Australian National University

14 UD Tank Opening Report

#131

23rd May – 20th of June 2019

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1 Reason for tank opening

After a long period recovering the vacuum from TO#130, the 14UD was conditioning and operating well. There were no signs of loading from the HE stripper as in previous runs, however, SF6 peaks were found in RGA scans, suggesting that the leak had not been eliminated.

A spark incident crippled the machine, and shorting rods were used to isolate the problem to U20 and U21. Something else also occurred resulting in very little or no beam getting through the machine, seemingly stopping in the HE stripper area. The machine was not operational, so opening the tank and investigating was the only option.

2 Summary of work

2.1 Tank opening #131

2.1.1 23/5/19 Thursday

- The SF_6 was pumped from the 14UD into the storage vessel.
- The porthole doors were opened, and the fresh air ventilation system was run overnight.

2.1.2 24/5/19 Friday

- Gas tests showed the atmosphere within the 14UD was OK and compliant with the Confined Space regulations and was safe to enter.
- Platform was deployed and tool and lighting setup loaded on.
  Performed initial 10kV HV entry test using the Megger only. Issues were found in all sections of U20 and U21. Issues were also found in 8 gappers of U13, U22, U25, and T3 on U25.
- Mechanical test of shafts and chains revealed that there is an odd sound in the top of U15 shaft, and chain 3 was a bit noisy.
- Observed stringer issues in U20 and U21

2.1.3 28/5/19 Tuesday

- Wiped down the column using warm water.
- Confirmed stringer issues- U20, screw attaching the bottom stringer to the post was missing and the stringer was hanging free in the air. U21, the stringer was broken and had rested on and eroded part of a post electrode.
- U26 ring 2 post C was loose, and U26 ring 13 post D was off.
- Radiation was checked around the HE stripper area, but nothing was detected. It was suspected there might be radiation due to something obstructing the beam.
- Started testing every gap and resistor pair in U20 and U21 with the Megger high voltage tester (see section *3 HV Resistor Measurements*).

2.1.4 29/5/19 Wednesday

- Continued testing with Megger
- U20 T1 G2 resistor lead broke when removing for testing and was retrieved from U28
- RGA SF6 tests were done (see section *4 RGA tests for SF6* for details)
- Checked for HE shaft noise reported in the mechanical tests. A cyclic harmonic noise was noticed somewhere around, perhaps inside the terminal. It was not a bearing. No action was deemed necessary.
- U21 T2 was retested and found to be good
    - G8 6.7TΩ gap and 595MΩ resistors
    - G9 9.5TΩ gap and 600MΩ resistors
    - G10 4.6TΩ gap and 602MΩ resistors
- U21 post D should be replaced due to the burnt electrode/spark gap
- Ball ended resistor lead in U19 needs replacing
- U20 stringer was reattached and U21 stringer was replaced
- Noticed a red spray deposit on the casting under the stringer

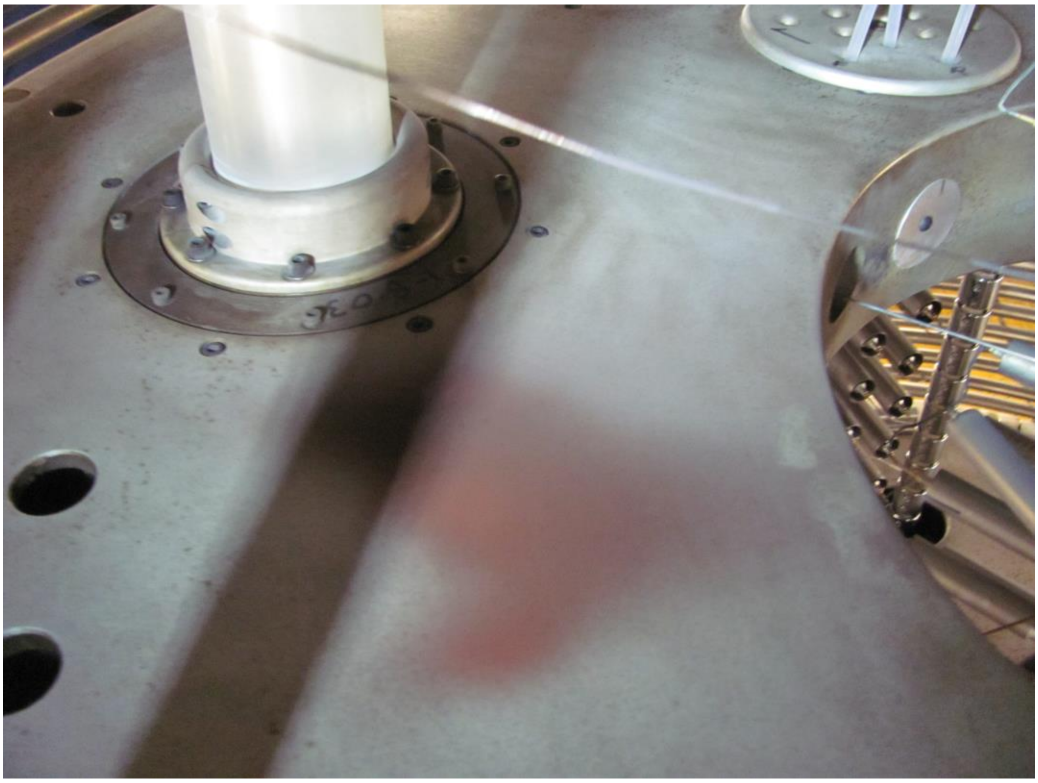

Figure 1 Residue under loose stringer

- Red deposit was cleaned up with Alcohol and Kimwipes
- Found a shorting rod contact housing was loose in U20 and evidence of sparking underneath. Housing, spring, mesh, and screws were replaced with new items

2.1.5 30/5/19 Thursday

- Re-measured the problem sections identified in the entry Megger tests
  - U13 8 gapper tested 2.79GΩ, ok!
  - U22 8 gapper tested 2.78GΩ, ok!
  - U24 8 gapper tested 2.79GΩ, ok!
  - U25 T3 measured 3.48GΩ, still different from previous exit test
- Extensively tested each gap and resistor on U25 T3 and corresponding posts. We found out of tolerance resistors on G8 (292 MΩ) and G11 (294MΩ), these were replaced with good items. We also found several out of tolerance resistors on the post- G14 (888MΩ and 957MΩ), G17 (957MΩ and 956Ω), and G18 (956MΩ and 961MΩ). Each was replaced with good items.
- Re-measured U25 T3 and got… the same result of 348GΩ. Looking at previous tests of this tube and typical results for similar (1 gap shorted) tubes, 348-350GΩ seems normal. Perhaps the measurement on last exit of 378GΩ was a typo? Previous measurements of this tube were also 348 GΩ soooo it looks good.
- Reconnected the HE mid pump and noticed some particles under the connector
- Post B U19 had a dodgy looking screw on the shorting loop which should probably be replaced.
- Searched the bottom of the tank and found:
  - Missing screw and washer from U20 stringer
  - A small pine cone
  - A screw and internal star washer as used in some stringer connections and U19 shorting loops
  - Large (5/16"?) internal star washer
  - Broken piece of Ethernet connector
  - 1x Orange hair, possibly pubic

Figure 2 Things found in the bottom of the tank

- Found debris on casting in U1, what looked like small hard pieces of plastic.

Figure 3 Debris on casting U1

- Found an o-ring on the casting of U2. Its origin is unknown, its cross section is not consistent with the o-rings from the shorting rod clutch.

Figure 4 O-ring piece on casting U2

2.1.6 31/5/19 Friday

- Swapped out U21 Post C which was damaged by the loose stringer. Serial #307 was removed and #2712 was installed in its place.

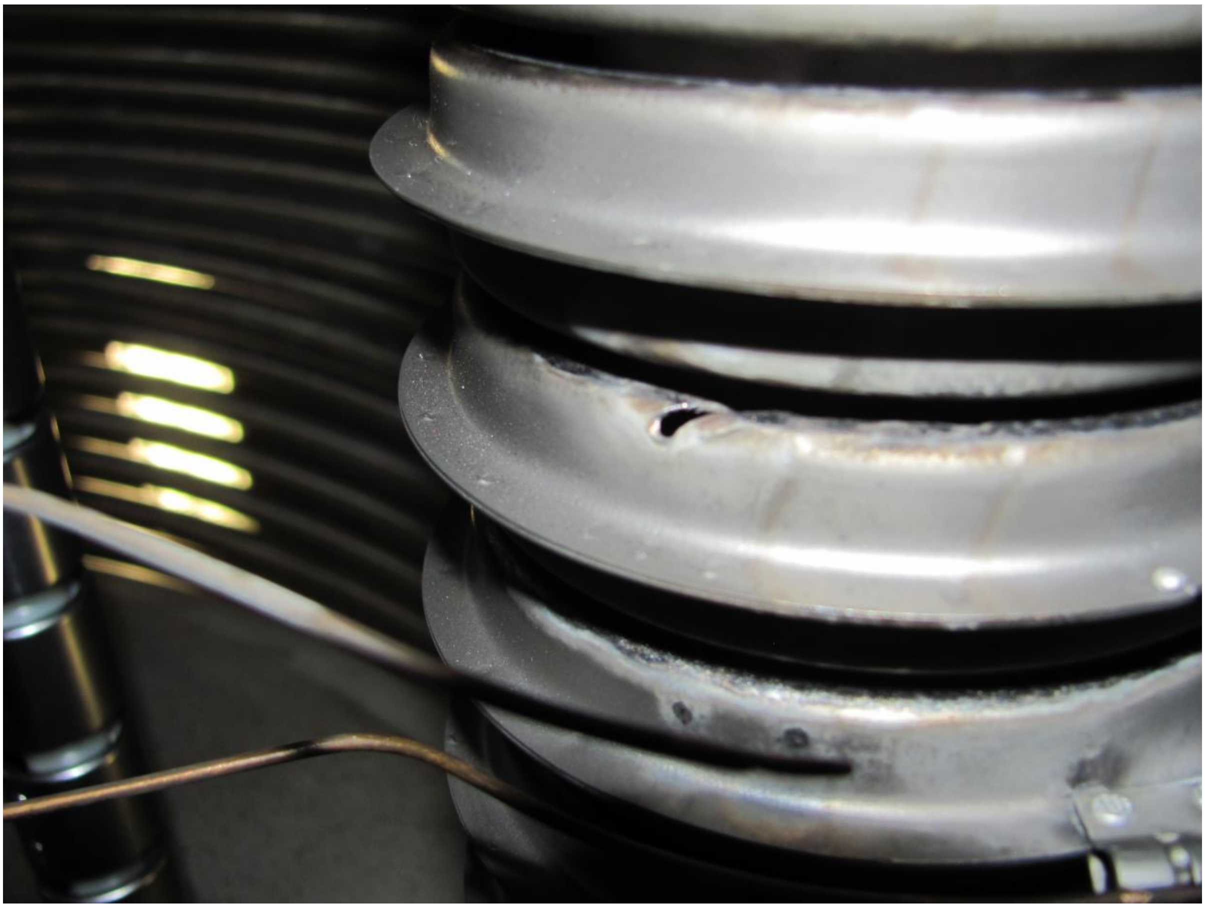

Figure 5 U21 post C damaged by loose stringer

- Manufactured 2x new stringer post attachment points. These were made by modifying resistor clamps to remove the tapered section, and turning the body down to Ø13mm.
- Replaced the dodgy screw on U19 Post B shorted loop

2.1.7 02/6/19 Sunday

- Ran tests powering up HE mid section ion pump from an external power source. Results seemed to show that the vacuum was marginally worse in both HE and LE sections, indicating the pump should be replaced.

2.1.8 03/6/19 Monday

- Opened the terminal to access the Weisser valve. Two spinnings down, the top was left in place.
- Weisser valve was closed and the HE tube was let up to Nitrogen according to normal procedures.
- Removed the HE stripper port blank to view the foil changer. There were three foils found on top of the lower aperture, and 3 more on the foil catcher.

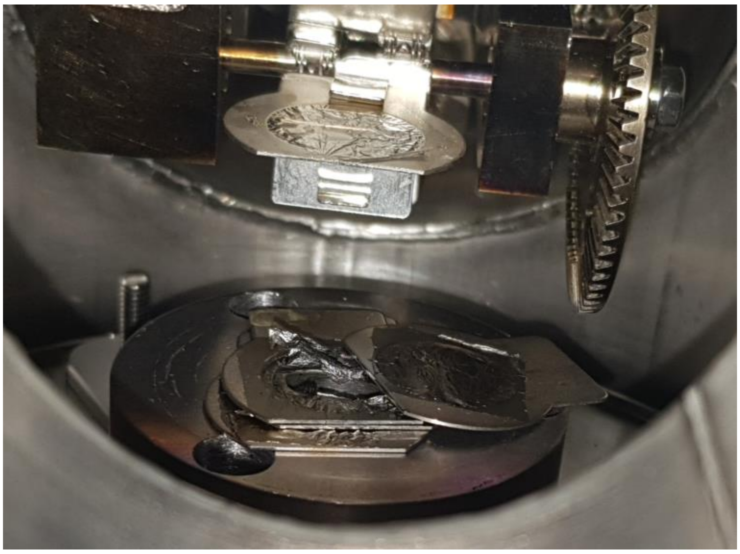

Figure 6 Foils obscuring aperture in HE stripper

2.1.9 04/6/19 Tuesday

- Prepared for stripper removal
- Moved the spinnings to their usual positions (2 up, 1 down).
- Manufactured new tube jack stands utilizing bearings to eliminate the bolts ‘walking’ on the casting. Also increased the height of the stands so we could jack from tube 2.

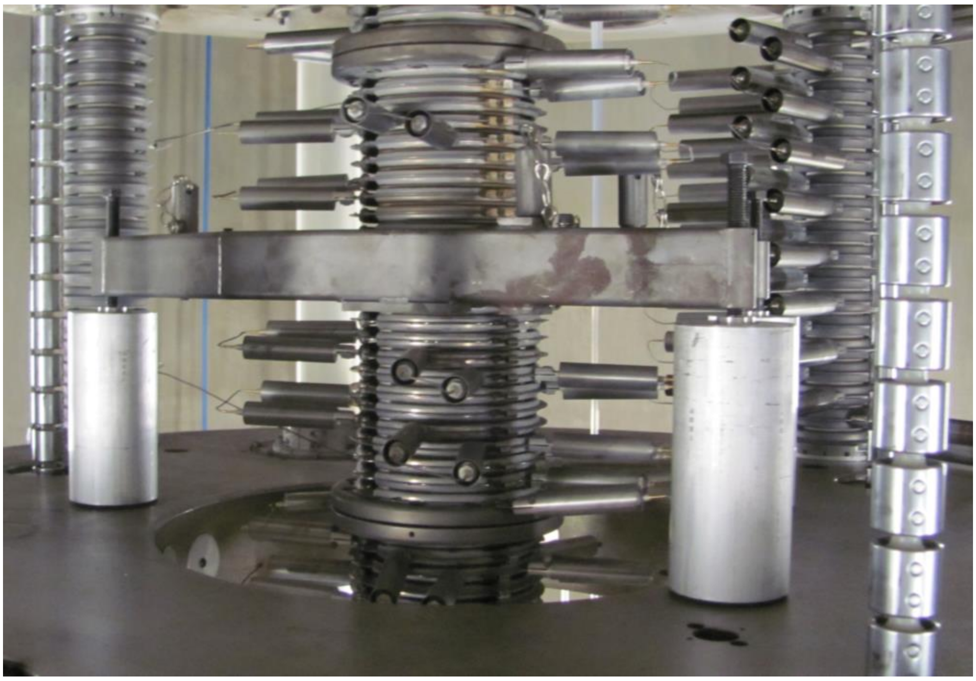

Figure 7 New jack stands

- Jacked tubes and removed the stripper.
- Capped HE tube and pumped it using the turbo on the multicup box.
- The tube section between the terminal bellows and U19 was capped and purged with Nitrogen. The remaining section between the terminal bellows and Weisser valve was left.

2.1.10 05/6/19 Wednesday

- Worked on modifications to the HE stripper outside the tank

2.1.11 06/6/19 Thursday

- Finished modifications to the HE stripper, cleaned, reassembled and aligned ready for installation

2.1.12 07/6/19 Friday

- Checked the stripper modifications by bolting up the foil mechanism on the bench and running through some foil changes. It all looked good.
- The HE tube section was let up to Nitrogen and the cap removed
- In order to maintain alignment, the spokes on the top of the tube in U19 were released by loosening the hose clamp band. The tube alignment jig was used to align the tube, spacer, and stripper and it was bolted up.
- The studs/nuts were torqued in stages of 5, 7, 9, and 10Nm tightening two at a time on opposite sides.
- The top flange of the stripper was capped again and the section was pumped for the long weekend.
- The source of the o-ring on the U2 casting was investigated. The missing piece of the o-ring was found inside the shorting rod ‘standpipe’. The pipe was removed and we found a groove in the pressed Nylon piece in the flange that was missing an o-ring.

Figure 8 Found o-ring parts

Figure 9 Location of missing o-ring

2.1.13 11/6/19 Tuesday

- Installed studs on top of the HE stripper then installed T3 on top (leaving out the upper v electrode to give enough room to slide in).
- Installed upper v electrode then lowered tubes down into position and bolted up.
- Torqued opposite sides of the tubes in stages of 4, 6, 8, and 10Nm
- Installed the terminal bellows. A wire gasket was attached to the underside of the bellows and the bolts nipped up. The top gasket was just slid into place and the cup assembly lowered onto it before tightening. Bottom bolts were tightened to 18Nm and the top were tightened as much as possible.
- The HE tube was pumped down to minimize exposure to atmosphere while waiting on the new ion pump and foils.
- Tube nuts were measured for future reference and are 12mm diameter and 12mm long.
- Shorting rod standpipes were also measured for future reference. The LE is ~861mm overall length, while the HE is ~1147mm.

2.1.14 12/6/19 Wednesday

- Refitted resistors in U18 and U19, noting half gradient (1 dummy in pair) on gaps 5,6,7,8 on the tube immediately above the stripper.
- Tightened stringers in U18, U19, and U20 replacing screws where necessary.
- Completed checks of resistors, stringers, and shorting rod contacts in U20 through to U27 (these units were not cleaned).
- Stringer mounting point rivets were recompressed U23 post as they were a bit loose.
- A loose resistor was found and tightened on U25 post.
- Replaced the spring in U26 shorting rod contact. Noted that the screws attaching the housing to the casting were different sizes (one thread in the casting was probably retapped after being stripped).

- Refitted the LE standpipe. The missing o-ring was left out as it was determined that it did not perform any specific function.
- Cleaned and performed checks on U1.
- Found a loose shorting rod contact housing on U1. The housing was very difficult to remove as it was located inside the casting. Looking at the location of other shorting rod contacts, there does not seem to any consistency as to their position inside or outside the casting. Our theory is that the housings were all originally inside the casting but as they were replaced with newer radiussed housings they were placed on the outside as it is much more convenient to work on.
- Four shorting rods were installed in the LE end to check the function and position of the shorting rods. It all looked good with the rod joints located in the middle of the castings when the system was in the parked position.

2.1.15 13/6/19 Thursday

- Measured the position of the shorting rod with respect to the end of the standpipe when two rods are inserted. The Both LE and HE measured 180mm (rod inside).
- Cleaned, inspected and closed U2 to U10, U17 and U18.
- Bottom stringer on U3 was found to be very loose, so it was tightened.
- U10 G7 post resistor lead was burnt, so lead and resistors were replaced.
- U18 bottom ring had a noise when vibrated. All screws were tight so it seems like there is something inside the ring. No action taken
- U28 shorting rod contact spring was not free moving, so it was replaced.
- U28 a loose resistor tab was tightened.
- Corona needles were visually inspected and deemed to be ok.
- The HE mid-section Ion pump power supply was modified to be positive in preparation for the new pump.

2.1.16 14/6/19 Friday

- Received information that the new HE mid-section ion pump had not been sent from Duniways in the USA so would not be here in time to fit quickly.
- Measured an Ion pump on the LINAC return line as a possible candidate for the HE mid-section. It looks like it will fit. The pump was removed and tested on the turbo cart.
- The temporary pump was installed along with the HE stripper foils and the tube section was pumped.

2.1.17 15/6/19 Saturday

- Started the new 11L/s ion pump with a Terranova controller.

2.1.18 16/6/19 Sunday

- The pump tripped off overnight and was restarted with the aid of a fan to keep it cool. After a short time pressure was high 10^{-6}

2.1.19 17/6/19 Monday

- Setup leak chaser on the multicup box turbo

- Ion pump was still running, pressure on the controller ~7.5×10^{-6}, HE pressure ~5×10^{-7}
- Closed the HE sublimer and turned off the ion pumps
- Helium background was ~1.7×10^{-9} and stayed there even after turning off the pumps
- Background reduced further to $1.3\text{-}1.2 \times 10^{-9}$
- Started leak testing on terminal bellows, top and bottom joints were good
- Moved on to U19. The tube above the stripper top and bottom joints, stripper flanges (spare, feedthrough, foil changer, ion pump, bottom joint to flange) all were good.
- Connected the portable sorption pump to the Weisser valve. It cooled down to 21mT over lunch and we opened to the valve space. It rose to 80mT then pumped down to 16mT.
- Valved off the sorption pump and opened the Weisser valve. Tube vacuum went to 10^{-4} range and quickly recovered.
- Weisser valve cover was reinstalled and the pump port capped with a conflat blank.

2.1.20 18/6/19 Tuesday

- Tried restarting terminal ion pumps, vacuum went bad- 10^{-5}
- Unplugged the terminal 60L/s (HE side) and the vacuum recovered, indicating there was an issue with that pump
- Found that the connector was in bad shape with evidence of prolonged breakdown. The connector, along with the fact that it had been letup during the stripper job, were reasons for its poor performance.
- Attempted to kickstart the pump with the Terranova power supply (see section 7 HE Terminal Pump for details)
- Shafts were turned on and left to run overnight

2.1.21 19/6/19 Wednesday

- Ion pumps were left on with the HE mid-section pump on the Terranova.
- Schematic of the HE mid-section 5kV ion pump power supply was made
- Checked the terminal and performed pre-closing tests
- Closed the terminal
- Refitted most casting covers
- Reassembled U19. Note that the bottom nut on the stripper motor mount could not be found and an executive decision was made to leave it off as it is extremely difficult to fit and remove and doesn't add to the strength of the mount.
- Resistors were reassembled in U20
- U19 and U20 were cleaned, checked and closed.

2.1.22 20/6/19 Thursday

- Finished clean, check, and close of U11-U16
- Fitted remaining casting covers
- Noticed U17 post D G2 was particularly black, but nothing showed up on standard high voltage tests.
- Commenced standard closing procedures.

3 HV Resistor Measurements

As part of the investigation into the out of spec. results in the Megger test, it was decided to measure each insulating gap and resistor pair in U20 and U21. Only U21 T2 G9 was found to be out of spec. so resistors were replaced here.

U20								
	Tube1		Tube2		Tube3		Tube4	
Gap	Insul. (TΩ)	Resistor (MΩ)	Insul. (TΩ)	Resistor (MΩ)	Insul. (TΩ)	Resistor (MΩ)	Insul. (TΩ)	Resistor (MΩ)
1	5.5	599	4.2	598	6.9	599	4.7	600
2	4.5	593	3.8	601	5.0	599	2.4	602
3	3.9	599	3.6	599	4.4	599	7.2	600
4	4.0	598	4.1	601	3.8	600	4.6	607
5	6.7	601	6.8	599	3.8	599	5.2	601
6	5.0	600	4.8	601	4.8	600	1.8/2.2	600
7	4.2	602	4.5	598	4.0	597	7.1	610
8	4.1	600	3.6	597	4.0	601	4.0	600
9	9.0	600	7.8	603	6.3	600	-	-
10	4.6	600	5.4	601	5.3	601	-	-
11	3.5	599	3.4	599	6.1	596	-	-

Table 1 U20 Tube Resistor Measurements

U21						
	Tube1		Tube2		Tube3	
Gap	Insul. (TΩ)	Resistor (MΩ)	Insul. (TΩ)	Resistor (MΩ)	Insul. (TΩ)	Resistor (MΩ)
1	7.5	599	5.6	599	4.6	601
2	10.6	596	7.2	600	5.3	595
3	7.8	599	5.5	600	8.7	600
4	11.3	597	5.2	598	11.0	600
5	8.4	597	4.3	600	5.2	600
6	6.8	602	4.9	596	9.2	598
7	8.5	601	6.6	599	7.1	598
8	4.5	600	10.7	595	7.6	599
9	9.6	592 (brd)	6 GΩ	545	3.0/4.9	600
10	12.0	599	5.7	602	3.4/4.3	599
11	9.0	600	2.5/5.8	600	2.9/5.5	600

Table 2 U21 Tube Resistor Measurements

Posts		
	U20	U21
Gap	Insul. (TΩ)	Insul. (TΩ)
1	2.3	3.7/2.5
2	3.3	7.4/4.5
3	3.5	9.9
4	3.1	11.9
5	2.0	13.0
6	2.5	13.1
7	2.7	4.1
8	2.8	2.2
9	2.4	9.5
10	2.6	15/4.2
11	2.3	13.8
12	2.9	15.0
13	1.8	11.2
14	1.4	10.3
15	2.8	10.2
16	2.6	10.7
17	2.6	12.8
18	2.7	4.4

Table 3 U20 and U21 Post Resistor Measurements

4 RGA tests for SF6 and Ion pump diagnosis

Some experiments were done to try and get some more data and clues on the apparent SF_6 leak. Logging of the LE RGA was started on the 29th of May. Even six days after gas out, there was a strong peak of SF_6.

- After scan 19, the shafts (and therefore pumps) were powered up and the SF_6 peak disappeared.
- After scan 33, the shafts were turned off and the SF_6 reappeared after a few scans.
- After scan 36, the shafts were turned on and the SF_6 was instantly gone.
- After scan 37, the shafts were turned off and the SF_6 reappeared.
- Scan 39 was done with only the HE shaft running
- After scan 40, both shafts were turned off
- After scan 53, the shafts were turned on with the HE stripper ion pump off (unplugged), the SF_6 immediately disappeared.

The next test was to look at the operation of the gas stripper ion pump.

With the shafts running from 10:45am to 11:25am, the vacuum status was

- LE 4.3×10^{-8}
- LE mid 2.0×10^{-8}
- Terminal LE 1.6×10^{-8}
- Terminal 20L/s 5.9×10^{-7}
- Terminal HE 1.2×10^{-8}
- HE mid 5.0×10^{-8}

- HE 5.3x10^{-8}
- Gas Stripper 0.03mT

Shafts were turned off from 11:30am to 12:25pm

- LE 5.91x10^{-8}
- HE 5.52x10^{-8}

Shafts were turned back on with the HE stripper ion pump turned off 12:25pm to 1:25pm

- LE 4.3x10^{-8}
- LE mid 2.3x10^{-8}
- Terminal LE 1.3x10^{-8}
- Terminal 20L/s 3.5x10^{-7}
- Terminal HE 8.1x10^{-9}
- HE mid -
- HE 5.0x10^{-8}
- Gas Stripper 0.05mT

The vacuum appeared to be slightly improved, indicating that the HE stripper pump was not working and should be replaced

Some more experiments were done looking again at the SF_6 issues. On the 30th of May, scan 486, SF_6 peak was ~8x10^{-10}.

- LE 7.3x10^{-8}
- HE 5.78x10^{-8}

The shafts were turned on at 10:41am with the HE stripper ion pump disconnected. SF_6 peak was gone on the next scan, 487. LE vacuum jumped to 6.2x10^{-8} then down to 4.7x10^{-8} over the next minute. HE vacuum jumped and stabilised slightly higher than before.

The shafts were turned off at 11:20am, scan 499. SF_6 peak was still gone. On scan 500 the SF_6 peak returned at ~6x10^{-10}.

The HE stripper ion pump was re-connected. With the shafts still off, scan 524, LE vacuum was 7.1x10^{-8} and HE vacuum 5.6x10^{-8}, SF_6 was 8x10^{-10}. Just the HE shafts were turned on at 12:40pm and the SF_6 peak went from 6x10^{-10} to 7x10^{-10} over the next 3 scans (525-527). The HE shafts power the HE stripper and HE (lower) 60L/s ion pumps, so these pumps did not get rid of the SF_6. There was also little effect on HE vacuum (5.5x10^{-8}). The LE shaft was turned on at 12:47pm and the SF_6 disappeared within 10 seconds. At 12:55pm the SF_6 peak was still gone and LE vacuum was improving to 4.2x10^{-8}, very little change in the HE vacuum.

- LE 4.2x10^{-8}
- Terminal LE 1.9x10^{-8}
- Terminal 20L/s 7.2x10^{-7}
- Terminal HE 1.2x10^{-9}
- HE mid 5.1x10^{-8}
- HE 5.2x10^{-8}

Shafts were turned off at 2:46pm and the LE mid section ion pump was disconnected. The SF_6 peak was 8 to 9x10^{-10} for scans 576 and 577. LE vacuum was 7.5x10^{-8} and HE vacuum was 5.6x10^{-8}. HE shafts were turned on at 3:21pm and the SF_6 peak remained unchanged after two scans. LE shafts were also turned on at 3:24pm, and the SF_6 peak remained for one scan (5 seconds after), then was gone on the next (579). The LE vacuum response seems similar to those with LE ion pump connected. At 3:48pm the SF_6 was still gone

- LE 4.6×10^{-8}
- Terminal LE 1.6×10^{-8}
- Terminal 20L/s 4.9×10^{-7}
- Terminal HE 7.5×10^{-9}
- HE 4.8×10^{-8}.

On the 31st of May, at 3:16pm, the HE stripper ion pump was powered up via an external power supply (no other in-tank pumps were powered). It was left on until 4:18pm. During this time, the HE vacuum degraded slightly (5.4 to 5.8×10^{-8}), indicating the pump was not working properly and possibly outgassing more than it was pumping. The Weisser valve was shut ~10:00am on the 3rd of June.

On the 20th of June with the tank closed and just before pumping out the RGA scans were restarted. With shafts and Ion pumps off, there was no SF_6 peak. However, on the 4th of July, the peak reappeared.

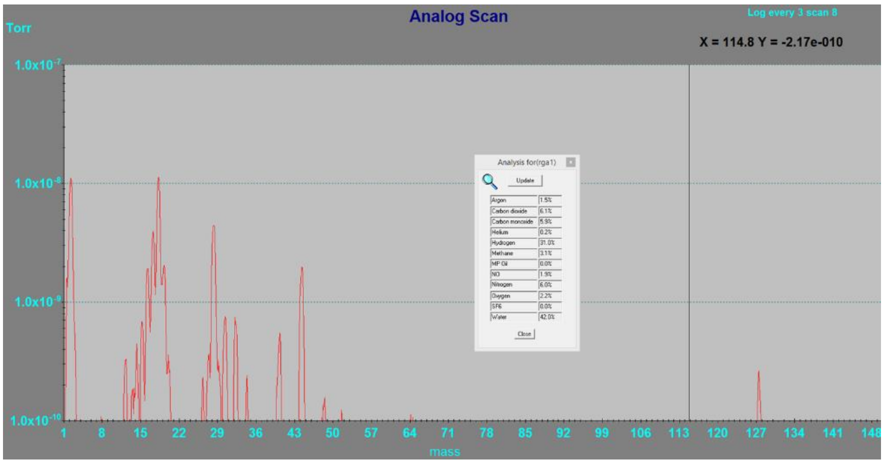

Figure 10 RGA scan 4th of July 2019

The spectrum was obtained in Figure 10 is after 5 minutes with all ion pumps off. The spectrum is dominated by a water as expected. The amplitude of peak mass 127 (SF_6) is 2 x 10^{-10}. The water peak with mass 28 is 10^{-8}.

Obviously, the SF_6 leak is still present in the 14UD. More likely, it is in the gas stripper plumbing because it was not affected by operation of the lower ion pumps as described above. We will continue the evaluation of possible leaks including turbo pumps and other fittings in the gas stripper plumbing. The good news is that the level of this leak is not significant enough to compromise the operation of the gas stripper or cause significant deconditioning of 14UD.

5 HE Stripper Modifications

When it was diagnosed that the beam was stopping in the HE mid section, it was theorised that perhaps a foil had dislodged and was blocking it. On inspection, it was found that several foils had fallen onto and around the Tantalum aperture below. Operating the foil drive mechanism showed the frames would strike the lower aperture and dislodge. Investigation showed that the lower aperture was ~9.5mm closer to the foil mechanism than on the old stripper.

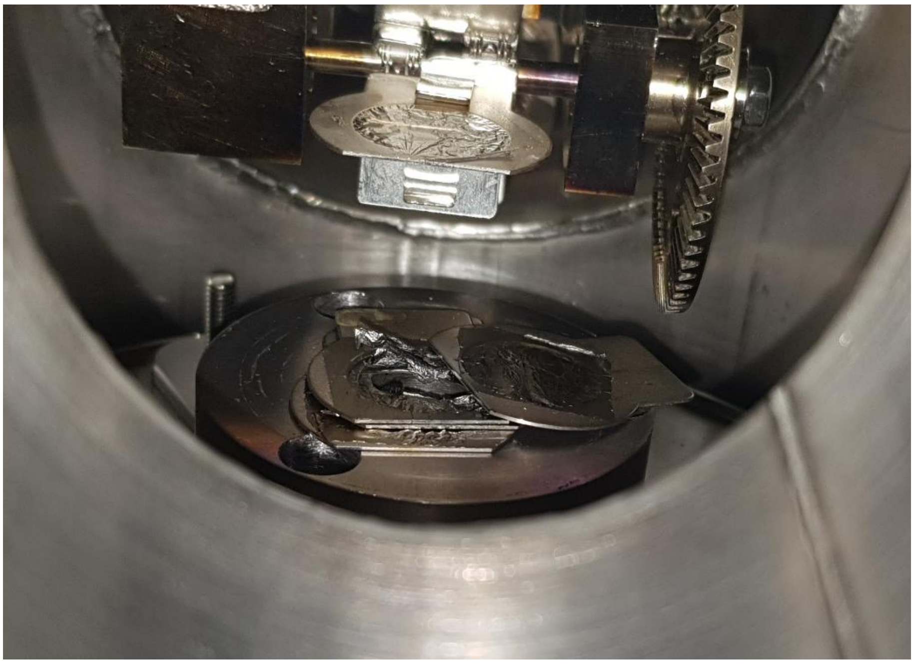

Figure 11 View showing the dislodged foil frames on top of the lower aperture

There were two sources of this error. Firstly, the standoffs holding the support for the lower aperture were ~7mm higher than in the old unit, and secondly the foil attachment nipple was ~2.5mm lower than the old unit. The height of the standoffs was correct to the original NEC drawings however it appears that due to an interference with the casting, the stripper was angled when originally installed in the 14UD. This angle required the lowering of the standoffs, but this was not recorded. New standoffs were made 9mm shorter to address both the aperture and nipple height discrepancies. A dry run with the foil mechanism on the bench proved the new arrangement worked.

While the stripper was out and under modification, it was decided that the foil catcher should also be modified to reduce pumping impedance. There was concern that the reduced free area was affecting the vacuum, so sections of the catchers were cut out and replaced with ~50% stainless steel mesh (see Figure 12 and Figure 13).

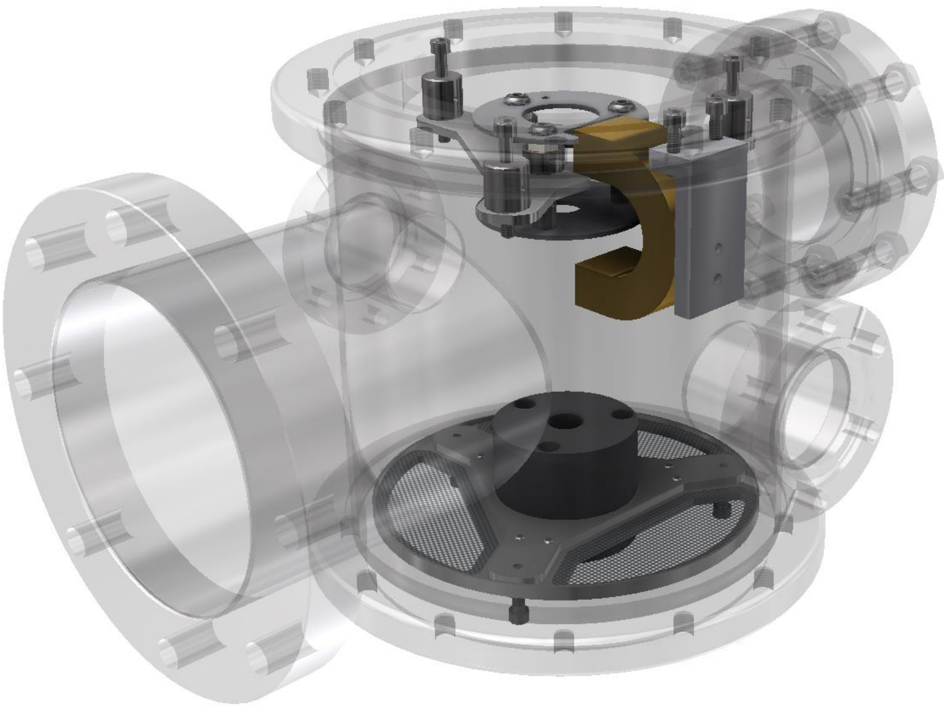

Figure 12 CAD image of the modified stripper assembly

Figure 13 CAD image of the new foil catcher and standoff

6 HE Mid-Section Ion Pump

It was decided to replace the HE mid section ion pump as the vacuum in the rest of the machined got slightly worse when it was turned on. The pump was removed with the HE stripper, and a strange, white, furriness was noticed on both the pump and port side of the flanges. The reason for this is unknown, but the stripper housing was cleaned in preparation for a new pump. It's worth noting that this was the new stripper housing that had only been installed in the last tank opening, so the deposit only had ~1100 hours to develop.

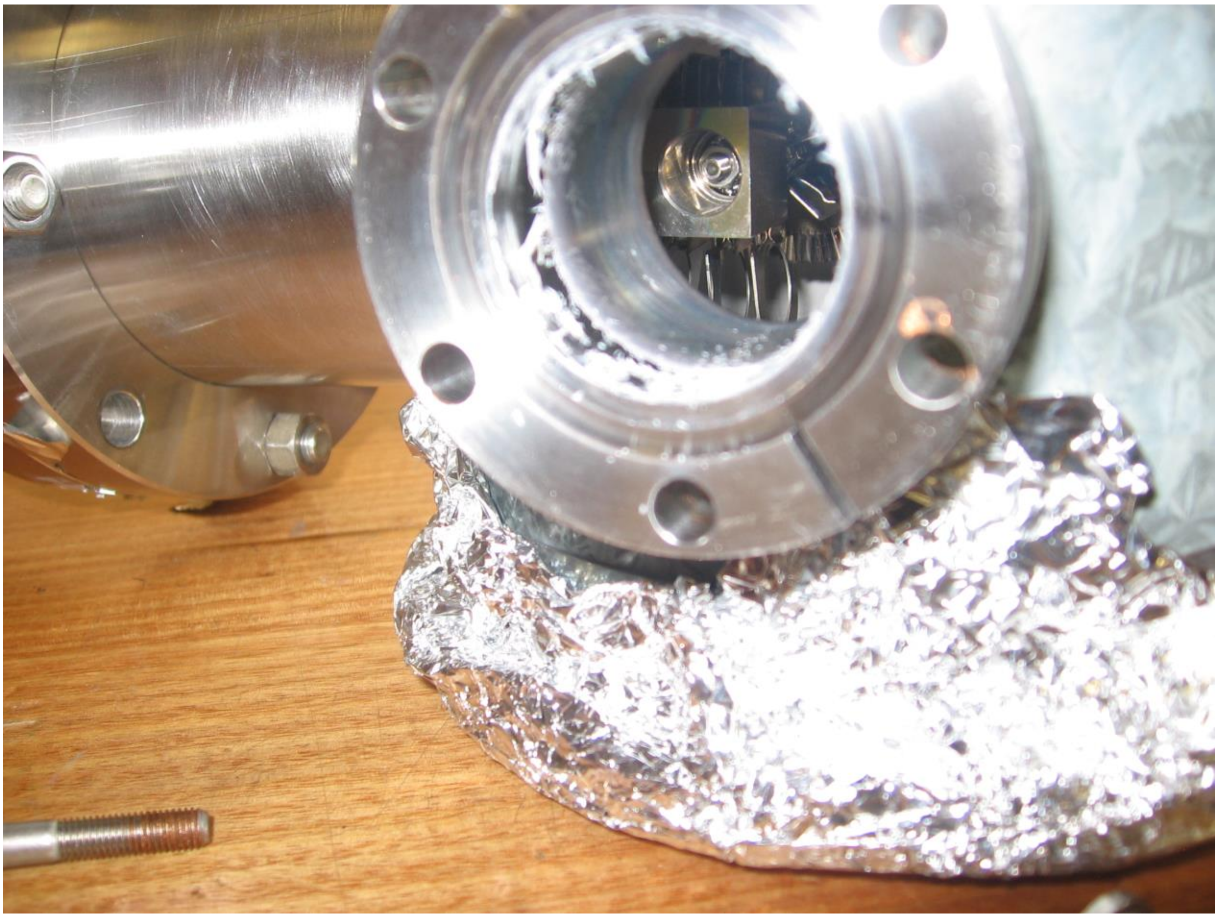

Figure 14 HE stripper pump port after old pump removal

A new pump of similar size and form was ordered from Duniway in the USA, however mixups with purchasing meant it would not arrive in time to fit during this tank opening. A pump was located on the old LINAC return line which is no longer used. The history of this pump was not fully known, it was likely to have come across with the Daresbury LINAC parts, but it looked in good condition internally, despite its age (48 years according to the date written on it). The pump was installed on the stripper body, requiring the bottom resistor pair on the tube above be moved around to avoid interference.

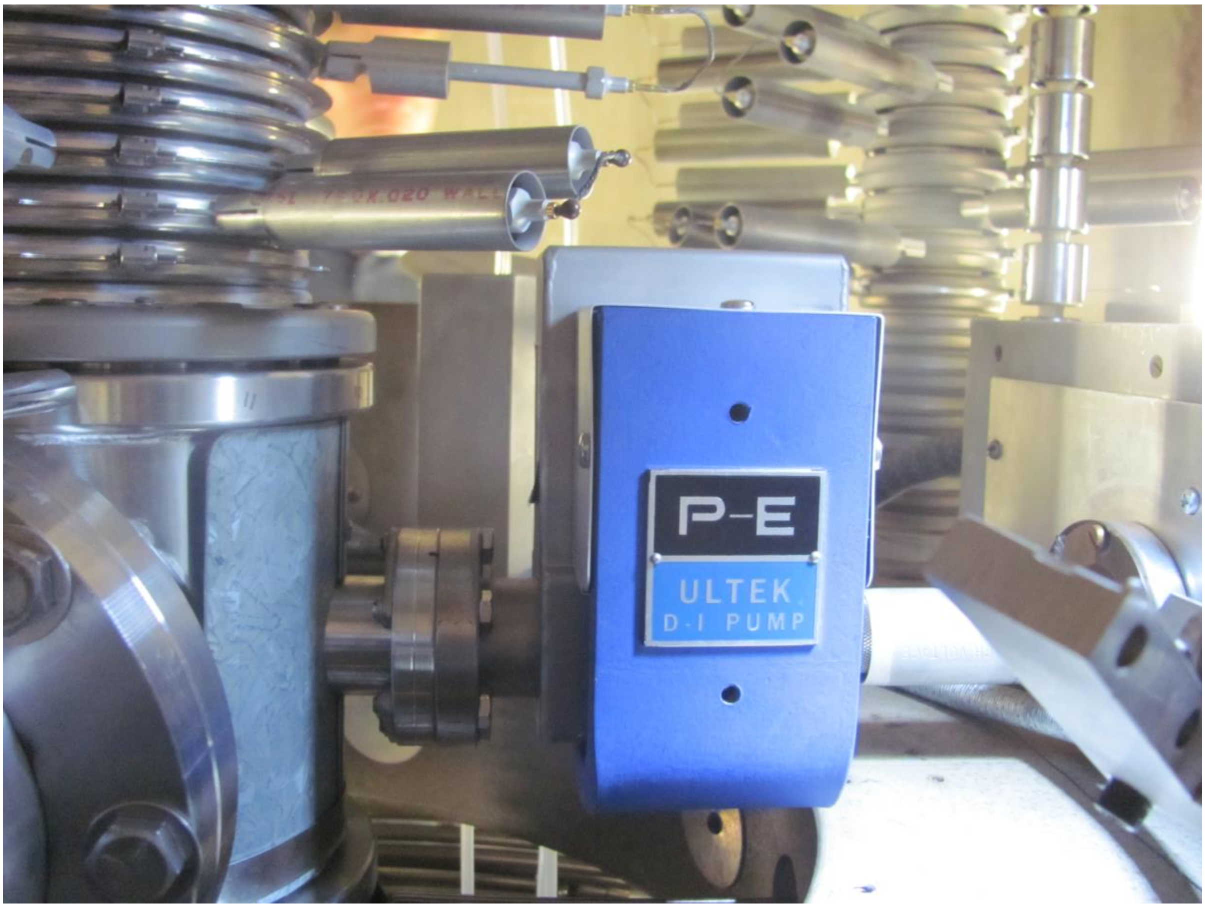

Figure 15 New HE stripper ion pump

The pump was powered up using the Terranova power supply. It started but tripped overnight. It was restarted the following day and ran in the high 10^{-6} range and was improving (consistent with pumping moisture). After taking the power supply to kickstart the 60L/s terminal pump, it was again connected to the new HE stripper pump. The power supply readings were initially 5kV, 10mA, $3x10^{-5}$ then after 2 minutes went to 3kV, 18mA, $2x10^{-4}$, then recovered to 4kV, 10mA, $1x10^{-4}$, before deteriorating to 3.5kV, 13mA, $1.3x10^{-4}$ and turning it off due to HE vacuum deteriorating. After the vacuum recovered, the pump was restarted and achieved 5kV, 650uA, $4.2x10^{-6}$, it was left running overnight and the next morning was at 5kV, 160uA, $9.7x10^{-7}$.

The next job was to reconfigure the HE mid-section power supply to supply +5kV instead of the -5kV required by the previous pump. The existing power supply was found to have an isolated output so the output terminals were simply swapped to provide the required positive 5kV.

The other consideration was the polarity of the control system input to read the pump's current for pressure reading. The 5K Ohm current sense resistor was previously setup to read a positive voltage and the input range was set to 0 - 5V. The Group3 analogue input did not appear to be isolated so it was decided to leave its wired polarity intact and modify the range of the input to +/- 5V as the new expected voltage range would be a similar amplitude but now it would be negative.

The change also required two EPICS records to be modified to work with the replacement ion pump. There were some fields that were required which were not included in the existing macro for ion pumps so all of the associated records were converted to a manual expansion of records and the following two were the only ones which required modification. These modifications all took place within tank.vdb.

```
record(ai, tank:hemid:pressure_current) {
  field(DTYP, "asynInt32")
  field(SCAN, "I/O Intr")
  field(INP, "@asyn( C2L3DCB2 2 )")
  field(LINR, "NO CONVERSION")
  field(ROFF, "-65535")
  field(ASLO, "30.51757812E-6")
  field(AOFF, "0")
  field(EGU, "mA")
  field(HIGH, "0.0")
  field(HSV, "MINOR")
  field(LOW, "-1.0")
  field(LSV, "MINOR")
  field(FLNK, "tank:hemid:pressure_calc PP MS")
}

record(calcout, tank:hemid:pressure_calc) {
  field(INPA, "tank:hemid:pressure_current")
  field(INPB, "-8.33E-6"
  field(CALC, "A*B")
  field(OUT, "tank:hemid:pressure NPP MS")
  field(FLNK, "tank:hemid:pressure_calc_mdel PP MS")
}
```

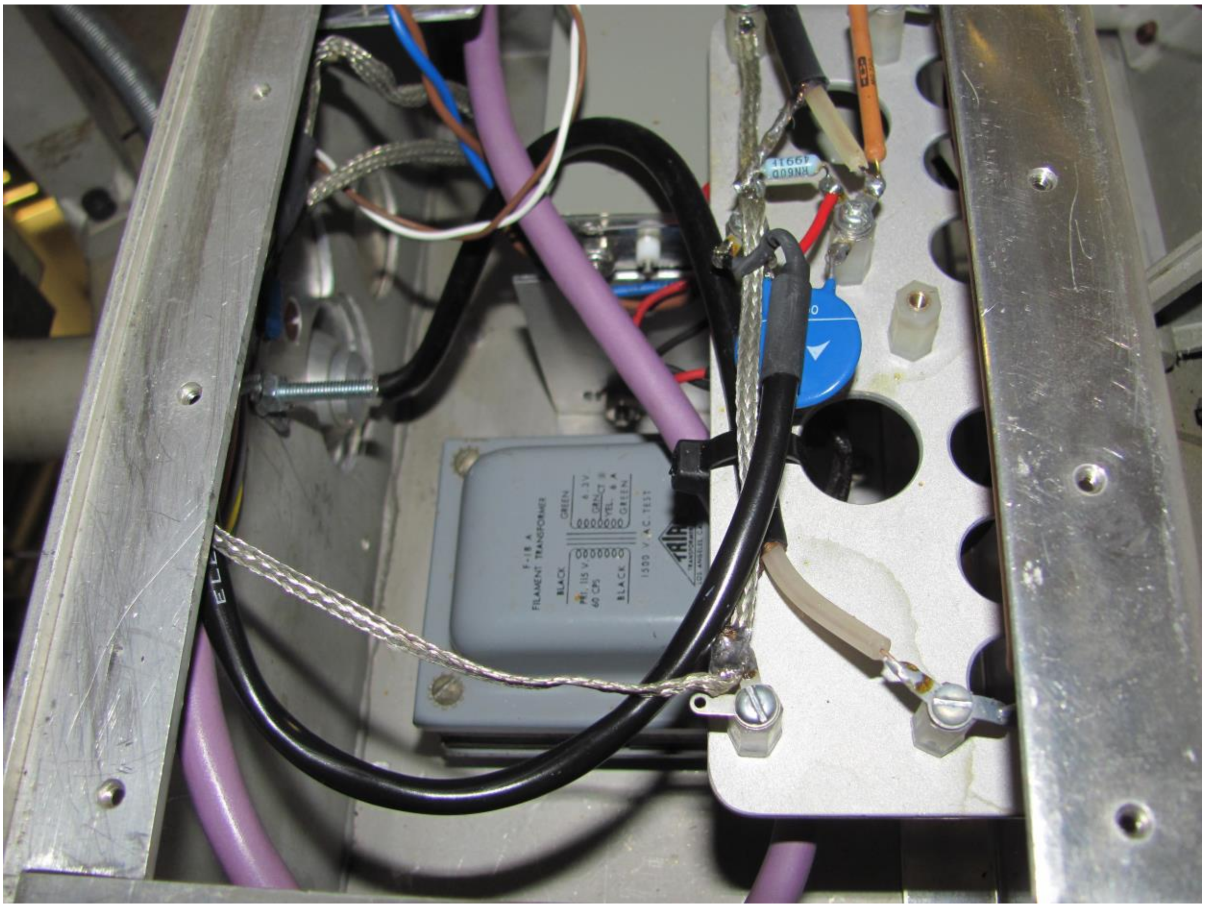

Figure 16 HE stripper pump power supply

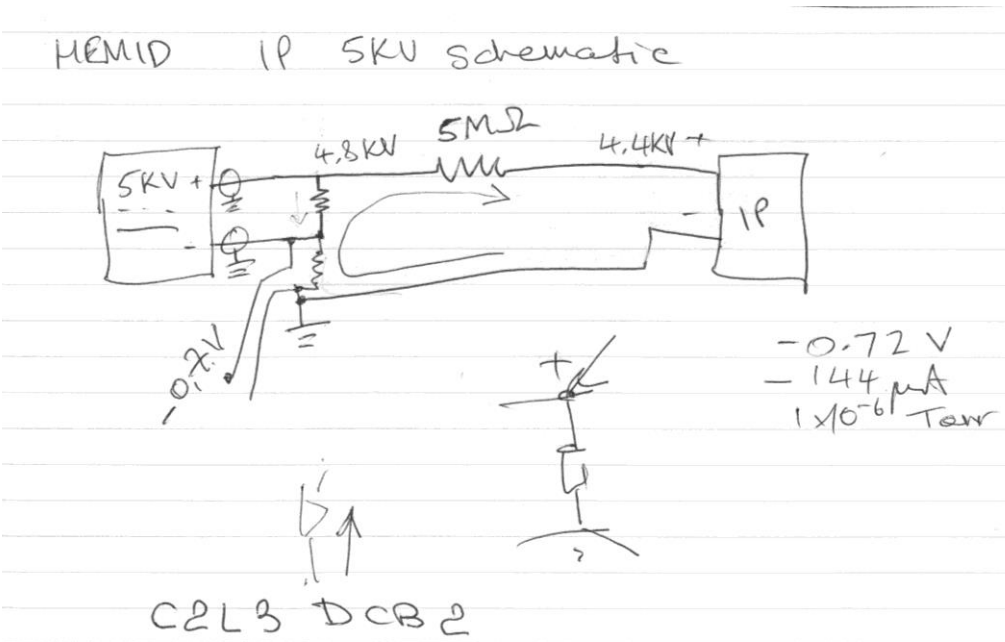

Figure 17 HE stripper pump power supply diagram

With the pump operational, the U19 deck was reassembled and a slight interference was noted between the top of the pump and the deck. A small cutout was machined into the deck piece to give clearance around the pump as shown in Figure 18Figure 18 U19 deck cutout for new HE stripper ion pump.

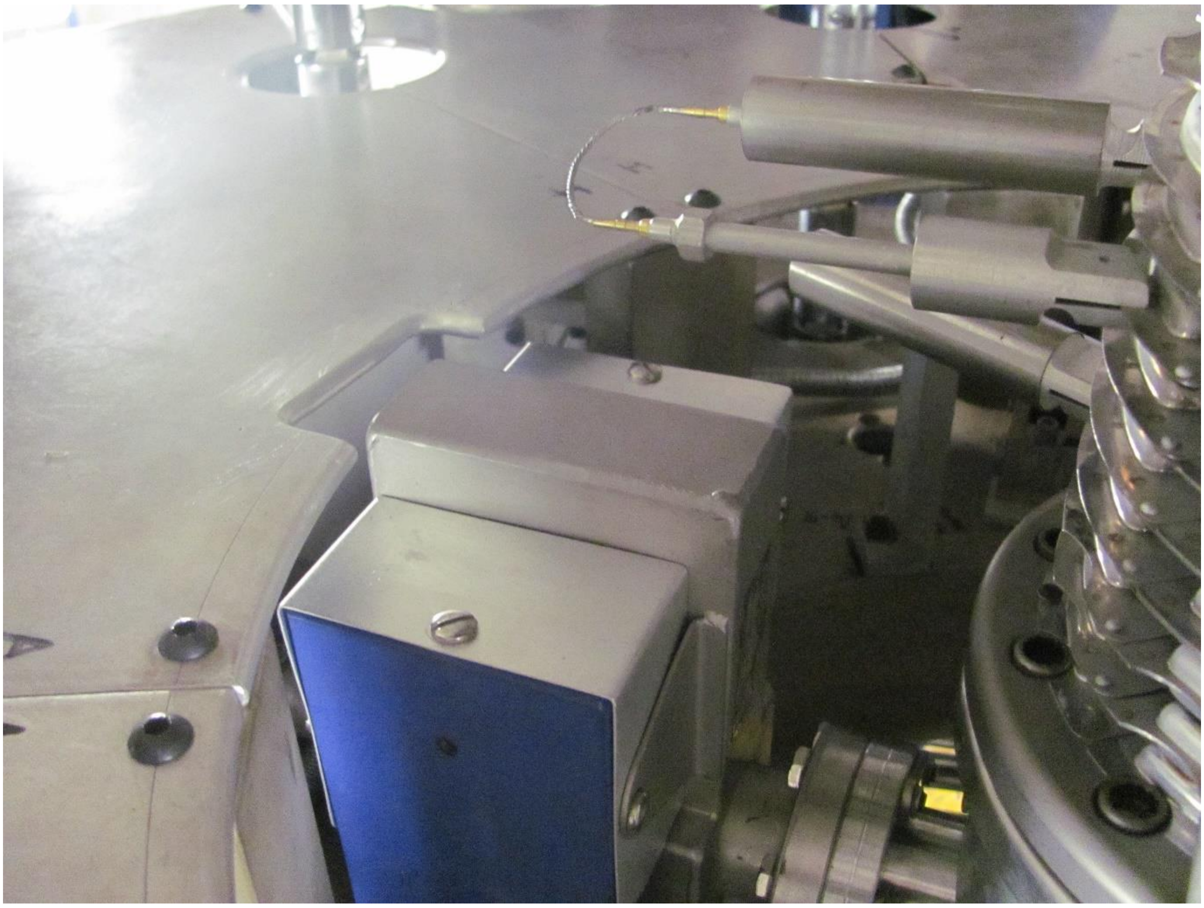

Figure 18 U19 deck cutout for new HE stripper ion pump

7 HE Terminal Pump

After opening the Weisser valve, the shafts were powered up to run the terminal ion pumps (60L/s LE, 20L/s, and 60L/s HE). With the pumps running, HE vacuum deteriorated to 10^{-5} range, indicating a problem. Suspecting the HE pump could be the issue (since it was in the section that had been let up), it was uplugged. Unplugging revealed a very dirty, black, sooty connector and feedthrough indicating a lot of breakdown/sparking had been occurring. The powder from the connector was collected for later analysis and the components were cleaned up.

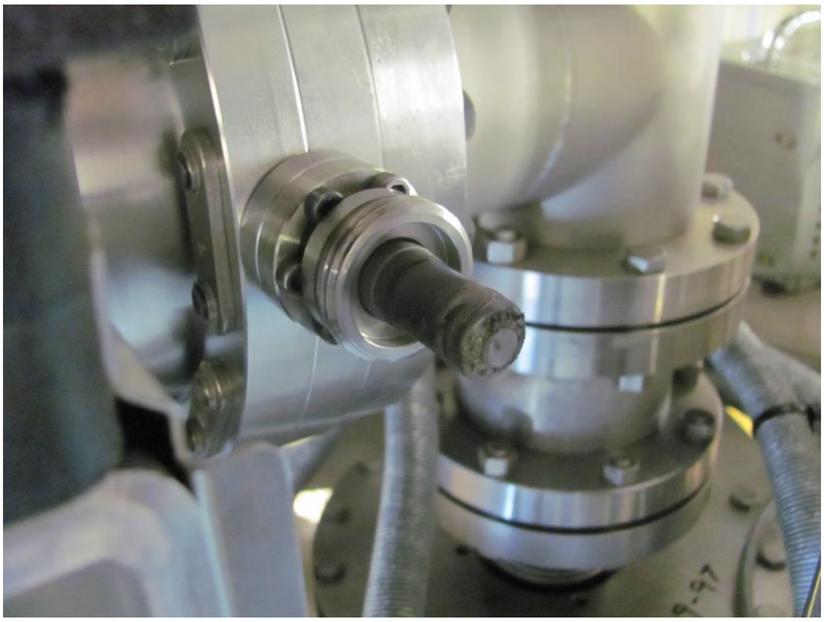

Figure 19 HE terminal ion pump feedthrough

Figure 20 LE terminal ion pump connector

Using a Terranova power supply, a kickstart of the pump was attempted using 5kV and 50mA as maximum setpoints. Within 10 minutes the HE vacuum had risen from $6.7x10^{-7}$ to $1.8x10^{-5}$, with the power supply auto adjusting to 1kV and 37mA. It was decided to turn the pump off and let the vacuum recover before trying again.

On the second attempt, the vacuum had recovered to $7x10^{-6}$, and after running the pump for ~10 minutes again, the power supply showed 1kV, 40mA, and $2.7x10^{-4}$ and the HE vacuum had degraded to $2x10^{-5}$. After the vacuum had recovered to $1.6x10^{-6}$, the pump was powered again and left on over lunch time. During that time, the pump had one self-restart and the parameters were 2kV, 15mA, $4.3x10^{-5}$, so it was improving. After one more hour, the Terranova was showing 5kV, 9mA, and $2x10^{-6}$. It looked to be on the right track so the Terranova was disconnected and the pump was connected back up to its power supply in the terminal box.

8 Watch list

These items were not checked on this tank opening. U17 post D watch has been added.

Table 4 Watch list of suspect items for review next tank opening

Unit	Component	Description	Condition/ Resolution	Retain watch
6	Post C, gap 10	May have small subtle cracks in ceramic		Yes
22	Post C, gaps 7 and 10	May be a small subtle crack, but also what may be two, small, surface divots at a “nine o’clock” position		Yes
28	Post B, gap 12	Marks including metallic deposits		Yes
6	Post gap 9	New unused resistors installed on both top and bottom, showing 18µA @ 20kV (lower than 19µA nominal).		Yes
14	Post gap 18	Current leakage of 0.02µA		Yes
14	Post A gap 1	Current leakage of 0.2µA@5kV		Yes
10	Post C, gaps 6, 8, 13 and 19	Visible spark marks across gaps		Yes
7	Spring contact upper	Flat section, a bit gnarly		Yes
8	Spring contact lower	Ugly coil form		Yes
17	Post D, gap 2	Very dirty gap		Yes

9 Tube ceramic insulator current leakage

The current state of shorted tube ceramic gaps is shown in Table 5. No new shorts were added in this tank opening.

Table 5 Summary of tube ceramic current leakage in the 14UD

Unit	Tube	Gap	Leakage though insulator @5kV (μA)		Discovery	Comment	Repair
			TO #123	TO #129			
3	2	2	8	8.8	TO #121		Dummy resistors top and bottom, dummy on post gap ????
6	1	2	1.1	1.2	TO #123		Dummy resistors top and bottom, dummy on post gap 5, top
6	1	3	60	80	TO#128		Dummy resistors top and bottom, dummy on post gap 4, top
7	3	10	12	14	TO #120		Dummy resistors top and bottom, dummy on post gap 10, top
12	1	1		32	TO #129		Dummy resistors top and bottom
12	1	2	0.25	43	TO #123		Dummy resistors top and bottom, dummy on post gap 5, top
12	1	3		4	TO #129		Dummy resistors top and bottom
12	1	4		73	TO #129		Dummy resistors top and bottom
12	1	9		7.2	TO #129		Dummy resistors top and bottom
13	1	10	0	0	TO #120	Suspicious arc mark across gap	Dummy resistors top and bottom, dummy on post gap 3, top
13	2	1	0.05	0.02	TO #120		Unshorted TO#129, deemed too small. Monitor.

13	2	2		95	TO #129	Short moved from U13 T2 G1	Dummy resistors top and bottom, dummy on post gap 8, top
24	3	10		18	TO #129		Dummy resistors top and bottom, dummy on post gap 14, top
25	3	10	7	7.2	TO #120		Dummy resistors top and bottom, dummy on post gap 16, top
26	3	5	0.15	>100	TO #123		Dummy resistors top and bottom, dummy on post gap 12, bottom
26	3	9		0.25	TO #129		Dummy resistors top and bottom,
26	3	10	0.01	>100	TO # 123	shorted TO129	Dummy resistors top and bottom,
26	3	11	2.5	16	TO # 123		Dummy resistors top and bottom, dummy on post gap 14, bottom
28	3	1	0.01		TO # 123		None, deemed too small. Monitor
28	3	5	0.47		TO # 123		Dummy resistors top and bottom, dummy on post gap 12, top
28	3	7	0.1		TO # 123		Dummy resistors top and bottom, dummy on post gap 13, top
28	3	9	0.02		TO # 123		None, deemed too small. Monitor
28	3	10	0.05		TO # 123		None, deemed too small. Monitor
28	3	11	0.28		TO # 123		Dummy resistors top and bottom, dummy on post gap 14, top

10 Machine hour meter readings

Date compiled	11 06 19					
Team member(s)	TT					
Reading	Chain #1 (1O)	Chain #2 (2N)	Chain #3 (3P)	LE shaft	HE shaft	Ch. volts
Notes	New @TO121	New @TO121	New @TO118			
Current reading	45772	45695	45859	67736	67729	41645
Previous reading (TO #126)	44817	44740	44904	66572	66564	41173
Change in hours	955	955	955	1164	1165	472*
Previous total hours	23285	23208	27714			
Current total hours	24240	24163	28669			

Table 6 Machine hour meter readings

*Note: there is a known issue with the charging volts meter

11 Terminal voltage distribution for period of service

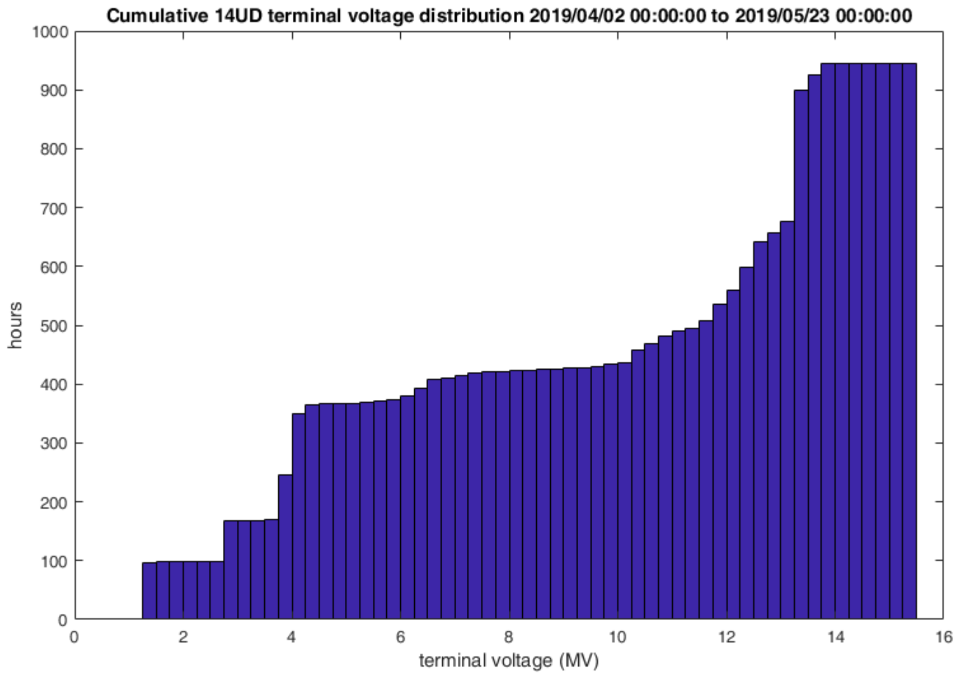

Figure 21 Cumulative terminal voltage distribution for period of operation from the end of tank opening 130 to the start of tank opening 131 (including any time spent conditioning the machine)

The total hours with voltage on the terminal was 955 hrs, which gives a utilization of 78% assuming a twenty-four hour, seven-day maximum.

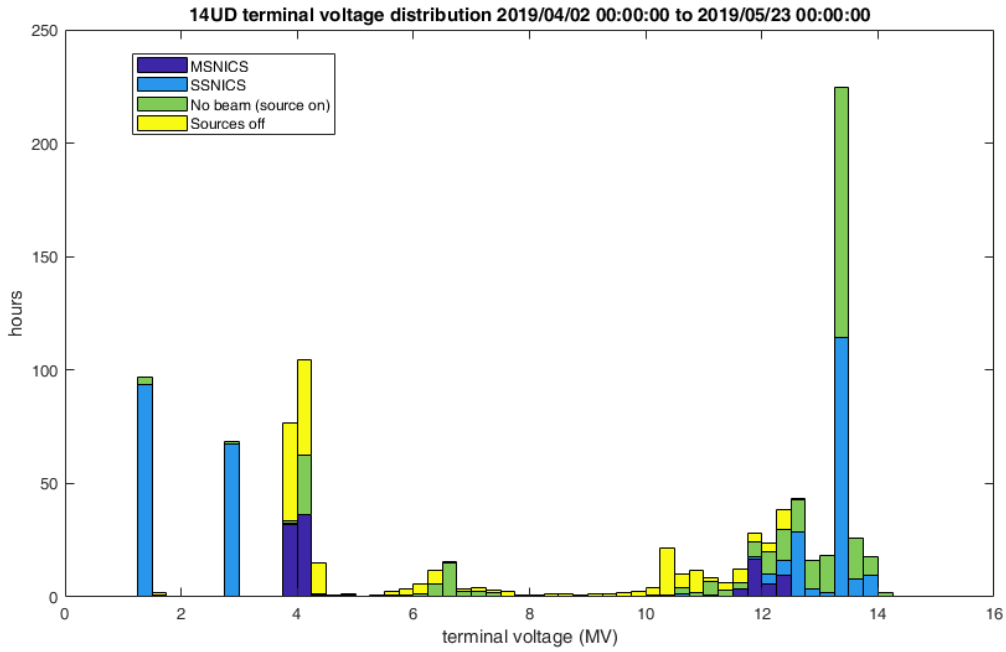

Figure 22 Terminal voltage distribution for period of operation from the end of tank opening 130 to the start of tank opening 131 with breakdown in type of usage.

12 Initial performance

Voltage was applied to the terminal at ~10:45am on the 21st of June, starting at ~5MV and working up to 10.3MV by 9:00pm. It was left at 6.5MV overnight and conditioning continued the following day reaching 10.3MV again. On the 23rd conditioning was started at 10MV, working up to 11.7MV with only two major spark events. On the morning of the 24th, shorting rods were inserted in the last 7 units of the HE end (U22-U28). The machine conditioned from 5.6MV to 6.9MV, which equates to ~0.99MV per unit or 13.5MV for the whole machine (13.66 Units). On the following day, an attempt was made to insert Nylon rods to short U15-U21, however, some resistance was felt while inserting the rods and the nylon rods were buckling under the stress so an executive decision was made to remove the shorting rods and condition the whole machine. Starting at 12.4MV the machine was conditioned to ~13.7MV over the day. There were several mid range sparks over this time. The first run commenced at around 3:20pm on the 26th, running a Nickel beam with double stripping at 13MV. HE vacuum during the run was ~1.5×10^{-7} over the run due to heavy loading. The run continued until the 4th of July, after which a small amount of conditioning was done, reaching 14.1MV before a run at 9.1MV. HE vacuum during this run was about 6×10^{-8}. In the 6 weeks after the tank was closed HE vacuum improved to 3.5×10^{-8} and conditioning has been done to 14.4MV with runs at 14MV.