Australian National University

14 UD Tank Opening Report

#128

16th October – 10th November 2017

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1 Reason for tank opening

This tank opening was scheduled maintenance operation. There were no major performance concerns and in fact, the accelerator was performing well.

SF_6 levels in the acceleration tube are also being monitored and there was a plan to re-check levels as the SF_6 was being pumped out. The plan was also to redo He leak tests on the acceleration tubes during the tank opening.

2 Summary of work

2.1 16/10/17 Monday

- 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.

2.2 17/10/17 Tuesday

- 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 30kV HV entry test. Very few issues were detected. These were:
    - Unit 2, tube 3 with marginally high current of 7.4 µA
    - Unit 6, tube 1 need to confirm number of shorted gaps
    - Unit 12, tube 3 need to confirm number of shorted gaps
    - Unit 13, tube 3 with marginally high current of 7.4 µA
    - Unit 14, tube 4 with a current of 7.6 µA
- Wiped down column using 20ml of RBS into 10l of water. The distribution of breakdown products toward the low-energy end was less than observed during recent tank openings. However, oil residue in units closer to the terminal in the high-energy end was higher than we can recently recall.
- Low-voltage tests were performed up to unit 12 with an issue in unit 5 found.

2.3 18/10/17 Wednesday

- Low-voltage tests were completed with Lauren and Ben volunteering to assist and experience the joy and intricacies of tank life. Major issues were:
    - Unit 6, tube 1 on the tube side
    - Unit 17, tube 3 on the post side
    - Unit 26, tube 1 on the tube side

  with a repeat measurement without using the plastic end bit suggested for a few other tubes/posts.
- Ran chains and shafts to test mechanicals
    - Unit 15 bottom bearing was noisy
    - Chain 1 was good with a rundown time of 39 seconds.
    - Chain 2 had a rundown time of 53 seconds with the unit 25 idler possibly noisy.
    - Chain 3 had a rundown time of 41 seconds and is a little noisier than the other chains. There is also some radial whip in unit 27, perhaps 30mm.

2.4 19/10/17 Thursday

- Removed shaft in unit 15 to remove bottom bearing
- Found loose bottom stringer in unit 15 at the post end. Replaced with new mini-clamp arrangement.
- High-energy sublimer pump seems to have perished. Body will be removed to strip the titanium.
- Made preparations for He leak testing. Closed the low-energy ball valve and switched off all pumps between there and the AMS MFC box in the tank base. Basically, it's only the MFC turbo pumping the tubes. Left pressure and base leak rate to settle.
- De-ringed entire accelerator.
- Started leak testing from unit 1, **with the ventilation fan off**. The base leak rate was 2.9×10^{-9} mbar·l/s and high-energy tube vacuum was 1.2×10^{-6} Torr (remembering that the high-energy sublimer was not in operation). There were some blips in the leak rate, but repeat measurements did not show a repeat reaction (and we know the He leak tester does "blip-out" occasionally for no apparent reason). There was no obvious leak found in any unit, but none of the mid-sections or terminal were checked directly (they were still closed at this stage). However, the base leak rate definitely drifted up to about 4.0×10^{-9} mbar·l/s, suggesting there may be something extremely small somewhere. The base leak rate drifted up even further in the early evening.

2.5 20/10/17 Friday

- Re-entered to track down issues found with low-voltage tests. Found:
  - a low-value resistor in unit 26, tube 1, gap 11. Fixed.
  - an incorrect resistor on the post (a "burnt end" post resistor) that was not associated with an 8-gap tube in unit 17. Fixed.
  - unit 14, post B, gap 18 leaking 0.4µA@3kV. May have to replace post.
  - unit 6, tube 1, gap 3 leaking with 65µA@3kV. This will need to be shorted.
  - unit 13, post B, gap 12 leaking 0.2µA@3kV. This is relatively low, but may decide to replace post as current leaks are often associated with cracks in the ceramic.
- Rebuilt unit 15 bearing, attempted to refit but top rotating flange is actually bent! Will have to rectify somehow.

2.6 23/10/17 Monday

- Entered the bottom of the tank for an initial inspection and clean. It doesn't look too bad, with not too much oil pooling at the bottom. Refilled the oiler reservoirs, which were depleted by about half. Also found some more nylon shards from that exploded shorting rod from a few tank openings ago.
- Measured the chain leg lengths:
  - Chain 1: 65mm
  - Chain 2: 80mm
  - Chain 3: 57mm (remeasured after shortening at 78mm)
- Refitted bearing to unit 15 and clocked shafts above and below
- Stringer 1 in unit 16 was loose at the tube end. Cleaned up and replaced old dome-head screw with newer rounded socket head screws.

- Stringer 3 in unit 16 was loose at the post end, but was able to be retightened.
- Opened the terminal, but lowered the middle spinning instead of raising as we normally do. This was create enough space to replace posts in unit 13 and unit 14 if required. Also checked with the radiation meter. There was 10µSv/hr at the foil stripper and 20µSv/hr at the top of the gas stripper canal.

2.7 24/10/17 Tuesday

- Powered up the terminal with mains and wound back the terminal stripper to its zero position.
- Prepared to leak test the terminal.
- Rechecked post B in unit 14 and it seems that it has self-healed! There is still current leakage, but at only 0.02µA this is too small to justify changing the post, so maybe just put this on the watch list.
- Leak tested the terminal, but could not find anything definite. We forgot to close the low-energy ball valve, so half-way through we started again. By the end, the base leak rate was about 7.0×10^{-9} mbar·l/s. We should really do it again.
- Disassembled the terminal foil stripper mechanical counter in order to change a burnt out light. This lead to many jokes about how many techs does it take to change a light bulb. It turns out a few, since the bulb is buried deep in the counter assembly.
- Decided to start clean & close procedure so as to break up the task later in the tank opening. Didn't get far as we found some issues with the shafts in both unit 1 and unit 2. The shaft flange clamp screws were loose in unit 2, so the whole clocking procedure was redone as a precaution. In unit 1, the shaft flange clamp screws were still the long ones, which doesn't allow them to be tightened properly. They were removed to be replaced with shorter ones.

2.8 25/10/17 Wednesday

- Continued with clean and close on unit 3 through unit 5. Found a couple of burnt resistor leads (unit 5, tube 1, gap 5 and post gap 8).
- Did a "single unit conversion" on units 3 & 4, 5 & 6 and 7 & 8.
- Retested unit 6, tube 1, gap 3 and confirmed a leakage current through the ceramic of about 60µA. So, we shorted that gap and installed a dummy resistor in the top position of post gap 4.
- Just for completeness, also retested the previously shorted gap in unit 6, tube 1, gap 2 and found a leakage current of 0.5µA, which was about half of what it was when discovered during tank opening #123 (see Table 2).
- Went and repeated 30kV high-voltage test on unit 2, tube 3 and found a current of 7.2µA, compared to the 7.4µA upon entry. So, we won't bother chasing any issue.
- Fitted shorter screws on clamp flanges of shafts in unit 7 and unit 8. Found that the shaft in unit 7 was not clocked properly at the top and it will be addressed.

2.9 26/10/17 Thursday

- Looked at shaft in unit 7 and decided to pull it out. We had assumed the diameter was too small, but it was not. Rather, it seems that the shims are matched to the flange and previously, the shaft was installed with mismatched flange/shim combinations.

- Blew down unit 6, tube 1 and then rechecked current leakage through gap 3. No change in current.
- Did a single unit conversion on units 9 & 10
- Cleaned and checked resistors in unit 9 and unit 10. Resistor lead in unit 9, post gap 9 had a burnt plug. Changed lead and fit new nuts on both resistors in the pair.
- Also tested some new low-lint rags for the tank from Tiddox Disposables in Sydney. Decided on two different types.

2.10 27/10/17 Friday

- It was a slow day today with work continuing on reinstating the high-energy sublimer pump.
- Polished unit 7 shaft and the clamp flanges
- Reassembled the bearing in top casting of unit 7 in-situ. Attempted to reinstall the shaft, but it seems we were missing some screws.

2.11 30/10/17 Monday

- Reinstall unit 7 shaft and clocked. The top flange was difficult to clock as there is some sort of depression in the shaft. There was still a screw missing in the top flange.
- Re-tested unit 13 post gap 12, which had earlier shown a leakage current of 0.2µA@3kV. The re-test showed no leakage current at all. Inspected gap and could not see any evidence of leakage.
- High-energy sublimer pump has been reinstalled and preparations are being made to pump it out tomorrow.
- There aren't many of us around to today, so a preliminary clean and check of units 19 through 24 was carried out.

2.12 31/10/17 Tuesday

- Installed new lamp in foil position indicator mechanism in the terminal, thus answering the question of how many department staff does it take to change a light bulb. The answer is six. Two to disassemble the mechanism, another to extricate the actual bulb, another to go buy a bulb form Supercheap Auto, another to process the reimbursement form and a department head to approve expenditure.
- Visually inspected the charging system feed through assemblies (outside the tank on the underside). They are clean inside with no evidence of stress.
- Did single unit conversion on units 20 & 21, 22 & 23, 24 & 25 and 26 & 27.
- Checked resistors and leads in units 19 through unit 23.

2.13 1/11/17 Wednesday

- Vacuumed out exposed castings in low-energy end and replaced casting covers
- Did a single unit conversion on units 13 & 14 and in doing so, replaced all radial resistors in the 8-gap tube in between units 13 and 14 with normal tube resistors.

2.14 2/11/17 Thursday

- Removed stripper foil mechanism from the terminal for repopulation. One foil frame was activated up to 50 µSv/hr after a Nuclear Reaction Dynamics run with 20 MeV protons just before the tank opening. It was removed and stored appropriately.
- Leak chased the low-energy end from a base leak rate of 2.2×10^{-9} mbar·l/s. Saw some very small reactions up to 3.2×10^{-9} mbar·l/s, but were not definite or repeatable. If there were suspect areas, it was the low-energy BPM and somewhere around units 13 and 14.

2.15 3/11/17 Friday

- Reinstalled stripper foil mechanism in the terminal
- Leak chased the low-energy end, again, from a base leak rate of 1.2×10^{-9} mbar·l/s. Saw some very small reactions up to 2.6×10^{-9} mbar·l/s, but were not definite or repeatable, again.

2.16 6/11/17 Monday

- Moved to prepare terminal for closing. Checked insulators and cleaned up terminal.
- Reassessed radiation levels in the terminal. There was 8µSv/hr at the foil stripper and 15µSv/hr at the top of the gas stripper canal.
- Baked gas stripper turbo backing traps in situ to see what reaction there may be on the RGA and on the tube vacuums. There was the usual increase in tube vacuums, but no increase in SF_6 levels above the noise floor.
- Tested terminal functions. All was OK.
- Closed the terminal.
- Installed remaining single-unit conversion kits. Hence **all units are now "single units"**.
- Replaced all casting covers.

2.17 7/11/17 Tuesday

- Cleaned all chains with an acetone wipe down (using new Tiddox Micromax "blue" wipes)
- Found a rivet that had come loose in chain 3, meaning failure was imminent. See Figure 1. Chain 3 is the oldest chain, but still well within the expected lifetime at under 22000 hours. We removed the offending link and re-joined the chain. Also note that the leg clearance needs to be remeasured.
- Proceeded with cleaning and checking resistors etc in remaining units. Some resistor leads were replaced.
- Noticed a crack in gap 1 of unit 16 post B. In fact, there was a piece of ceramic missing. This will have to come out. It wasn't noticed earlier since it was covered by a terminal spinning.

2.18 8/11/17 Wednesday

- Removed post #1808 in unit 16 position B and replaced with refurbished and tested post #282.
- Re-ringed all units, replacing ring screws where necessary.

- Performed blow down of column as the first step in tank exit-procedure.

2.19 9/11/17 Thursday

- Performed 30kV HV test. The only out-of-spec result was in unit 15, tube 3, with a current of 7.6µA (~7.2µA expected). Closer investigation with low-voltage tests revealed some “imbalanced” resistors, namely the top resistor of post gap 16. This was swapped out and the end result was better. However, a 5kV HV test across the post gaps showed a 2.2µA leakage through gap 18 of post A. This was not there upon tank entry. An attempt to clean the gap and apply a heat gun made things worse, with a leakage current of 5 µA, then 10µA. After some time (after all important tea), this reduced to 7µA. Changing the post would require reopening the terminal, so at this stage, the hope is that within an SF_6 environment, the leak will go away and we’ll just place it on the watch list.
- Wiped down of column with clean water.
- Unloaded majority of tools on platform at level 2
- Vacuumed platform and bottom of tank
- Performed tank close checks. All OK.
- Closed porthole doors

3 Imminent failure of chain 3

Chain 3 is nominally in the prime of its life, with just under 22000 hours of spin time. However, as mentioned above and shown in Figure 1, we avoided another trip into the tank before Christmas by catching a loose riveted connection. Chain is older than the other two and does show more lip-to-lip spark damage.

Figure 1 Loose rivet on chain 3

4 Ceramic cracks

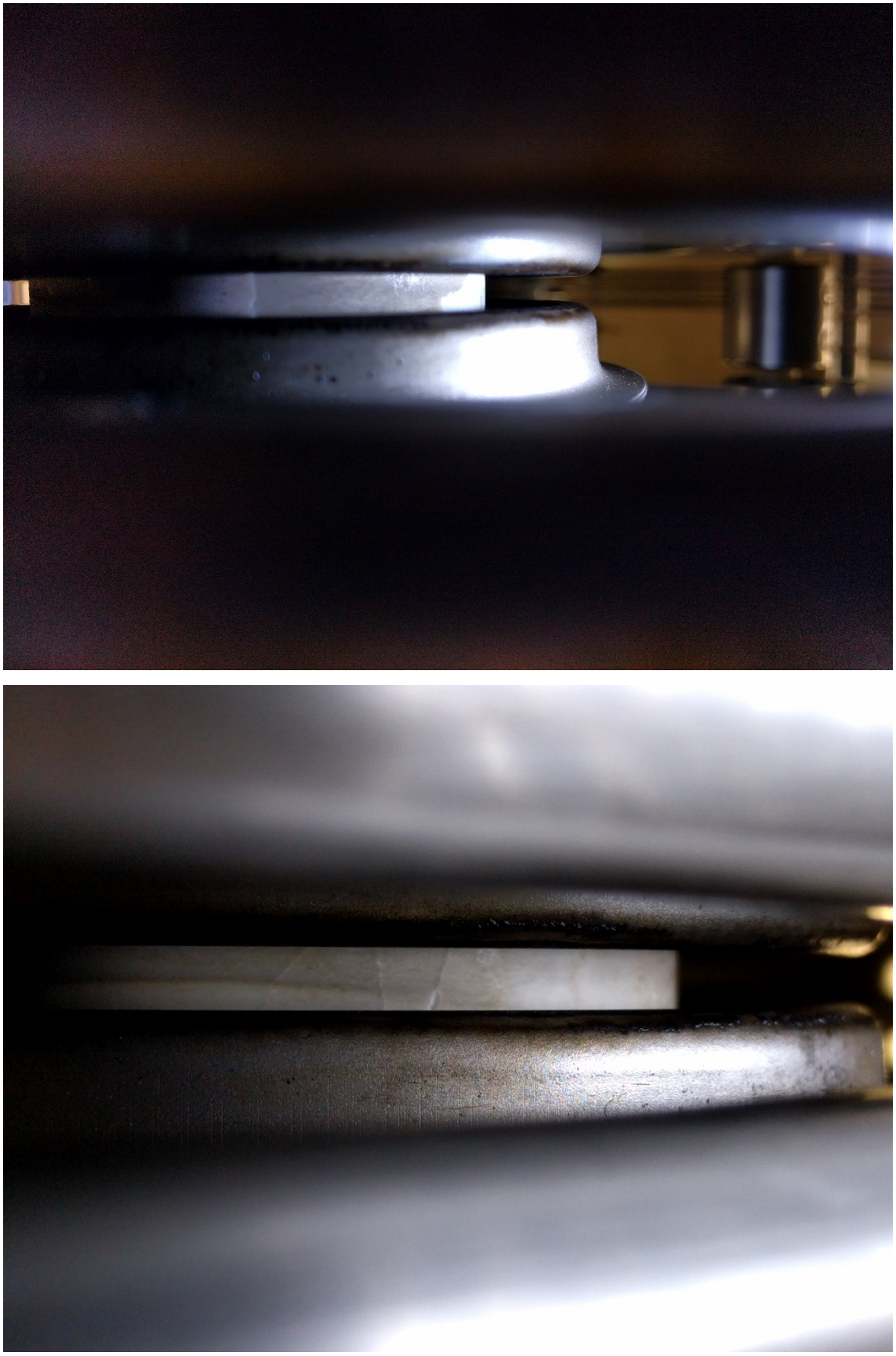

Figure 2 Unit 16 post B gap 1 cracks in ceramic

5 SF_6 measurements

There has been some question about SF_6 ingress into the acceleration tube. There have been temporal examinations of SF_6 levels before, but this time we managed to scan across an entire pump/gas out procedure. We did not like what we saw. The scan showed a sudden increase in tube vacuum, with an increase in the relative level of SF_6, sometime on the morning of the 16th October just after pump out had begun. The SF_6 level did not disappear after few weeks with no SF_6 in the tank. This is consistent with observations during previous tank openings.

The RGA scan continued throughout the tank opening and there was no sudden change in vacuum and relative levels during gas up. However, the RGA did seem to be "noisy" and we are investigating if it is because we have just run the poor RGA continuously for four weeks. Overall, there was a downward trend in the SF_6 level.

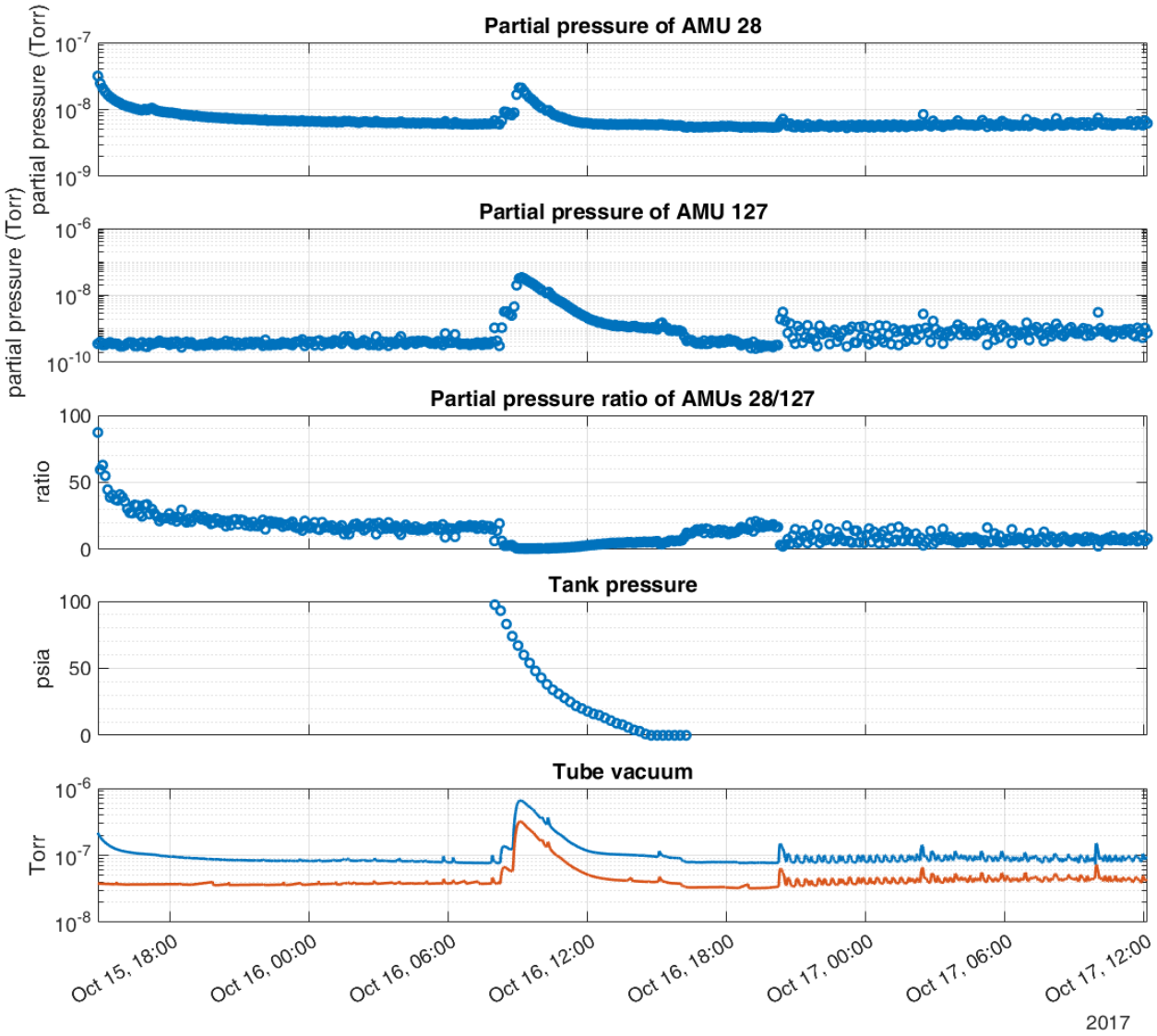

Figure 3 RGA scan over pump/gas out at the start of the tank opening

6 Watch list

Table 1 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	Increased discoloration, no current leak at 6 kV	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	No deterioration	Yes
28	Post B, gap 12	Marks including metallic deposits	No deterioration	Yes
6	Post gap 9	New unused resistors installed on both top and bottom, showing 18µA @ 20kV (lower than 19µA nominal).	Keep track of current as resistors age	Yes
14	Post gap 18	Current leakage of 0.02µA	Restest, as current leakage after test on immediate entry was much higher.	Yes
15	Post gap 18	Current leakage of 7µA	Restest upon next entry, change post if required.	Yes

7 Tube ceramic insulator current leakage

The current state of shorted tube ceramic gaps is shown in Table 2

Table 2 Summary of tube ceramic current leakage in the 14UD

Unit	Tube	Gap	Leakage though insulator @5kV (TO #123)	Discovery	Comment	Repair
3	2	2	8 µA	TO #121		Dummy resistors top and bottom, dummy on post gap ????
6	1	2	1.1 µA	TO #123		Dummy resistors top and bottom, dummy on post gap 5, top
6	1	3	60µA	TO#128		Dummy resistors top and bottom, dummy on post gap 4, top
7	3	10	12 µA	TO #120		Dummy resistors top and bottom, dummy on post gap 10, top
12	1	2	0.25 µA	TO #123		Dummy resistors top and bottom, dummy on post gap 5, top
13	1	10	0 µA	TO #120	Suspicious arc mark across gap	Dummy resistors top and bottom, dummy on post gap 3, top
13	2	1	0.05 µA	TO #120		Dummy resistors top and bottom, dummy on post gap 8, top
25	3	10	7 µA	TO #120		Dummy resistors top and bottom, dummy on post gap 16, top
26	3	5	0.15 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 12, bottom
26	3	10	0.01 µA	TO # 123		None, deemed too small. Monitor.
26	3	11	2.5 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 14, bottom
28	3	1	0.01 µA	TO # 123		None, deemed too small. Monitor
28	3	5	0.47 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 12, top
28	3	7	0.1 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 13, top
28	3	9	0.02 µA	TO # 123		None, deemed too small. Monitor
28	3	10	0.05 µA	TO # 123		None, deemed too small. Monitor
28	3	11	0.28 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 14, top

8 Machine hour meter readings

Table 3 Machine hour meter readings

Date compiled	16/10/17					
Team member(s)	PL, SB					
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	38704	38642	38791	59916	59909	36586
Previous reading (TO #127)	34984	34923	35071	55340	55331	34343
Change in hours	3720	3719	3720	4576	4578	2243
Previous total hours	13452	13391	17881			
Current total hours	17172	17110	21601			

There has been an intermittent problem with the charging volts meter and it appears that the problem has returned. The total hours of 2243 is very different from the chain hours and the total hours with voltage on the terminal as calculated in section 9.

9 Terminal voltage distribution for period of service

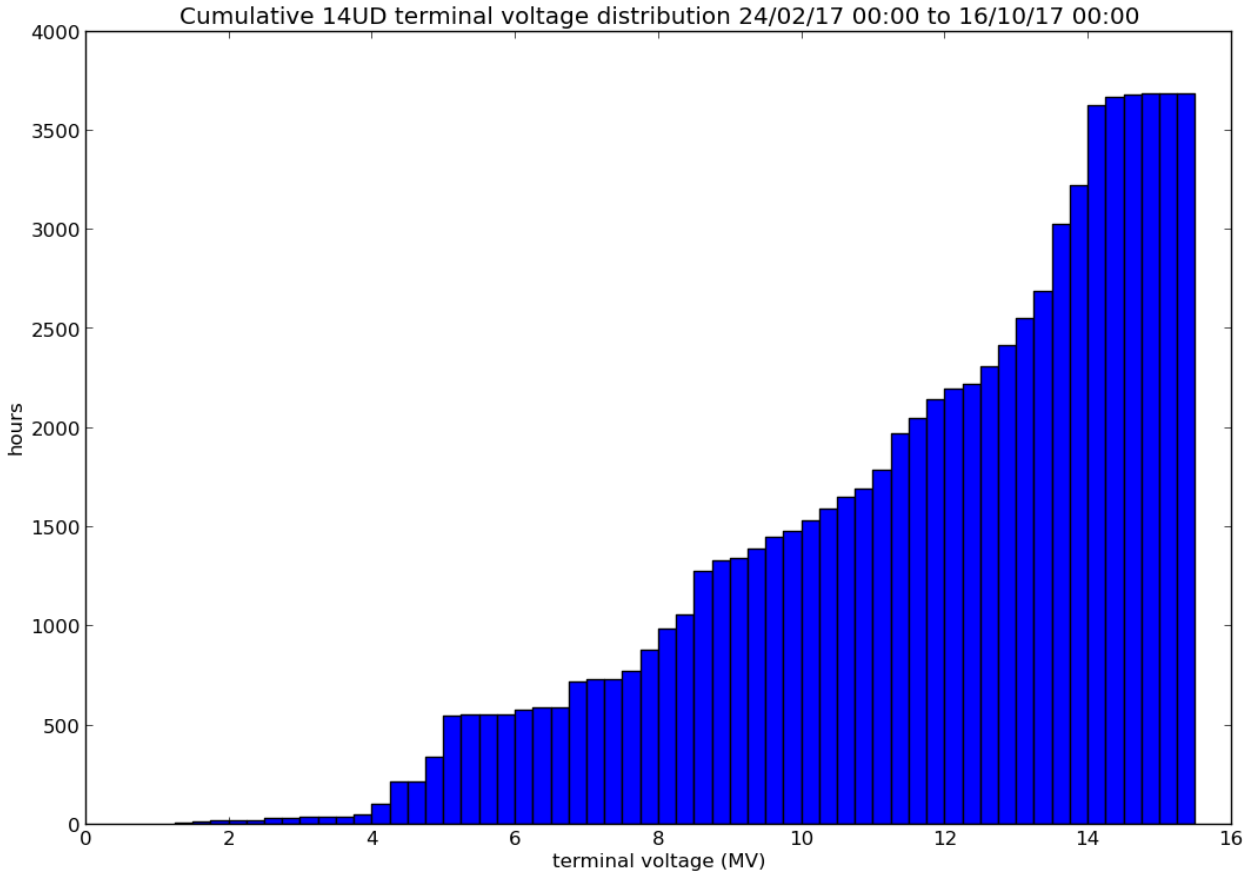

Figure 4 Cumulative terminal voltage distribution for period of operation from the end of tank opening 127 to the start of tank opening 128 (including any time spent conditioning the machine)

The total hours with voltage on the terminal was 3685 hrs, which gives a utilization of 66% assuming a twenty-four hour, seven-day maximum.

10 Initial performance

Initially, the machine was operated up to 5 MV for an experimental run. By the middle November, the 14UD was briefly conditioned up to 14 MV with all units live. In late November the 14UD reliably operated up to 13.3 MV.

The first opportunity for proper post tank opening conditioning was on 4-7th December 2017. Initially, 5 outer units were shorted at high-energy end and conditioning continued until 1.09 MV/unit was achieved. After that, the shorting rods were removed one by one at each step conditioning up to 1.09 MV/unit. The same procedures used at the low-energy end of accelerator. At the end of conditioning, the full machine voltage was raised to 14.5 MV. The described procedure seems to be an important step after a tank opening.

It is still in the early stages of re-conditioning, with the goal being to condition up to 15 MV to allow reliable operation up to14.7 MV.