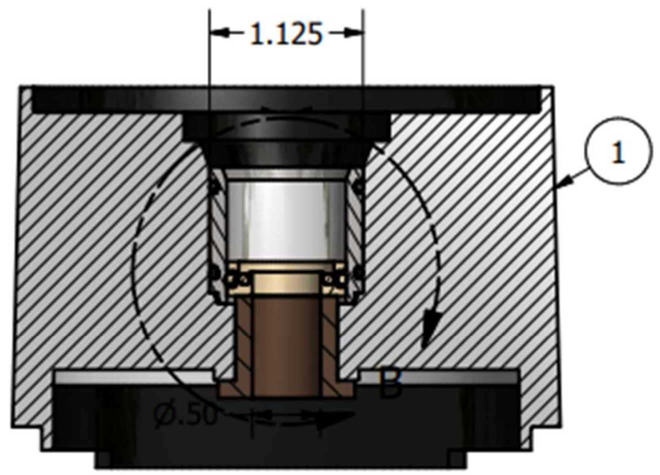

20
_On
SP1
Alarm 1-High P
C301
LD
K1
OUT
DB-Alarm 1
V5000
21
_On
SP1
Alarm 1-High P
C301
LD
K0
OUT
DB-Alarm 1
V5000
22
_On
SP1
Alarm 2-Low V
C302
LD
K1
OUT
DB-Alarm 2
V5001
23
_On
SP1
Alarm 2-Low V
C302
LD
K0
OUT
DB-Alarm 2
V5001


24
_On
SP1
Alarm 3-High I
C303
LD
K1
OUT
DB-Alarm 3
V5002
25
_On
SP1
Alarm 3-High I
C303
LD
K0
OUT
DB-Alarm 3
V5002
26
_On
SP1
HPU Switch
C2
LD
K1
OUT
DB-HPU SWITCH
V5003
27
_On
SP1
HPU Switch
C2
LD
K0
OUT
DB-HPU SWITCH
V5003

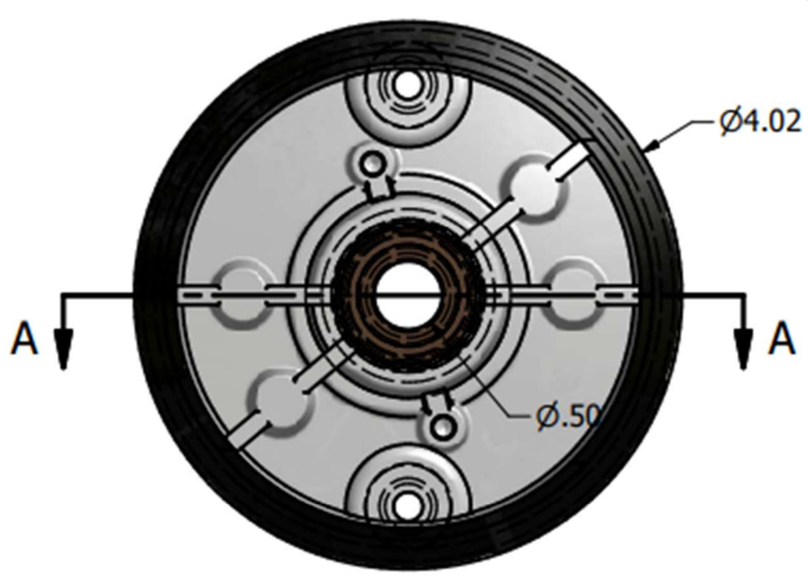

28
_On
SP1
OP-Event
C10
LD
K1
OUT
DB-OP-EVENT
V5004
29
_On
SP1
OP-Event
C10
LD
K0
OUT
DB-OP-EVENT
V5004
30
END
31
NOP

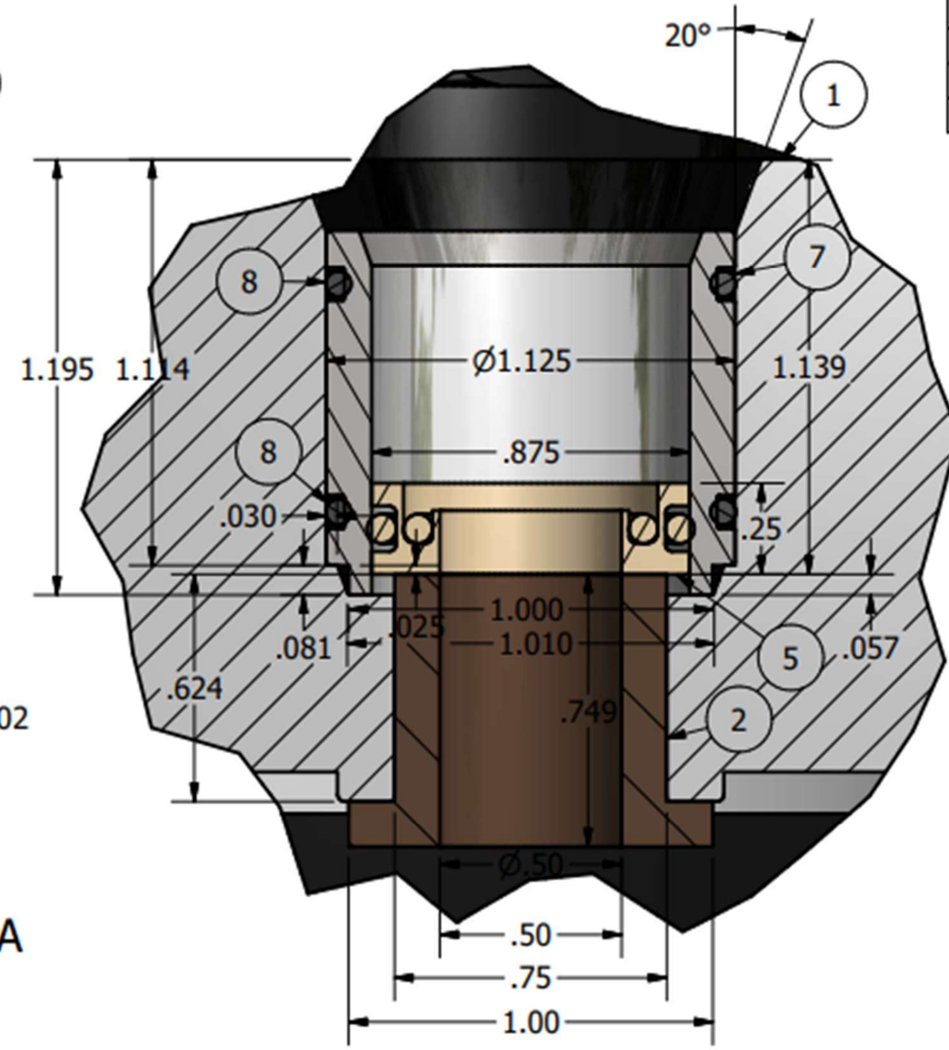
Appendix D – Drawings

REVISION HISTORY				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	1	INITIAL	10/6/2023	CLR
	2	Replaced Epoxy bore with aluminum bore reduction bushing	2/27/2024	CLR
	3	Added some dimensions	2/28/24	CLR
	4	Added second o-ring	2/9/2-24	CLR/AS
	5	Changed color of Seal Adapter in Drawings	3/10/2024	CLR/AS
B-3	5	Added 20 degree chamfer to aid seal insertion	3/16/2024	AS/CLR



SECTION A-A
SCALE 3:4





DETAIL B
SCALE 2 : 1

NOTES:

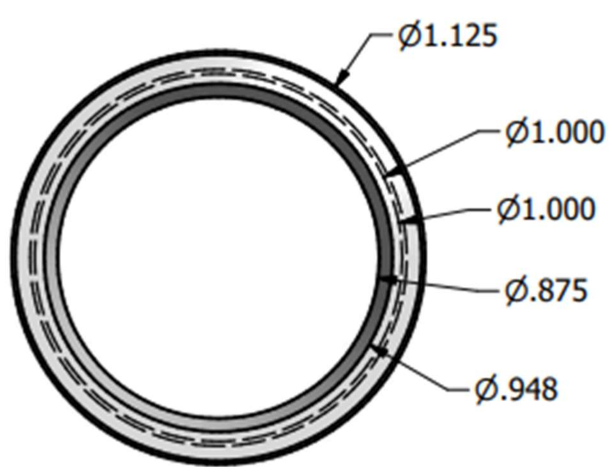
1) Minn Kota Brush End Housing Assembly FW 92-300-160 is base part.
2) FW 92-300-160 will come with the factory prop shaft seals and bronze flange bearing already installed.
3) Replace factory lip seals and spacer with Parker FlexiSeal rotary PTFE lip seal part number 0301FCS180700500260SCM
4) The gland seat in the MK FW 92-300-160 has an ID of 1.125". The OD of the Parker FlexiSeal rotary PTFE lip seal is 0.875".
To accomodate this difference, a seal adapter is used to reduce the bore to 0.875" ID.
5) See drawing AS-CLR 002 for details of a seal adpater.

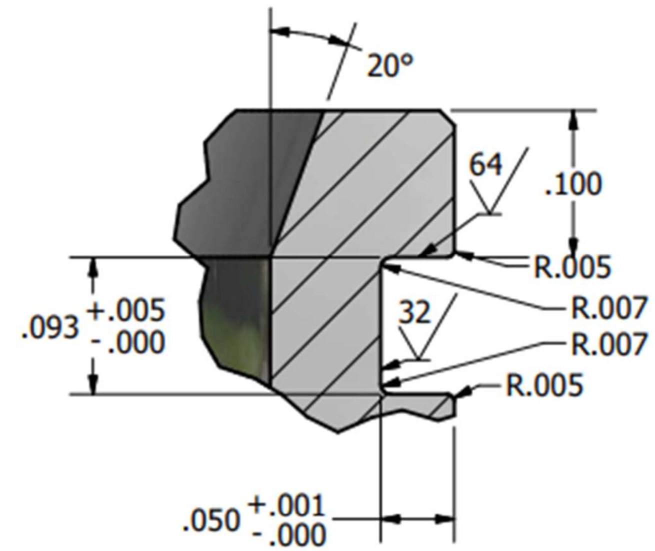
PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	R400-03-170	Minn Kota Brush End Housing Assembly FW 92-300-160
2	1	LRG 144-017	Minn Kota Flange Bearing LRG 144-017
5	1	Parker HP Lip Seal FCS-C	Parker FlexiSeal Rotary Seal part no. 0301FCS180700500260SCM
7	1	Seal Adapter	Aluminum OD 1.125 x OD 0.875 X 1" 6061-T6, MC 9390N22
8	2	O-ring dash 022	O ring 1/16 Frac.l Width, Dash no. 022, Buna-N O-Ring, MC 9452K76

DRAWN AS	10/6/2023	Alec Smyth / Cliff Redus
CHECKED CLR/AS	3/10/2024	
QA		TITLE
MFG CLR/AS	3/10/2024	MK-101 Brushed End Assembly With Seal Adapter to Accomodate Parker FlexiSeal rotary PTFE lip seal part number 0301FCS180700500260SCM
APPROVED CLR/AS	3/10/2024	
		SIZE B · DWG NO AS-CLR 001 · REV 1
		SCALE · SHEET 1 OF 1

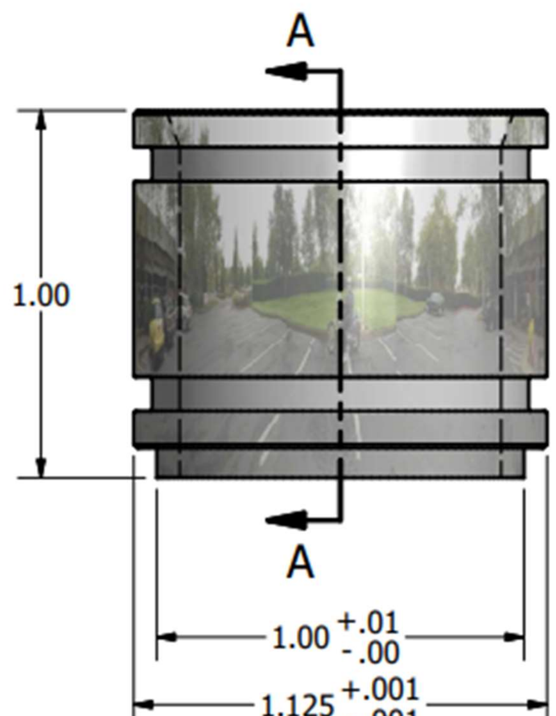
MATERIAL 6061-T6 ALUMINUM
WEIGHT 0.033 lb

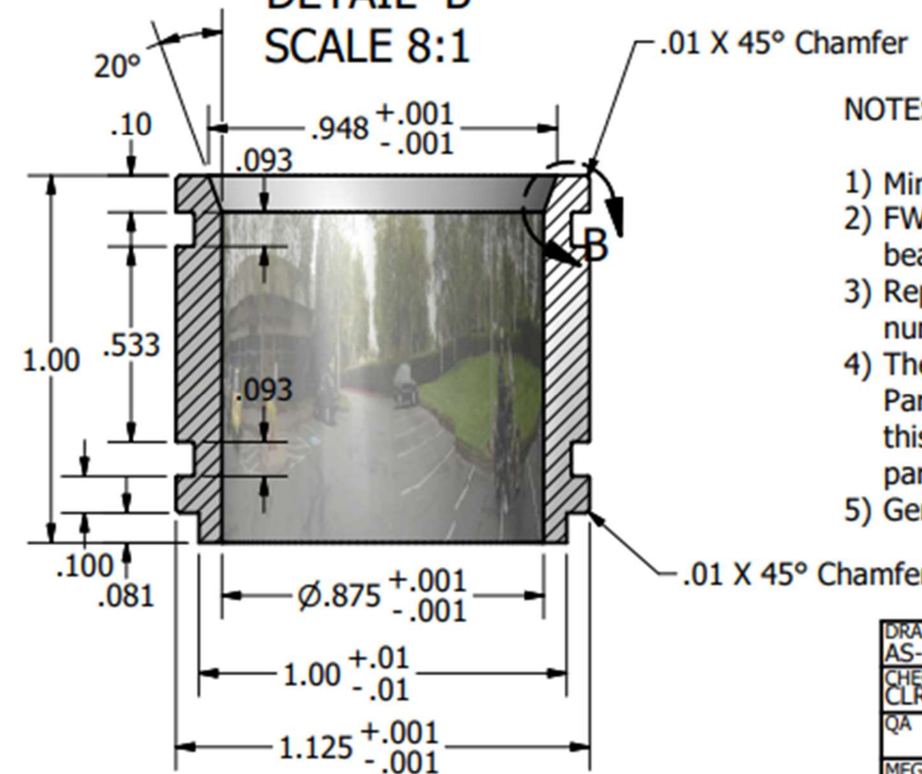
REVISION HISTORY				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	1	INITIAL	2/27/2024	AS/CLR
	2	Added tolerances	2/28/24	AS/CLR
	3	Added second o-ring	2/29/2024	AS/CLR
	4	Changed color of Seal Adapter in Drawings	3/10/2024	AS/CLR
B-3	5	Added 20 degree chamfer to aid seal insertion	3/16/2024	AS/CLR





DETAIL B
SCALE 8:1





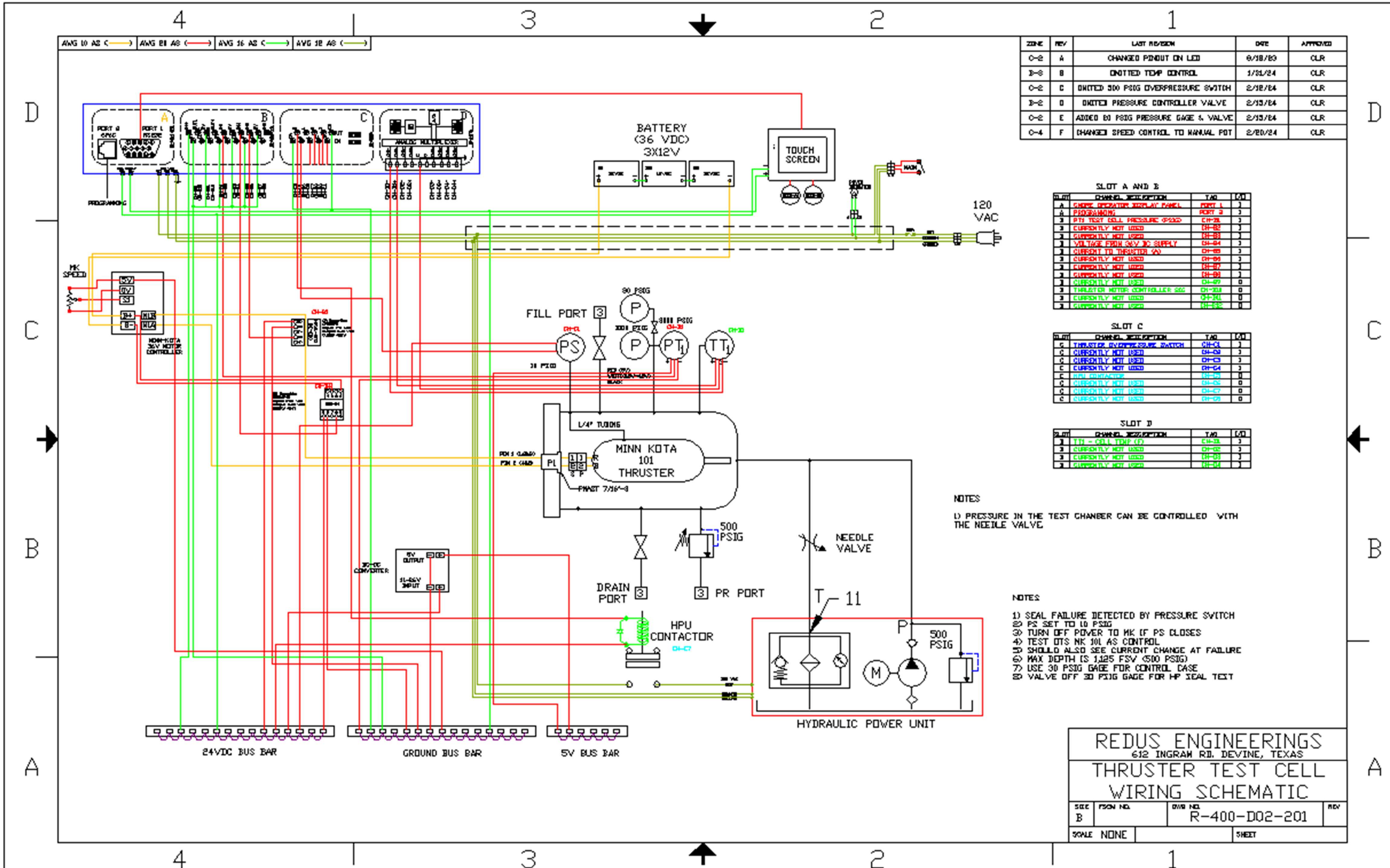
SECTION A-A
SCALE 2 : 1

NOTES:

1) Minn Kota Brush End Housing Assembly FW 92-300-160 is base part.
2) FW 92-300-160 will come with the factory prop shaft seals and bronze flange bearing already installed.
3) Replace factory lip seals and spacer with Parker FlexiSeal rotary PTFE lip seal part number 0301FCS180700500260SCM
4) The gland seat in the MK FW 92-300-160 has an ID of 1.125". The OD of the Parker FlexiSeal rotary PTFE lip seal is 0.875". To accomodate this difference, this seal adapter is used to fill the 1.125" bore and then is machined to accept the parker 0.875" OD lip Seal.
5) General tolerance ±0.01" for all dimensions

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Seal Adapter	Aluminum OD 1.125 x OD 0.875 X 1" 6061-T6, MC 9390N22

DRAWN AS-CLR	2/27/2024	Alec Smyth / Cliff Redus
CHECKED CLR/AS	2/27/2024	
QA		TITLE
MFG CLR/AS	2/27/2024	Seal Adapter for Parker FlexiSeal rotary PTFE lip seal part number 0301FCS180700500260SCM
APPROVED CLR/AS	2/27/2024	
		SIZE B · DWG NO AS-CLR 002 · REV 1
		SCALE · SHEET 1 OF 1


ZONE | REV | LAST REVISION | DATE | APPROVED
C-2 | A | CHANGED PINOUT ON LED | 8/18/23 | CLR
D-3 | B | OMITTED TEMP CONTROL | 1/31/24 | CLR
C-2 | C | OMITTED 300 PSIG OVERPRESSURE SWITCH | 2/12/24 | CLR
D-2 | D | OMITTED PRESSURE CONTROLLER VALVE | 2/13/24 | CLR
C-2 | E | ADDED 30 PSIG PRESSURE GAGE & VALVE | 2/13/24 | CLR
C-4 | F | CHANGED SPEED CONTROL TO MANUAL POT | 2/20/24 | CLR
SLOT A AND B
PROGRAMMING
CURRENTLY NOT USED
THRUSTER MOTOR CONTROLLER SIG
SLOT C
CURRENTLY NOT USED
SLOT D
TT1 - CELL TEMP (F)
CURRENTLY NOT USED
BATTERY
(36 VDC)
3X12V
TOUCH
SCREEN
120
VAC
MK
SPEED
FILL PORT
30 PSIG
PS
P
PT1
TT1
L/4" TUBING
MINN KOTA
101
THRUSTER
PL
DRAIN
PORT
500
PSIG
PR PORT
NEEDLE
VALVE
T - 11
P
500
PSIG
M
HYDRAULIC POWER UNIT
HPU
CONTACTOR
5V
OUTPUT
24VDC BUS BAR
GROUND BUS BAR
5V BUS BAR
NOTES
1) PRESSURE IN THE TEST CHAMBER CAN BE CONTROLLED WITH THE NEEDLE VALVE.
NOTES
1) SEAL FAILURE DETECTED BY PRESSURE SWITCH
2) PS SET TO 10 PSIG
3) TURN OFF POWER TO MK IF PS CLOSES
4) TEST OTS MK 101 AS CONTROL
5) SHOULD ALSO SEE CURRENT CHANGE AT FAILURE
6) MAX DEPTH IS 1,125 FSW (500 PSIG)
7) USE 30 PSIG GAGE FOR CONTROL CASE
8) VALVE OFF 30 PSIG GAGE FOR HP SEAL TEST
REDUS ENGINEERINGS
612 INGRAM RD. DEVINE, TEXAS
THRUSTER TEST CELL
WIRING SCHEMATIC
SIZE B
DWG NO. R-400-D02-201
SCALE NONE
SHEET