Australian National University

14 UD Tank Opening Report

#125

15th February – 17th March 2016

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1 Reason for tank opening

This tank opening was a scheduled maintenance operation, but partially forced by issues encountered during the LINAC run of late 2015.

The 14UD was unable to hold its terminal voltage while a beam was accelerated, since the loading was abnormally high. This loading caused instabilities and a drop in the terminal voltage of about 2 MV. No issues were observed without a beam and in fact, the 14UD had been conditioned to beyond 15 MV. Insertion of a shorting road to isolate the issue revealed a problem in unit 19 (the high-energy midsection and the location of the second foil stripper). Unit 19 was then shorted and the LINAC run continued successfully.

Tests performed in February immediately before the tank opening showed the same issue. An attempt to remove the shorting rods during this test also revealed that a nylon shorting rod had broken in the tank.

The main goals were:

- Replacement of the corona needles
- Close inspection of the charging and voltage gradient systems
- Inspection of the acceleration tube internals around unit 19
- Retrieve broken nylon rod
- Inspection and replenishment of the terminal and secondary stripper foil mechanisms

2 Summary of work

2.1 15/2/15 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 16/2/15 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 additional photos were taken for update of tank entry manual
- Performed initial 30kV HV entry test. Found:
    - unit 8, tube 2 slightly high current at 7.3 µA
    - unit 12, tube 3 slightly high current at 7.3 µA
    - unit 13, tube 4 (8 gap) sparking
    - unit 15, tube 1 high current at 7.9 µA
- Found a broke nylon shorting rod in unit 21, which has clearly been damaged by a spark. There is an intact nylon shorting rod in unit 20, which means there is a steel shorting rod still shorting unit 19. The 30kV HV test showed abnormal results for unit 19, so it will be re-tested when the shorting rod is removed.
- Low-voltage tests began

2.3 17/2/15 Wednesday

- Low-voltage tests continued and were completed. Three issues cross match with issues found with the HV tests. All issues were:
    - unit 5, tube 1 abnormal voltage distribution
    - unit 5, tube 3 open or microbreak in resistor chain
    - unit 9, tube 3 abnormal voltage distribution
    - unit 13, tube 4 (8 gap) open or microbreak in resistor chain
    - unit 22, tube 2, gap 11 nylon debris across gap
    - unit 8, post gaps 9-13 abnormal voltage gradient
    - unit 15, post gaps 4-8 abnormal voltage gradient
- Ran chains and shafts to check mechanicals. Found:
    - chain 1 has a slight knock at unit 16 down idler
    - chain 3 is generally noisier (it is slightly older than chains 1 and 2 and may have a bit of twist)
    - low energy shaft bearing in unit 4 clicks at low speed and needs attention
- Proceeding with column wipe down, noting that the breakdown products “cake” off and that there are many more spark marks than usual on the low-energy end. The high energy end had areas with – what we have come to believe over the last the years is – wheel material. The terminal stain opposite the corona needles is the worst it has been in recent tank openings. Also, there were oval shadows in the film of breakdown products on the terminal opposite *both* CPO electrodes. Don’t think we’ve noticed this before.
- Lowered shorting rod down clear of unit 19, and redid 30kV HV test (just on that unit). Results seem normal.
- Removed and inspected broken/shattered nylon rod that was in unit 21. It looks to have snail trail marks that end abruptly at the spring contact. A 10 cm length of the rod has disappeared/exploded. There is debris everywhere, including stuck on the resistor shields. Remaining steel shorting rod and connected nylon rod had to be lowered to the bottom of the machine manually. Steel shorting rod has extensive damage at what would have been the spring contact points for unit 19. The spring contacts in this area should be inspected.

2.4 18/2/15 Thursday

- Stripped rings from unit 19 to inspect second stripper suppressor supply. The conclusion after tests was that the suppressor is OK.
- Went back to troubleshoot abnormal high- and low-voltage tests.
    - 14µA leakage current across unit 15, post B, gap 8 with 5 kV
    - Still some issue with unit 22, tube 2 seems to be gap 11.
    - Found blown resistor lead in unit 13, tube 4, gap 7, replace lead, but need to clean spark gap in resistor as there are no spares available
    - Isolated microbreak to resistors across unit 6, tube 3, gap 3. Replaced with serviceable spares. Can’t see anything on resistors, but will analyse later. Rechecked low-voltage performance of tube, all OK
- Entered tank bottom, there is lots and lots and lots of nylon debris from the blown shorting rod. Everything else looks to be OK.
- Measured chain leg lengths:
    - Chain 1: 75 mm
    - Chain 1: 80 mm

- Chain 3: 80 mm

2.5 19/2/15 Friday

- Removed bearing from unit 4 (bottom). Found that that the lower flange is loose around the bearing. We have new spares available to replace. The shaft was also removed for an opportunistic clean.
- Looked at abnormal high- and low-voltage results for tube 2/post gaps 9-13 in unit 8. Found that the current through the top gap 13 resistor on the post was 14µA@10kV (~10µA expected). Replaced with a spare unit, retested and saw 10µA@10kV, replaced rings and redid low-voltage test to confirm normal voltage gradient.
- Checked abnormal voltage gradient in unit 22, isolate issue to gap 11. Changed bottom resistor and it's fixed. Closer inspection of the resistor showed a narrow, but intact, track. It will be inspected further.
- Entered the bottom of the tank to do an initial clean. Even after a thorough vacuum, there are still bits of nylon all over the place. This will have to be cleaned up before we close the tank. Wiped up some oil and cleaned chain inductors.
- Inspected charging/suppressor standoffs. Lowest/first suppressor system standoff had some spark damage on the underside of the exposed portion. Distribution standoff for suppressor side was OK. Both standoffs for the charging side were OK, but with some evidence of sparking across the spark gap on the distribution standoff.

2.6 22/2/15 Monday

- Removed casting covers in preparation for moving the terminal spinnings
- Since we forgot to move the stripper foils back to their "000" position, we need to replace the shaft in unit 4 before we vent. So, we put the bearing back in and clocked the shaft. Ran the low-energy shaft and checked that the new bearing sounds good. It does.
- Ran both shafts to power the terminal and high-energy midsection to move both foil stripper positions back to zero in preparation for tube venting.
- Stripped resistors and rest of mid-section plates from unit 19 in preparation for acceleration tube removal.
- Replaced corona needle assembly with a new spare. Noticed some spark marks on the shaft and some black greasy material. Not sure if we have noticed either of these recently (or ever). Cleaned it up and moved on.

2.7 23/2/15 Tuesday

- Set up alignment telescope at level 4.5 to look through to target at the end of the analysing magnet at level 1. Target is illuminated from the rear using an LED torch with a bit of paper in between as a diffuser, and from the front using the old fibre light. With this set up, we can get a pretty good view of the target.
- Did a survey of the position of the top and bottom of the stripper canal, and the high-energy slits. The high-energy slits are pretty close to where they should be and we wouldn't adjust with the resolution that we can get through the level 4 to level 1 alignment set up anyway. Recorded position of stripper canal.
- Opened the terminal by lowering/raising the terminal spinnings. For the record, it's one down, two up, in that order. We hand cranked for pickup and touchdown operations to minimise impact on the column posts.

- Rechecked the position of the stripper canal, doesn't appear to have moved. It's what we thought, but good to confirm.

2.8 24/2/15 Wednesday

- Removed high-energy mid-section foil stripper mechanism. We need to write something up on how to do this without damaging a whole lot of things.
- Stripped some resistors and stringers from unit 18 to allow access for the tube jack. Did a test fit of the tube jack and we can lift at the top of the 8 gap tube, directly in the unit 18 casting without using the spacers.
- Looked at lower bellows in the terminal and wondered how we were going to get it out. Turns out, we have to jack up the terminal faraday cup to give us enough room to get the bellows out. We loosened the collar on the faraday cup and you can lever it up. We had to go make some chock blocks. So tomorrow for the bellows it is.
- We wiped all three chains with acetone to get the black wheel material and oil off. Chain 3 was particularly dirty, as was the down side area in the terminal pulley for chain 3. It also corresponded to some black material seen on the outside of the lower terminal spinning at that same position. Chain 3 also has some spark damage, lip to lip and some on the actual pellet surfaces.
- Removed high-energy ball valve (since it had been leaking) and found deep gashes in the ball, along with some foreign material jammed in between the sealing surfaces. At this stage, we are panicking and thinking it may be stripper foil debris.

2.9 25/2/15 Thursday

- We jacked up the terminal faraday cup about 23mm. What we didn't realise is that there the aperture in the bottom terminal bellows actually sticks up about 50mm from the lower flange (who knows why), so you cannot just slide the bellows out sideways. So we carefully tipped up the aperture mount, slid a plate underneath and pulled the bellows and the aperture mount out.
- With space now available, we unbolted the acceleration tube at the unit 19, tube 1, top flange. Jacking was relatively easy and we made about 15 mm of space, which was enough to retrieve the V-electrode. With that out, the tube came out easily. While on repeat, did the same for unit 19, tube 2. For future reference, all V-electrodes showed a small amount of activity (<5 µSv/hr).
- Removed the high-energy stripper body. This required unbolting of the conflat flange to the ion pump and backing off one of the shielded electronics boxes to get at the MGHV connector for the stripper suppressor.
- Removed all three 11-gap acceleration tubes from unit 12 in one go. Had to back off the alignment spokes, and noted that the natural position is at least 10mm off the aligned position.

2.10 26/2/16 Friday

- Had a team briefing to plan direction of tube assembly.
- Removed terminal foil stripper mechanism. Did not observe much debris in housing, practically nothing when compared to the high-energy foil stripper.
- Checked high-energy foil stripper suppressor electrics
    - Continuity from the MHV connector to the suppressor is OK
    - Insulation tests at 1 kV and was OK.

- The group of three acceleration tubes removed from the machine yesterday was disassembled on the bench. As the second tube was bagged, up flew a bit of stripper foil debris. This means that our thesis was correct, that foil debris is causing problems in the tubes.
- We decided that it would be best if we replaced the leaky post B in unit 15 before we tried to do any realignment of reinstalled acceleration tubes. This meant moving a whole of rings to allow the bottom terminal spinning to be moved further down. This we did.
- Looked closely at the high-energy mid-section suppressor body to try to understand if it was causing the machine loading. As we were doing that, another bit of stripper foil debris escaped and floated whimsically up the tank just out of our grasp. Some expert platform driving and vacuum cleaner operation soon had the debris captured.

2.11 29/2/16 Monday

- Removed unit 15 post B (S/N: 2180) and replaced with refurbished post 252. The post was orientated so that the non-slotted ring mounts faced outside, to match the removed post. Left one screw out of the bottom flange of the new post as the tapped hole did not seem to align to the through hole in the casting. Also had to replace some of the screws as one was UNF instead of UNC and the other was galled to oblivion.
- Had an initial attempt at aligning the stripper canal in the terminal by tightening or loosening post jacks. It's not easy as the alignment can get worse at a certain point.

2.12 1/3/16 Tuesday

- Continuing an attempt at alignment of the stripper canal shooting through from the top of the tank to a target at the bottom of the analysing magnet. By adjusting mainly the jacks in the casting at the bottom of the terminal, we achieved alignment on axis aligned with the SNICS source and 0.006" to the left of the MSNICS source axis. Given the person-to-person error involved in alignment, we deemed no advantage in chasing the 0.006" error. Curiously, the aperture that we thought was the gas stripper canal is meant to be 8mm is diameter, but we swear we're seeing 4mm diameter hole.
- Clean and close on unit 15 and unit 16. Found:
    - Scorched resistor lead on unit 15, tube 3, gap 1
    - Frayed resistor lead on unit 15, tube 2, gap 9. Also had to change resistor nuts to accept new leads.
- Moved terminal and parked back at unit 16, then moved many, many rings to open up units 19 and 20 for reinstallation of tube section.

2.13 2/3/16 Wednesday

- Resinated pre-assembled three-tube section into unit 20, used a clean but used v-electrode rinse in ethanol.
- Aligned three-tube section using a target in the top of the tube and looking through from level 4 through to the analysing magnet. We thought it interesting that with little tension on the alignment spoked in the bottom unit 19 casting, it was pretty much spot on aligned. Couldn't leave the spokes un-tensioned though, so tensioned them up and moved it about until it was aligned.

- Clean and close on unit 21 and unit 22 while we were waiting for the high-energy mid-section stripper body to be ready.
    - Replaced unit 22 chain 2 down casting idler as it was pretty much jammed and appeared to have material rubbed off from the wheel surface. Replaced with new wheel (actually new), but had to counterbore the washer to get the inner races of the bearing to clamp.
    - Unit 22, post resistor lead on gap 11 was singed, so replaced with new lead from our rapidly dwindling supply. Had to replace nuts on both resistors to accept new leads.

2.14 3/3/16 Thursday

- Received new HE stripper aperture from the workshop. Aperture was cleaned in Nitric Acid (20% for 10 minutes) then rinsed with de-ionised water and dried with nitrogen.
- Aperture was installed in the stripper assembly and the old aperture was removed and stored in the radiation area due to its 20uSv/hr reading.
- New daughter installed in the Linardakis family.
- A gasket was placed on top of the tube and the thick V electrode was carefully lowered into position. It would be desirable in the future to have a peg arrangement to help guide the thick V electrode down into position. Note that the OD of the electrode is 144mm
- A gasket was placed on top of the thick V electrode and the HE stripper was lowered into position, sandwiching the thick V electrode. Nuts were installed but only snugged up, as a new tool end is required for the torque wrench to reach the nuts.
- The ion pump was connected with a new conflat gasket and the suppressor connector and shield were installed.
- It was realised that the V electrode spacer (V electrode assembly minus electrode) was missing from the top of the tube before installing the stripper. The stripper was then removed, the spacer installed and the stripper refitted. The nuts have not yet been torqued.

2.15 4/3/16 Friday

- Re populated 2nd foil stripper. During inspection foil holder in position 15 was missing. Later it was found inside foil vacuum vessel. All foils inventory out of 14UD was photographed.
- Tightened bolts on re fitted stripper to 85 in.lbs
- Installed 2 tubes above He stripper
- Electrode on top of tube 1 was installed but V looked crooked, so it was replaced with another that looked better.
- Had problems with rotational position of holes when trying to connect top U19 tube 1 to bottom U18 tube 4. Used laser to check alignment of bolt holes down the newly installed tubes and found the misalignment was caused by a stack up of errors over all the newly installed tubes.

2.16 7/3/16 Monday

- Attempted to realign between U18 tube 4 and U19 tube 1 by releasing alignment spoke clamps over 2nd stripper. Released terminal spoke clamp and U17-18 clamp only (leaving U15 clamp untouched as it was covered by spinning).
- Tubes realigned, 4 bolts were fitted, alignment jig back in (~2mm gap still between tubes).
- Tubes (top) were lowered down until lifting jig was loose
- Even with 4 bolts (90° to each other), other holes were slightly misaligned.
- The upper tubes were rotated slightly by hand (as allowed by the now loosened spokes), and all the bolts dropped into place.
- Last joint was tightened gradually by working around opposite holes and building up the torque - 40,60,75,85in.lbs (alignment jig remained until after 60in.lb round)
- Check alignment top of HE tubes with loose spokes. Was pretty good, slightly shifted towards post A
- Started tightening spokes between U17-18, alignment was still very good.
- Started tightening spokes in terminal and it moved a bit towards post B (~0.5mm). Releasing spoke at post B and tightening spoke D fixed the alignment.
- Checking alignment with step target in second stripper, comment was 'bloody good' with only little shift toward post A.
- Fitted bellows with wire gasket on the bottom. Getting a gasket on the top was tricky, so it was decided to make a precision gasket to put in place with no foil/tape and lower the above assembly onto it, pinching in place. 4 precision gaskets were made.
- Installed single unit conversion on bottom of U1 casting.

2.17 8/3/16 Tuesday

- Bottom terminal bellows installed. During installation, the terminal Faraday cup was slid down on the top of the bellows. Because of the difficulty in securing a normal wire gasket in situ, a custom 118mm gasket was made (instead of 112mm) which was stretched over a buck and flattened so it could be installed without the need to foil/tape it down.
- Charging system in the terminal evaluated:

	Chain 1	**Chain 2**	**Chain 3**
Tyre	?	TO#111 9/09	TO#113 6/10 ok
Idler Up	TO#123 7/14 good	? Good	TO#120 7/13
Idler Down	TO#123 7/14 good	? Good	TO#120 7/13 adjustment position

- ~~Inserted 2nd stripper at position 999. Note: on bench it was re-calibrated, the position marker was shifted by ~45° (possibly the magnetic coupling slipped in the past) possibly during pressure operation the second stripper was not completely out in blank position~~

- A bit of confusion about positioning of 2nd stripper: we also found big blue mark which was consistent with proper position (disregard above comment).
- HE ball valve refurbished (new ball) and installed.
- Started installation of ceramic isolator and bellows below Buncher.

2.18 9/3/16 Wednesday

- Installed bellows under Buncher.
- Idler on Chain #3 (down) adjusted as per other chains (ie can induce slight movement on the chain by rocking idler).
- Checked terminal inductors/supressors, adjusted Chain #3 (down).
- Started pumping HE beamline under refurbished HE ball valve (magnet box cap installed first).
- Checked N_2 stripper gas pressure, found it to be 0.256barg which is the same (or slightly higher?) than the reading from TO#124. No new gas was added. Refer to photos for testing/fill setup.
- Installed terminal stripper and reassembled counter/motor drive.
- Repaired LE iris by skimming the magnetic coupling which would scrape during operation.
- Started pumping whole tube from level 5.

2.19 10/3/16 Thursday

- Tube under vacuum overnight (Wednesday night), still in 10^{-3} range this morning. Decided to close Weisser valve to determine where the problem is. Appears to be in LE, possibly still out gassing from turbo traps.
- Started fitting resistors.
- Leak chasing inside tank, leak chaser at L5 background 2.3×10^{-7}
    - Top U19 T1 no leak
    - Bottom U19 T2 no leak
    - Ion pump no leak
    - 2nd Stripper no leak
    - Top U20 T1 no leak
    - Bottom U20 T3 no leak
    - Terminal Stripper/Weisser valve no leak
- Finished fitting resistors (bar one on tab in U18)

2.20 11/3/16 Friday

- Vacuum improved overnight after baking out traps.
- Leak chased again from L5 with improved background of ~3.0×10^{-9}
- Fan turned off and started testing, background had improved to 2.6×10^{-9}
    - Turbos in terminal KF fittings (slight increase to 3.0×10^{-9} on top turbo) OK
    - Terminal Stripper OK
    - Weisser valve OK
    - Terminal Bellows top and bottom OK
    - Bellows interface to tube OK
    - U19 T1 top and bottom OK
    - U19 T2 bottom OK
    - U20 T1 top OK

  - U20 T2 top and bottom OK
  - U20 T3 bottom OK

Background had improved to $2.2x10^{-9}$

  - Turbo 1 KF fitting (again slight jump to $2.5x10^{-9}$) OK
  - Terminal Stripper gas tube connection OK

- Put lead piece (900x80x3.2mm) on bottom terminal bellows. Originally had two pieces fitted, now just one because the aperture in the bellows was not hot when check on removal.
- Cleaned inside terminal and blew down.
- Closed terminal. Note: close order of bottom, middle, top was not great because the bottom terminal had to be lowered to get the jacks out when the middle was in place. In future, order should be middle, lower, top.
- Fitted heater tapes to U15-16 for baking over weekend.

2.21 14/3/16 Monday

- Public Holiday.

2.22 15/3/16 Tuesday

- Baking out was continued over long weekend, U17-18, U19-20, and U21-22.
- Heater tapes removed. Noted U22 tape was cold, checked tape with Megaohmeter, still ok electrically, visually there was some cracking of the silicon. Resistor with blown lead from U13 was refitted with new nut.
- U13 Post B G8 had fried banana plugs on both ends (resistor and dummy). New nuts and leads were installed.
- Note: resistors leads have run out, new leads are required for next tank opening, either from EU or NP.
- Note: Platform unreliable in DOWN direction, suspect pendant or fail safe is to blame. Pendant was opened and terminals tightened and cleaned but platform failed again near the bottom porthole. Bypassing the failsafe seemed to fix the problem, indicating a problem with failsafe unit.
- Bakeout of U13-14 setup.

2.23 16/3/16 Wednesday

- Removed heater tapes from U13-14.
- U13 Post B G13 had a dodgy lead, replaced lead and both nuts on resistors.
- Note: Consider replacing trial radial resistors in LE section. These resistors are difficult to work on and the clamping system is unreliable.
- Performed final leak chase of tube. The helium delivery gun was modified with the tip from the tank air hose to reach the tube without removing rings. Base leak rate was $\sim 9x10^{-10}$.
  - LE (U1-14) and HE (U15-28) were all checked and found to be OK. Terminal was closed so could not be rechecked.

- Note: should evaluate mechanical properties of old, new, and exploded shorting rod nylon.
- Dust from exploded nylon rod found and vacuumed from units below U19. The dust content reduced progressively down to the bottom of the HE units.
- Note: should model resistor structure in SIMION, also compare to NEC structure and any new design.
- All units opened, cleaned and closed except U11-12
- Bakeout of U11-12 setup.
- Blew down all units from top to bottom except U11-12
- Post condition observation was done during blow down (see section 9).

2.24 17/3/16 Thursday

- Removed heater tapes from U11-12, blew down and closed.
- High Voltage testing performed. Some abnormal readings were expected due to poor vacuum especially around the terminal (LE/HE vacuum ~10^{-6}, vacuum around terminal ~10^{-5})
  - U18 8gap tube sparking across 5th gap, found two pairs of resistors across 4th gap, so one pair was moved down and problem was fixed.
  - U19 Tube 2, G5, same problem with 2 pairs of resistors on 5th gap. One pair was moved down and problem was solved.
- Checked inductors/supressors at bottom of tank.
- Filled oilers
- Carried out closing procedures.

3 Damaged shorting rods

While removing shorting rods from the high-energy end of the 14UD before the tank opening, it became apparent that a nylon shorting rod was broken. It was assumed that this was due to spark damage during the LINAC run of late 2015. Upon entering the tank, we found a shattered nylon shorting rod in unit 21. The undisturbed rod is shown in Figure 3-1 Shattered nylon shorting rod in unit 21Figure 3-1. There was much nylon debris scattered around the high-energy end of the machine, from the terminal all the way down to the bottom of the tank. Some of this debris field is shown in Figure 3-2 with the extent of the shattered section shown in Figure 3-3.

In addition to the shattered nylon rod, the single steel shorting rod that had been shorting unit 19 was also damaged, as shown in Figure 3-3. There was severe spark damage at the shorting rod spring contact points. This damage could not be polished out or repaired, so it was replaced with a different rod (the entry “bullet” is actually its own small rod that can be placed on the end of any rod). The replacement rod had a ring machined in the back to indicate that it is the last rod when inserting and removing shorting rods (as did the damaged rod).

Figure 3-1 Shattered nylon shorting rod in unit 21

Figure 3-2 Debris field from shattered nylon shorting rod

Figure 3-3 Comparison of shattered nylon shorting rod with good rod to show how much of the rod shattered. Also note the severe spark damage to the steel shorting rod at the spring contact points.

4 HE Stripper and Tube Inspection/replacement

With contamination of the tubes around Unit 19 thought to be causing the beam loading issues, it was decided to replace the tubes in that unit (2 above and 3 below the HE stripper).

4.1 Tube Removal

To gain enough free space to remove tubes, it was decided to remove the lower bellows in the terminal. To do this, the bellows was unwrapped (from its lead sheet) and disconnected. Then, bracing against the frame, the terminal cup section was levered up and captured with aluminium spacers across the frame under the terminal cup bolt heads.

Note: the terminal cup section is not clamped and is free to spring between the upper and lower bellows. It is unsure if this is intended or not.

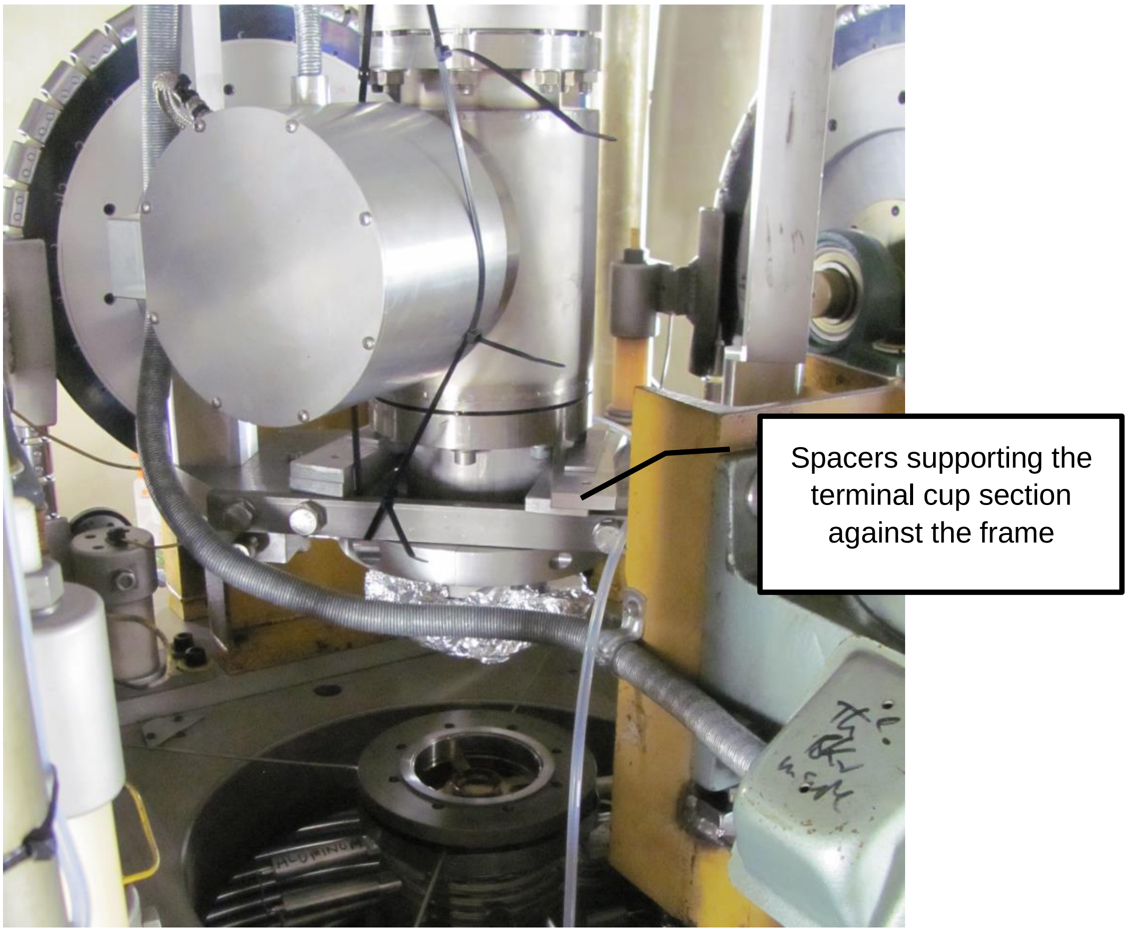


Figure 4-1 Terminal, bellows removed

It was discovered that within the bellows was an aperture stack that was sitting loose inside. After careful consideration it was decided to slide a piece of sheet metal underneath the bellows to capture the aperture stack inside and slide them out together.

With the bellows removed the tube jack was placed in U18 and used to jack. Spokes were not released, there was enough flexibility to allow them to remain tensioned.

4.2 HE Stripper Removal

In order to remove the stripper, much of U19 had to be disassembled. This involved removing casting covers, rings, deck, pedestals, stripper motor, and loosening the electronics boxes. The foil stripper was removed for repopulation, and the conflat connection to the Ion pump was disconnected.

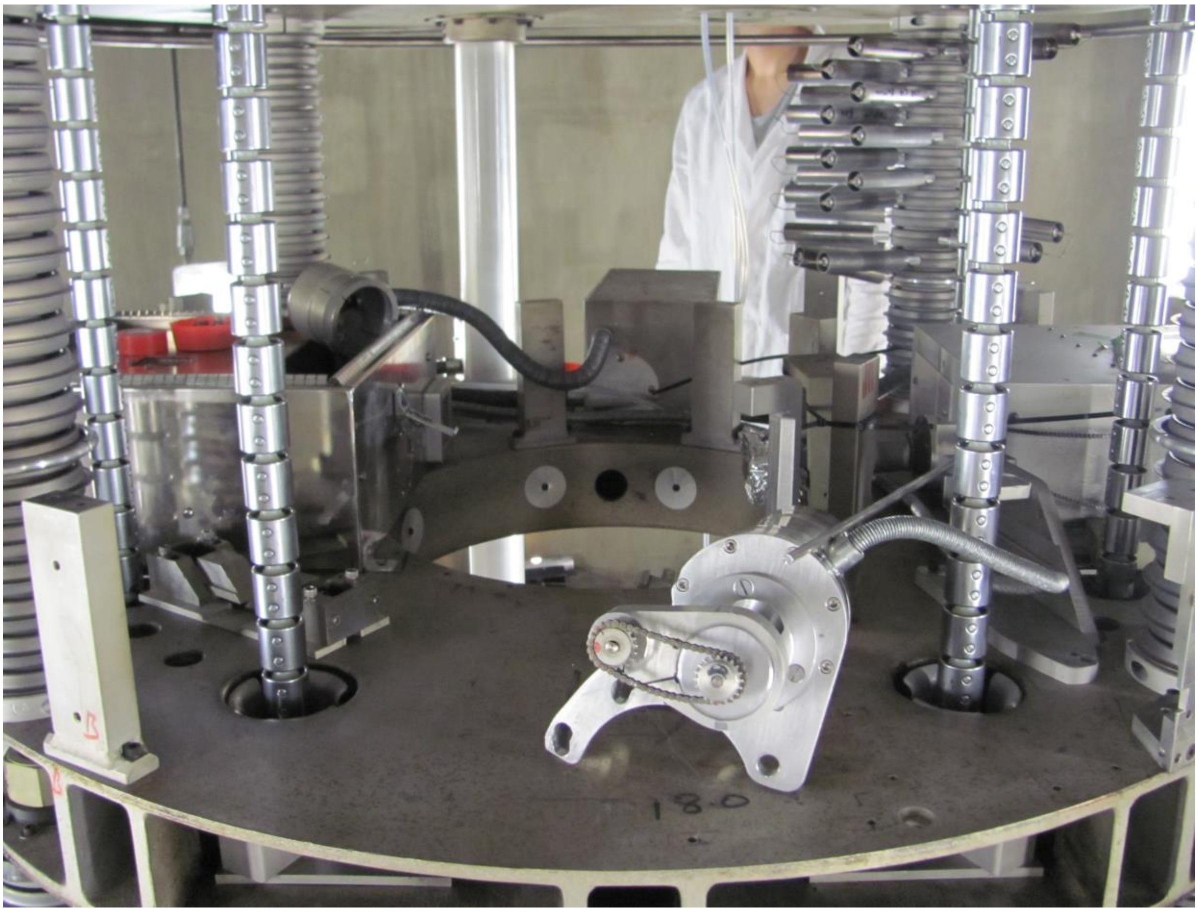


Figure 4-2 U19 Stripped

4.3 HE Stripper Inspection

The foil changer assembly was removed from the HE stripper while it was in place. Immediately debris could be seen on the bottom of the foil changer port.

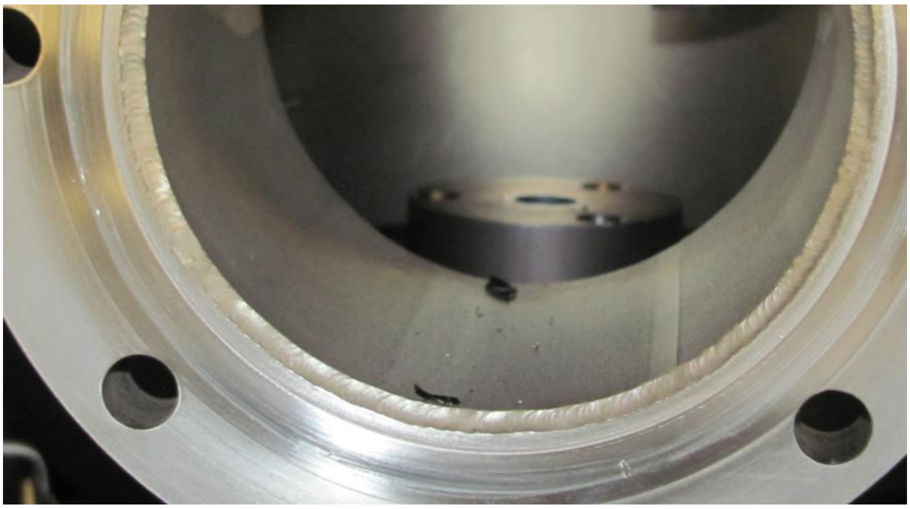


Figure 4-3 HE stripper debris

The HE stripper assembly was removed and inspected on a bench. During the inspection, more foil debris floated out of the assembly.

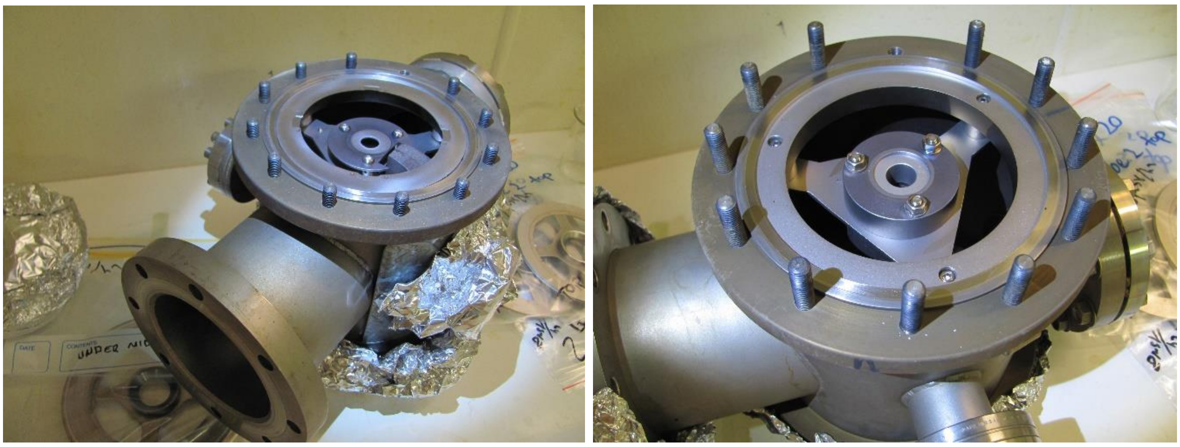


Figure 4-4 HE stripper assembly Top (left) and Bottom (right)

It was noted that the top suppressor aperture of the HE stripper had a sputtered area of about 25mm around its 12.5mm hole and this may be the source of a lot of backstreamed electrons. It was also noted that the set of 3 suppressor apertures are all biased to the same voltage. The suppressor arrangement was perplexing and further investigation will need to be done to understand how it works (or doesn't) and if it can be improved.

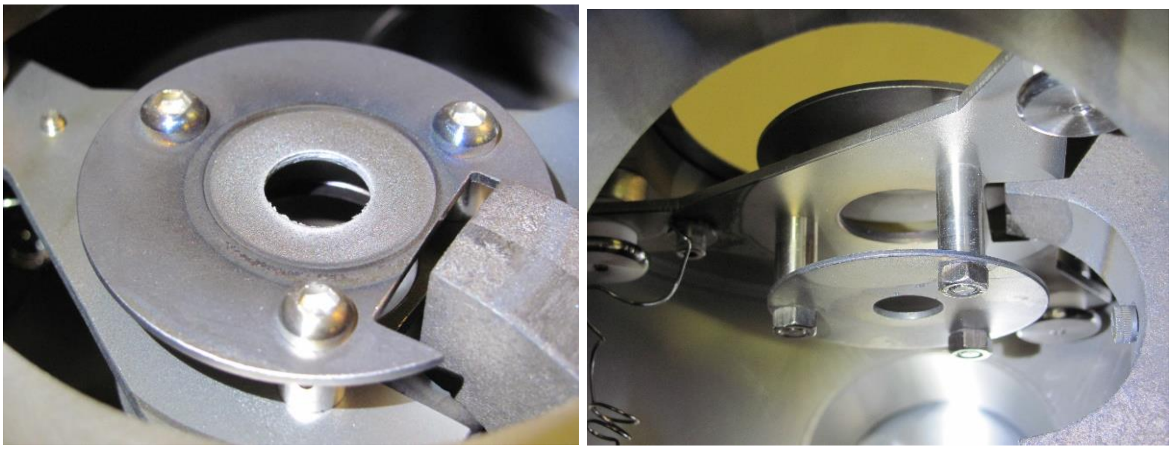


Figure 4-5 HE stripper apertures

A new tantalum aperture was ordered from the workshop. This aperture was wire cut so it was cleaned in Nitric Acid (20% for 10 minutes) then rinsed with de-ionised water and dried with nitrogen to remove any deposits on the cut surface from the wire. The aperture was installed in the stripper assembly and the old aperture was removed and stored in the radiation area due to its 20uSv/hr reading.

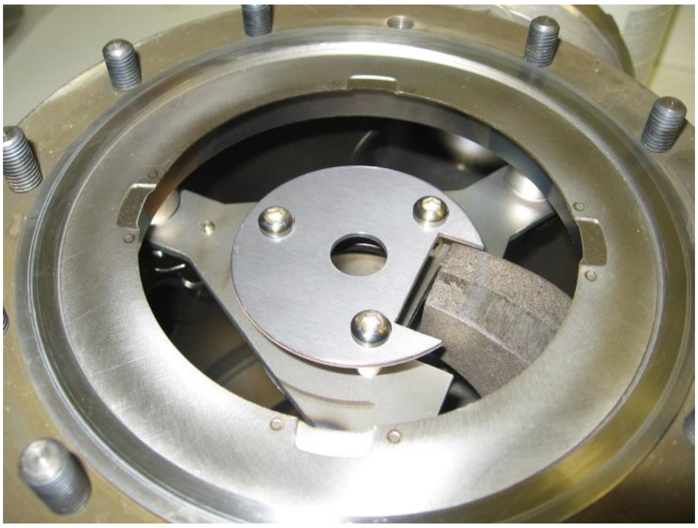


Figure 4-6 New HE stripper top aperture

4.4 Tube inspection

The removed tube sections were inspected. The tube immediately above the HE stripper was very brightly discoloured, thought to be from backstreaming of stripper electrons.

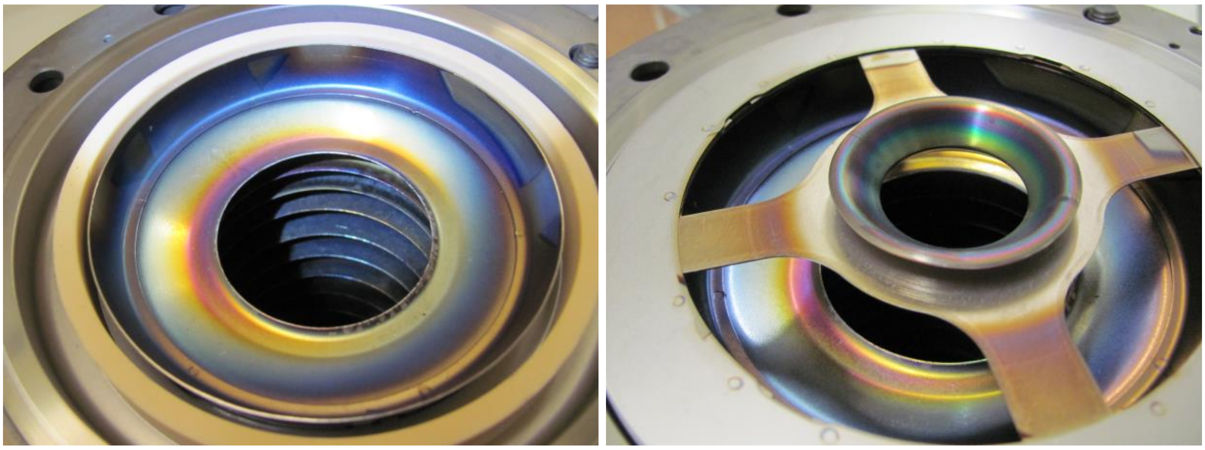


Figure 4-7 U19 Tube 2 discolouration (above HE stripper)

As suspected, the tubes below the stripper contained debris from broken foils.

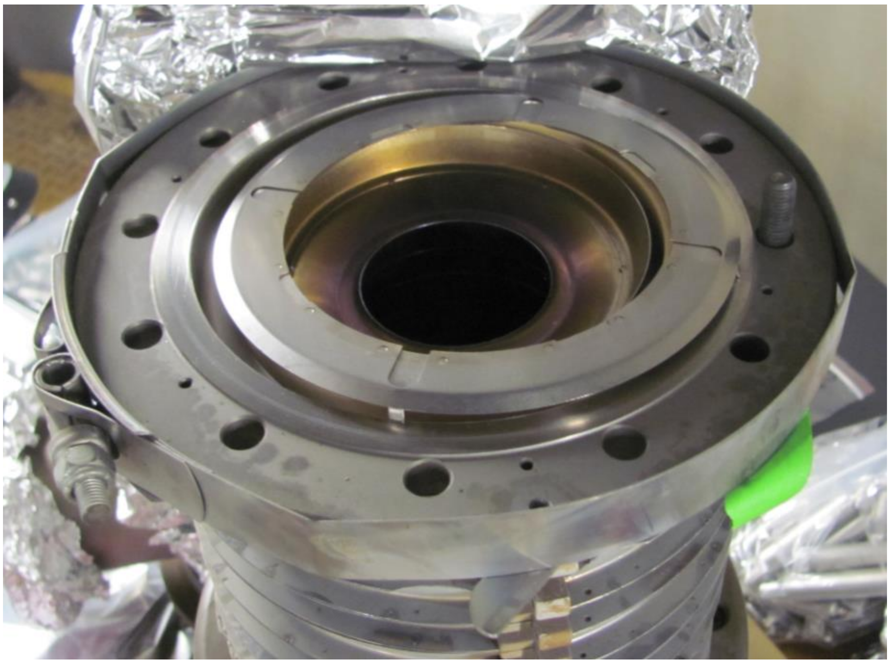


Figure 4-8 U20 Tube 1 (below HE stripper)

Tubes immediately above and below the removed sections were also inspected. The downstream tubes exhibited white marks on the electrodes. The cause of these marks is unknown. The U20 8 gap tube also had a small white piece of something sitting on the top electrode. Originally it was thought to have already been there when the tube was exposed, but the consensus later was that it was nylon debris from the shorting rod that must have fallen in during the tube removals.

Figure 4-9 U20 8 Gapper

The tubes above the removed sections still showed discolouration on the electrode surfaces, consistent with the theorised bombardment of backstreaming electrons from the stripper aperture and foils.

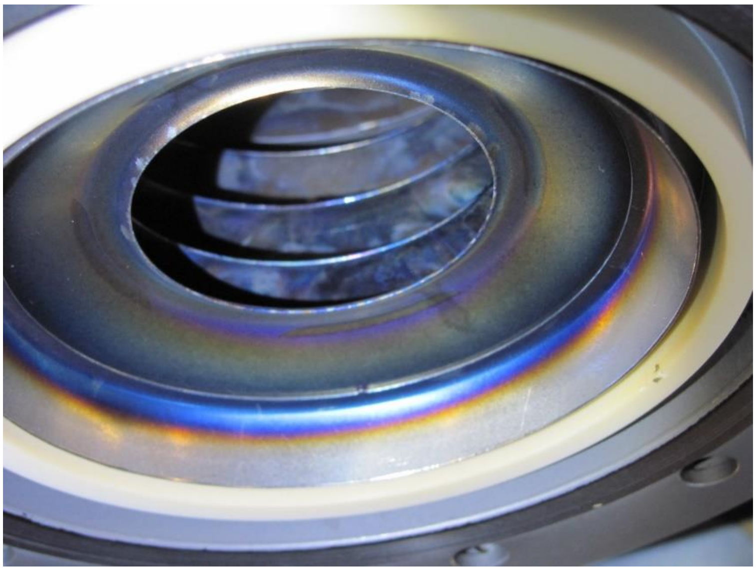


Figure 4-10 U18 8 Gapper

4.5 Terminal Bellows Installation

When the bellows was removed, the aperture stack was loose, however four tags on the base of the aperture stack seemed to indicate that it fit snuggly in the bore of the bottom flange of the bellows. Heating the bellows flange (130°C) created enough expansion for the stack to drop into the recess and securely hold it when cooled.

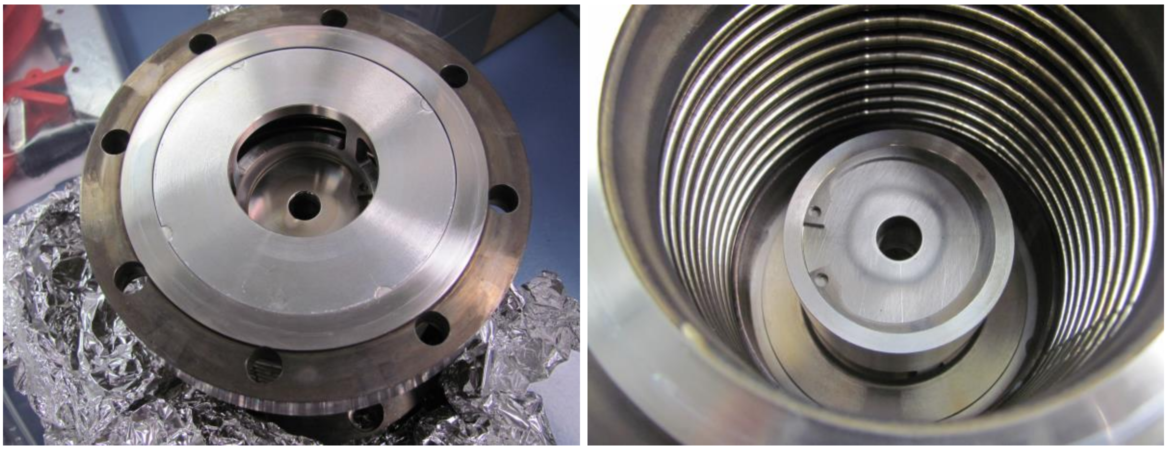


Figure 4-11 Bellows Aperture Stack Installed

A wire gasket was fitted to the bottom of the bellows and it was put in place and the bottom flange tightened. Getting a gasket on the top was tricky, so it was decided to make a precision gasket to put in place with no foil/tape and lower the above assembly onto it, pinching it in place. The standard gasket for the bellows flange is 112mm diameter, however, the mating flange had a smaller ID, so to ensure the gasket was pinched between the two flanges a custom 118mm gasket was made. The gasket was stretched over a buck and flattened so it could be installed without the need to foil/tape it down.

4.6 Alignment

The Taylor-Hobson telescope was set up at level 4.5. To create a ‘gap’ to look through, the tube section between the LE buncher and the electrostatic quad had to be removed. Note that this can be left in one piece, consisting of the tube, insulator and bellows.

There is a bracket in a wooden box on Level 4.5, this dowels onto the post at tank top and cantilevers out over the tube. The adapter ring is from Super-E and the T-H Telescope attaches to it.

It’s worth noting that any pressure on the cantilevered telescope mount flexed the system and threw the measurement off. If the telescope operator has to lean on anything then it should be the upper beam tube support structure which is hanging from above and thus independent of the tank entirely.

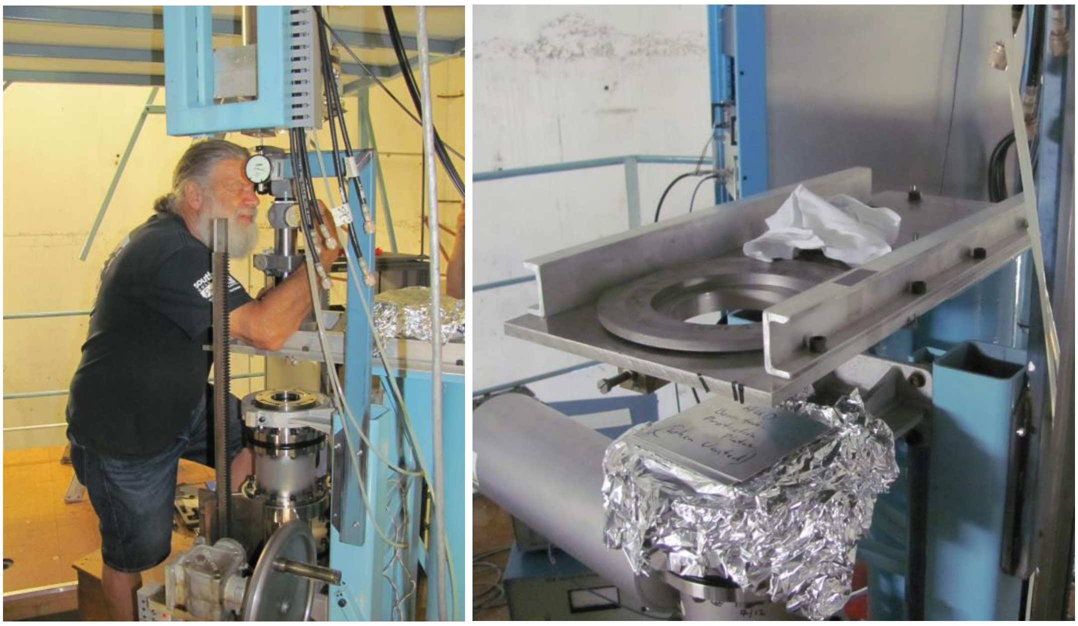


Figure 4-12 Telescope Setup

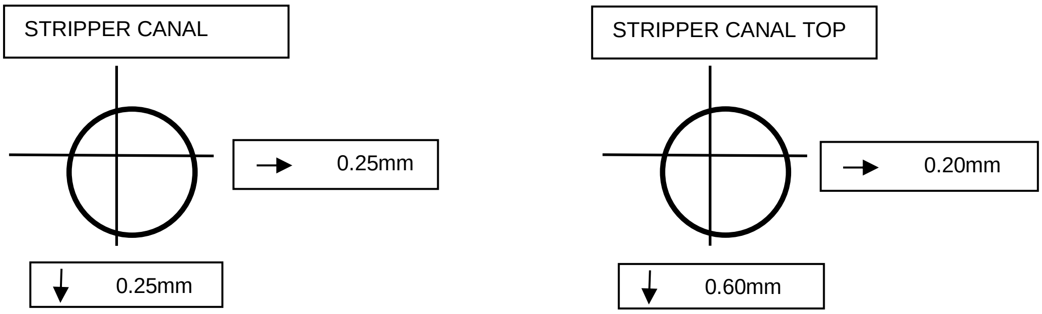
A Perspex target (from alignment cupboard) was placed in the ball cup underneath the analyzing magnet at the base of the tower. This was back lit with a current stores-issue type 3W LED torch which was modified to be a push fit into the cup from below. This illumination proved to be a little bit too bright in fact, very harsh on the eye through the alignment telescope. To reduce brightness a couple of sheets of paper were placed on top of the torch and this proved to be just right. The torch batteries had to be replaced several times throughout the job but for such an infrequent task it's probably sufficient. Report from Alan Cooper was that the clarity of the target was better than before. It did take a little practice to get a clean shot down through the machine and focus clearly on the target, but it was certainly repeatable.

Figure 4-13 Light Source Setup

Note, don't forget to open up the high energy slits! The photo shows the target and torch used, although in service the torch was inserted into the ball cup from below through the hole in the post.

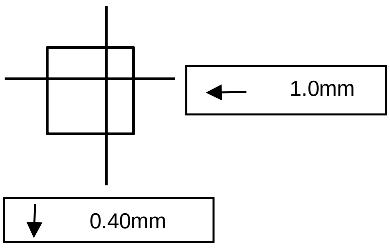
Looking down through the machine the Taylor Hobson was set at the centre of the bottom target with the X and Y on zero. Focus was then brought up and the HE Slit position could be observed and then back up to the stripper canal. The top end of the stripper canal was quite easily identifiable, while the lower end needed quite a bit of interpretation and was not totally repeatable. In general the lower end of the canal was visible as a sharper edge to the circular light spot which indicated the interior diameter of the canal. As the measurement was arrived at by interpretation of the position of the cross hairs relative to the circular feature, it was repeated several times and with different users.

Before work commenced inside the tank, the alignment was approximately thus:

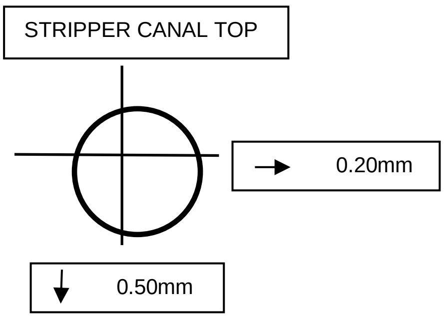


This represented the orientation of the crosshairs as viewed by the operator on Level 4.5. In the above the left approximately corresponds with the position of Post C, the right Post A, up with Post D and down with Post B.

With slits at 0.040" open the following alignment was observed:



Once the terminal was opened the top of the Stripper Canal measurement was repeated by Peter L, his measurements broadly similar to those taken earlier;



4.6.1 29/2/2016

Disassembly of the accelerator began by removing the terminal bellows, then the Unit19 tubes, the mid-section and then the Unit 20 Tubes. Once the spokes below the mid-section were removed the nearest set of spokes were three tubes below, and the tube stack was surprisingly flexible, it's natural position without spokes perhaps 10mm out! A check of the top of the stripper canal repeated the previous measurements of approx. 0.6 and 0.2mm.

Interestingly, the stripper canal aperture is reported to be 8mm. The Taylor-Hobson was graduated in thousandths of an inch and has a travel of only 50 thou in each direction. A 4mm radius of the aperture would be 0.157" but based on the measurements taken with the T-H the radius of the aperture was only around 0.100", giving a diameter of around 5mm ID. Of interest, a 5/16"x16g tube would be around 5mm ID. All the measurements quoted here are as-read by the Taylor Hobson graduations (converted to mm). So either the stripper canal is ~5mm ID or the Taylor-Hobson is not measuring as expected. *We need to check the accuracy of the T-H against ruler graduations next time we are aligning something*.

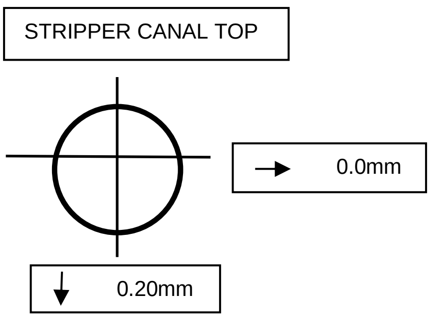
NOTE: Subsequent checking of drawings of parts around the Weisser valve indicate several components with a ¼" or 6.35mm inner diameter. As these parts did not appear to be visible through the Taylor-Hobson, the idea of a 5mm ID stripper canal seems likely.

At various times the bottom target at the analyzing magnet was checked to confirm the telescope was still set correctly. It was totally stable and was not adjusted again throughout the alignment process.

After replacement of the post at Unit15 the alignment of the stripper canal was checked again. It remained almost identical after the post replacement. Adjustments to post tension were made and alignment was improved to approximately ideal in the horizontal and 0.15mm vertically (as viewed in T-H, corresponds approximately toward Post B). Another few tweaks to make it perfect saw it go out to 0.75mm in the vertical and did not respond to attempts at correction.

4.6.2 1/3/2016

Further adjustments to posts (mainly immediately below the terminal) arrived at an alignment at the top of the stripper canal of:



So overall we feel we improved the alignment at the Stripper Canal by approximately 0.5mm.

4.6.3 Tube alignment:

The three tubes for Unit 20 were assembled in the clean room and installed in one piece, the spokes being reattached. A Perspex target was installed and interestingly the top of the stack showed almost perfect alignment with no spoke tension. Spokes were tensioned and until target centre dot was in the middle. Resolution of this procedure would be estimated to be <0.1mm.

The mid-section was installed, and subsequently the other two tubes. Rotational alignment problems were encountered on the last joint due to progressive errors in the tubes. The spoke clamps of the upper section of the tubes was released and the tube stack was able to be rotated until all holes lined up.

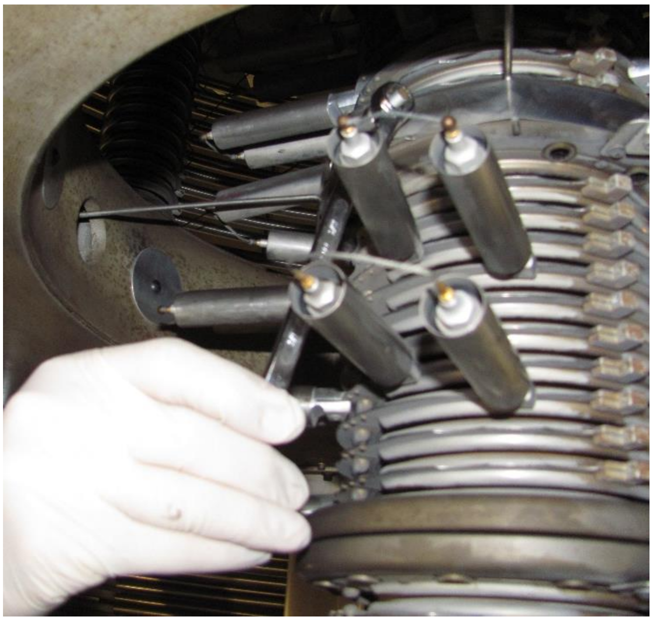


Figure 4-14 Loosening Spoke Clamp to Allow Rotation

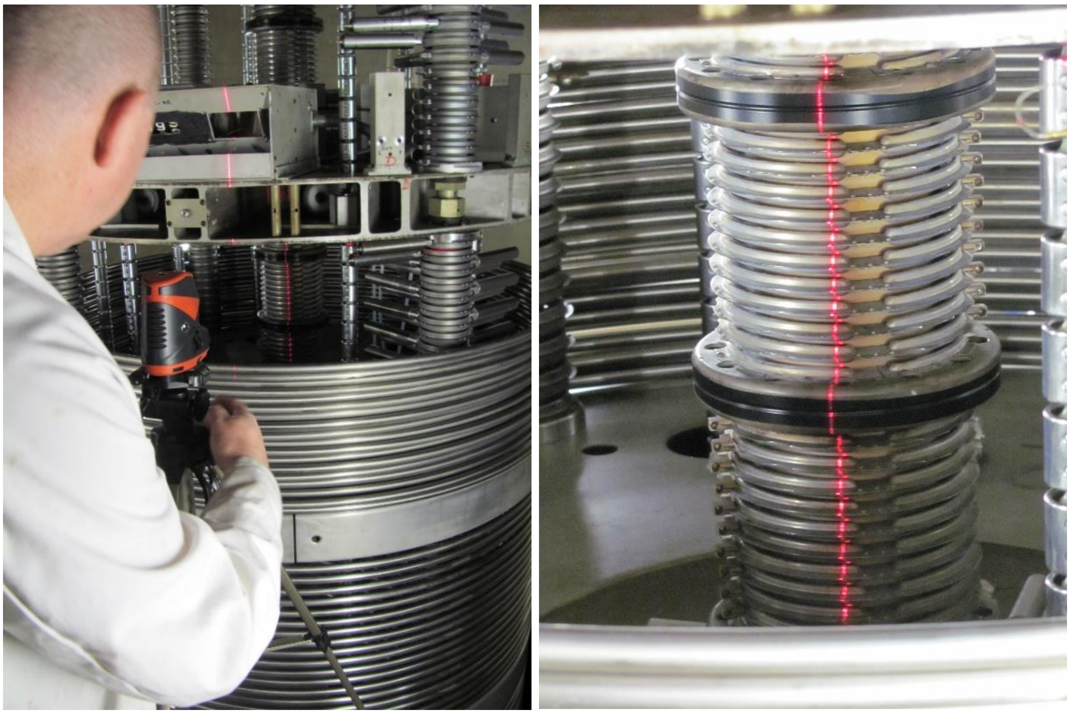


Figure 4-15 Using Laser Level to Check Hole Alignment

Alignment was once again checked at the top of Tube1 Unit15 and also in the High Energy Stripper. Everything was as perfect as could be viewed with the telescope, once again likely to be within 0.1mm precision.

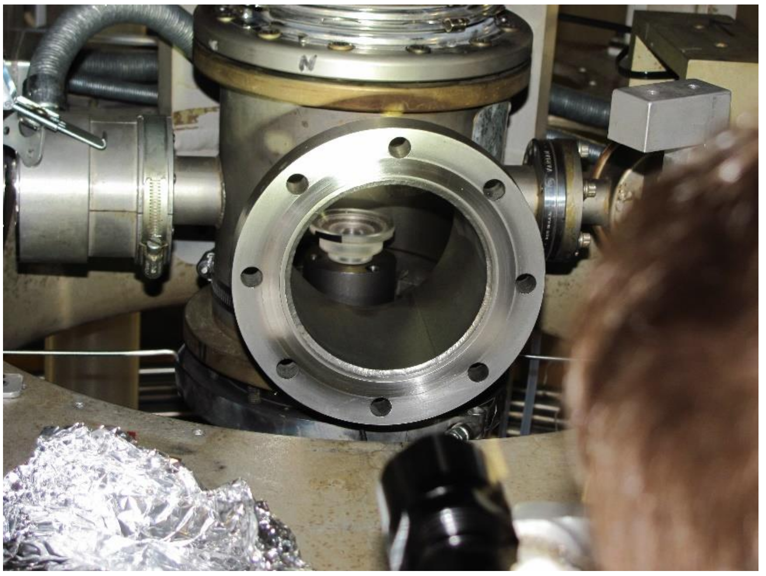


Figure 4-16 HE Stripper Target

Alignment was deemed to be as good as it could be, vacuum tube was closed up and gap reinstalled at Level 4.5.

5 Blown Resistor Lead, U13 Tube

During the entry High Voltage testing, an abnormality (ticking?) was found in unit 13, tube 4. On retesting, sparking was noticed across gap 7 and led to the discovery of a blown resistor lead.

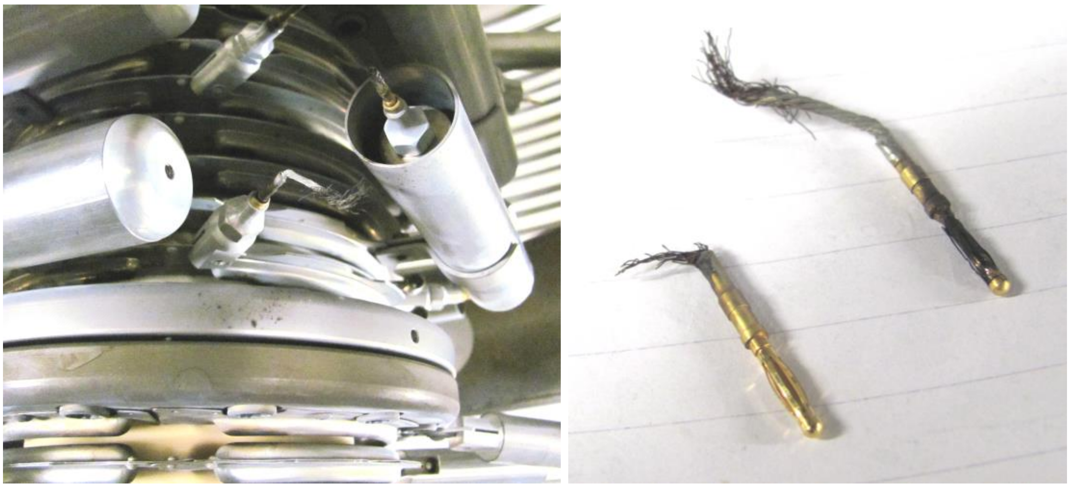


Figure 5-1 U13 T4 G7 blown resistor

The discovery was unusual in that the blown lead did not hamper the machine performance, indicating that either it occurred just before the tank opening, or there was a good enough corona across the gap to mask the problem (though no indication of higher levels of breakdown product in the area).

Prior to reinstalling, the resistor was tested and found to be good (32uA @ 20kV). New nuts were installed on the resistor assembly and dummy to accommodate the new lead. The spark gap also had significant spark damage and was cleaned up prior to reinstalling.

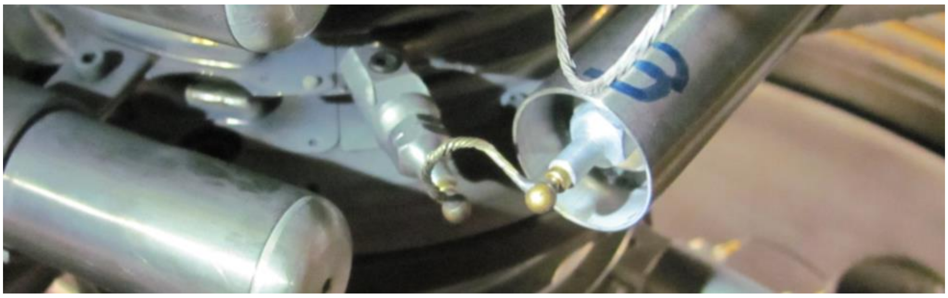


Figure 5-2 Replaced resistor lead

Note: the resistors on this tube are a radial design, installed for testing and assessment during TO#72 (April/May 1990). After working on this tube and resistor set, it has been deemed that the design is not appropriate. The resistors are difficult to install and the mounting system is unreliable with other resistors becoming loose when bumped.

6 Damaged Banana Plugs, U13 Post B

During cleaning and inspection on U13, it was noticed that the banana plugs on Post B Gap 8 were black and damaged. The plugs were very loose (poor connection) but were extremely difficult to remove as the ends felt like they had expanded and could not pass back through the nut. The plugs broke in the process of removal, leaving part of the plug still inside the nut.

The nuts and lead were replaced and the resistors reinstalled.

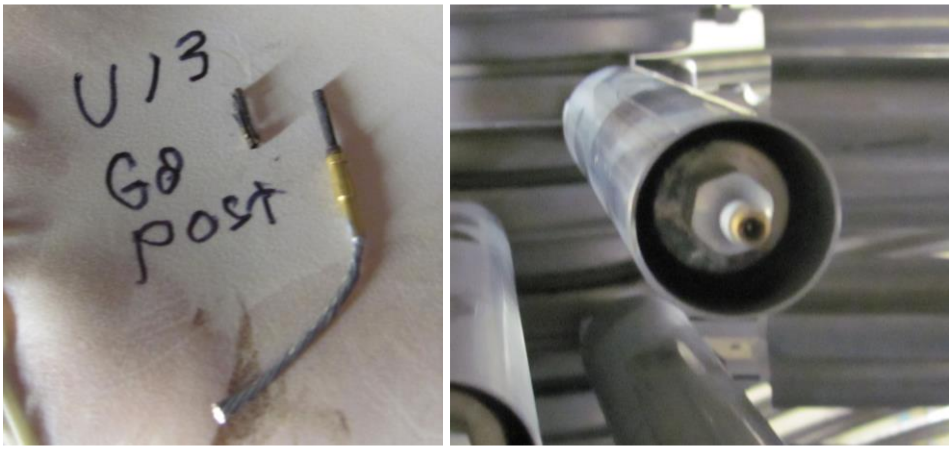


Figure 6-1 U13 PB damaged banana plug

7 Charging system standoffs

During TO#124, damage was found to two charging systems standoffs. It was thought that creating a spark gap on the first standoff in line would protect the rest of the line. Evidently, the exposed nylon standoffs are still vulnerable, with the un-sparkgapped suppressor standoff exhibiting damage from a large spark. For this tank opening, this standoff was replaced with a new nylon standoff, however it may be wise to introduce a spark gap in the future on the two remaining exposed standoffs.

Figure 7-1 Supressor standoff spark damage

8 High energy ball valve

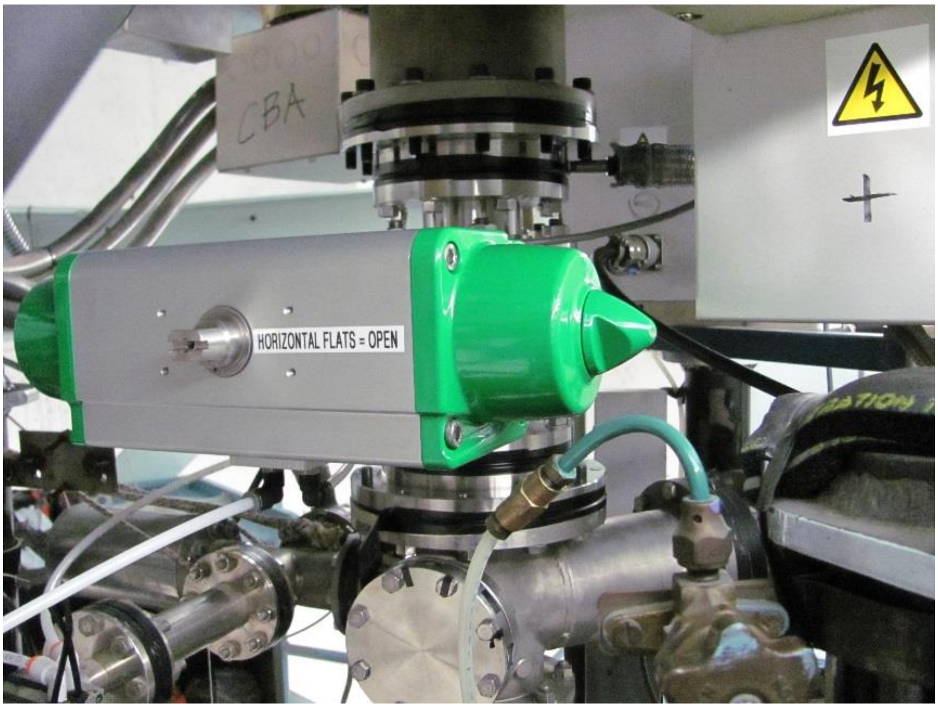


Figure 8-1 HE Ball Valve in situ

The HE ball valve sits just outside the tank and is used to isolate the vacuum in the 14UD tube from the HE beam line. It also serves as a fast acting valve to isolate the tank in the event of a SF_6 gas leak into the tube.

This new HE ball valve was installed during TO121 in February 2014. Since its installation, we have had a consistent problem with leaking through when in the closed position. It was decided to remove the valve during this this tank opening and install new Teflon seals to the ball.

Removal of the ball valve required supporting of the HE cross piece below the ball valve and the attached sublimer pump. Steel angle and slings were used as a support structure. New threaded rod u-pieces enabled the sublimer pump to be lowered and supported. The heavy actuator was also detached from the ball mechanism before removing the valve body.

Once on the bench the ball valve was serviced following the instructions and spare parts received from the manufacturer (A&N Corporation)

On inspection there were scratches on the ball and there was also a defect – like impact damage/weld spatter? – which would be damaging the Teflon seals when opening/closing. A new ball was ordered from A&N.

See the following photos of damage.

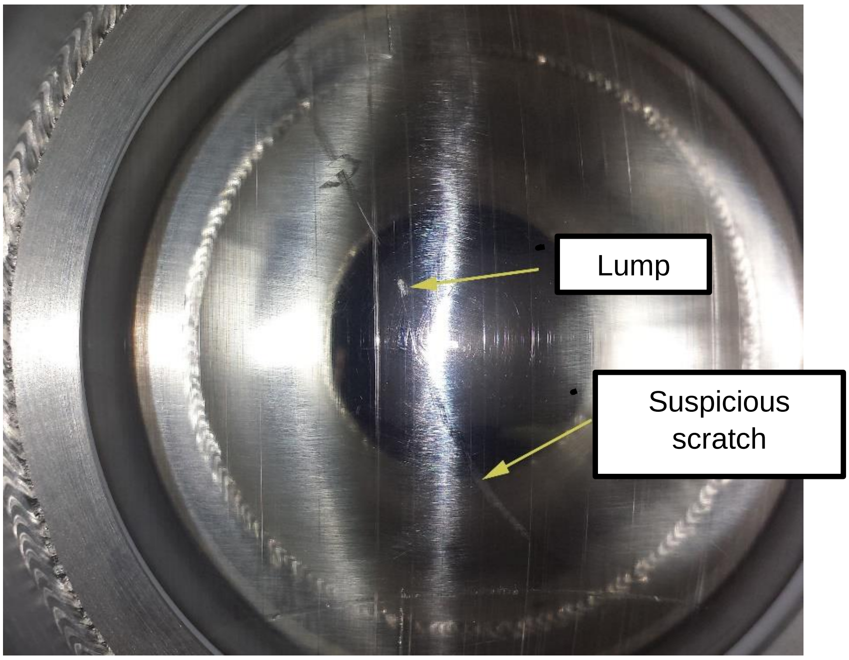


Figure 8-2 View of ball surface damage

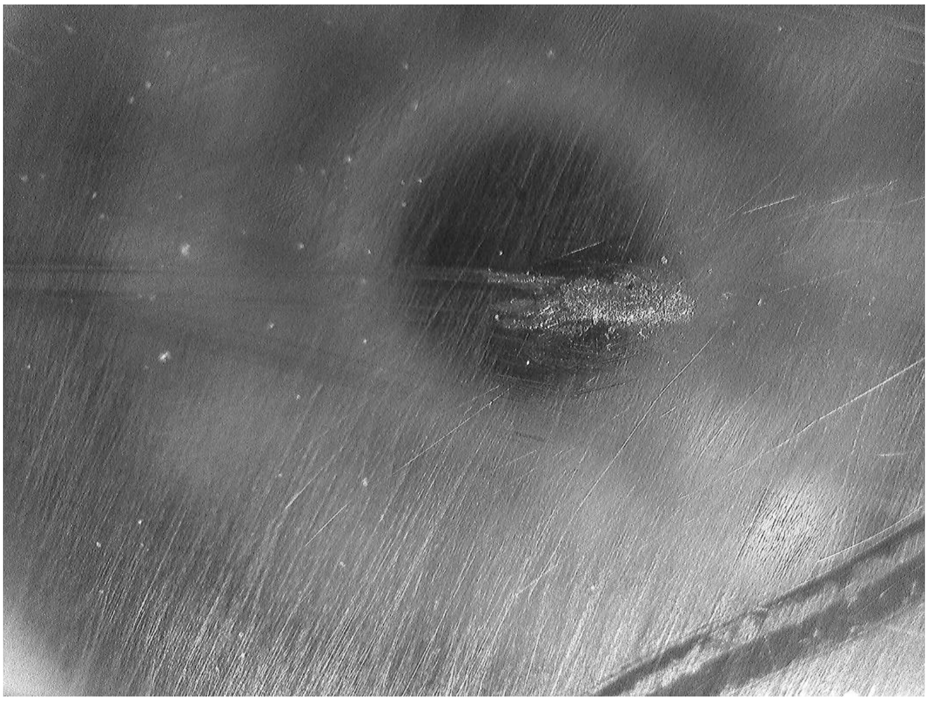


Figure 8-3 Microscopic view of ball surface damage

Valve was reassembled with new parts.

Valve ports were blanked and helium leak detection used to check valve in open and closed positions and at inlet and outlet sides. Valve passed all testing okay.

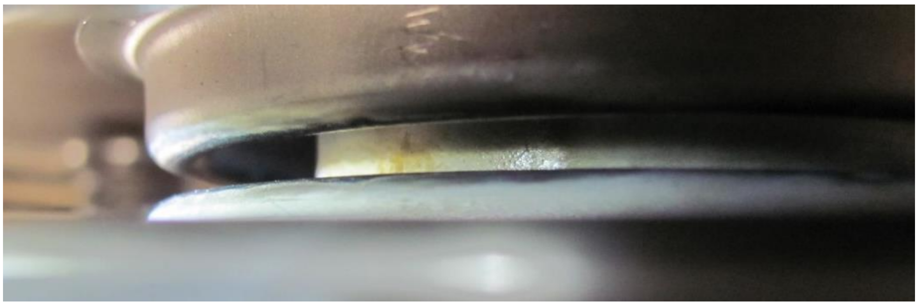
Valve was reinstalled and has since been found to be working as it should, with no leaking through when closed.

9 Post Condition Observation

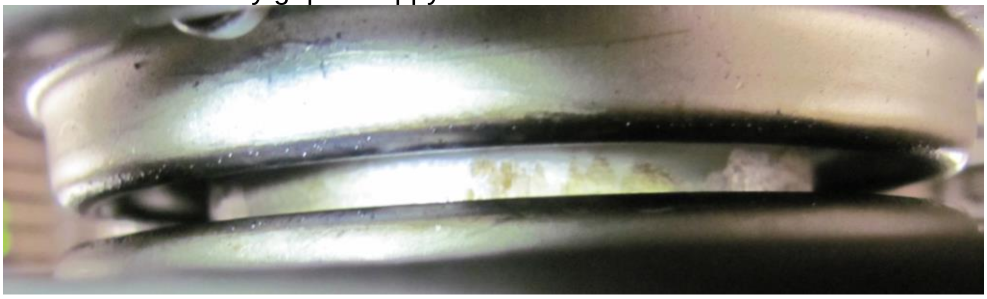
During the blowdown process, Lobanov observed and documented post conditions.

- U10 Post A G12: black trace
  Post C G18: black trace across insulator
- U14 Post D G1-3: bad looking ceramic

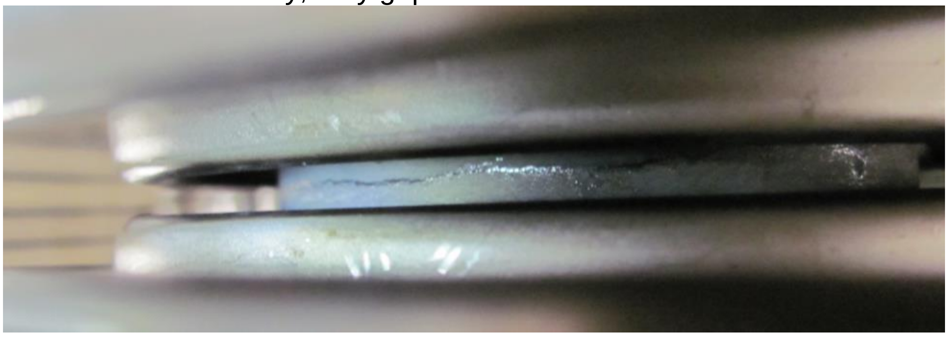
- U15 Post A G7:



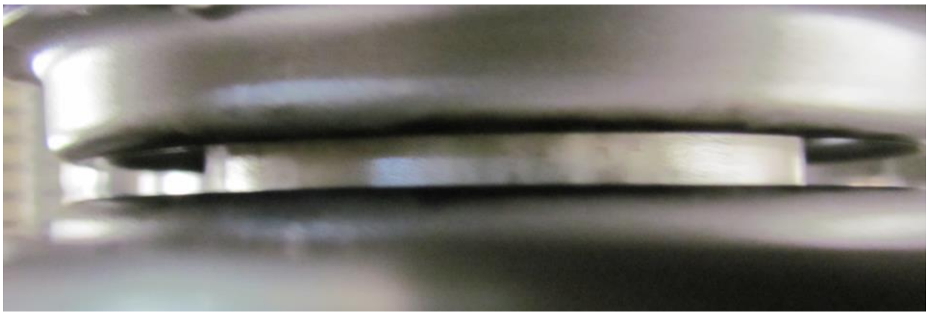
- U16 Post B many gaps: crappy



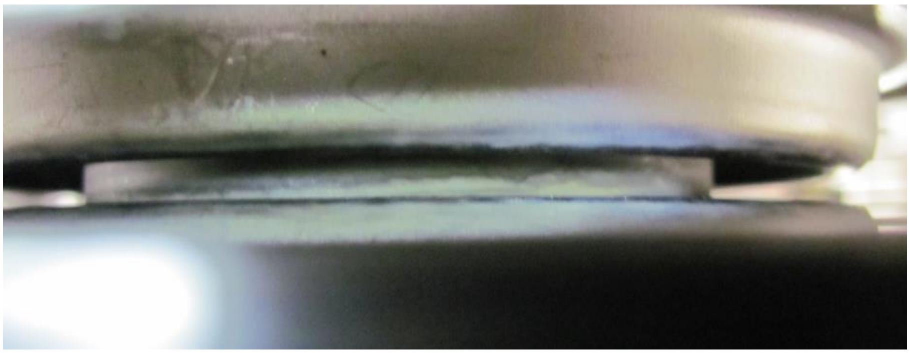
- U17 Post B G2: Oily, dirty gap



- U18 Post B G17-18: dirty

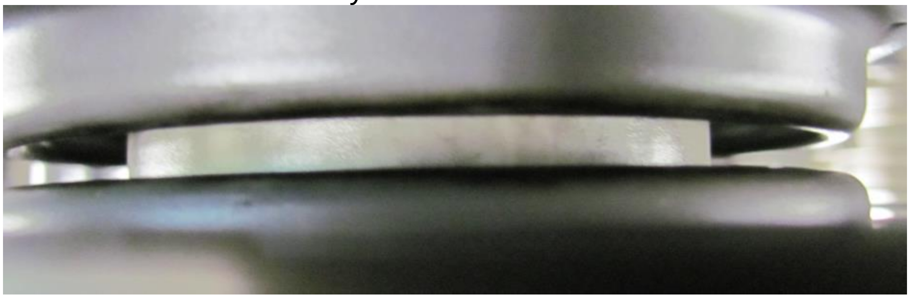


- U19 Post B G1-3: circular marks

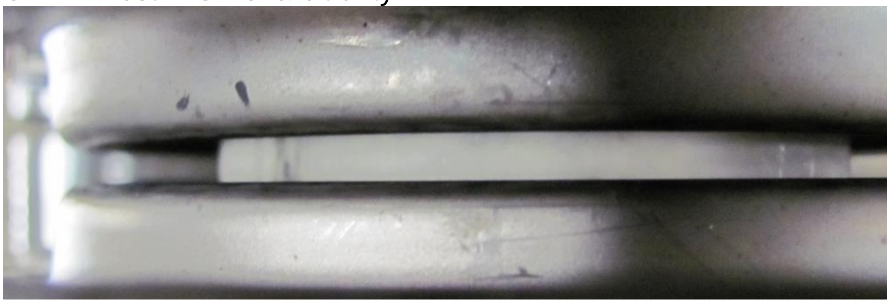


- U21 Post D G18: black mark across insulator

- U22 Post B G15-18: dirty



- U25 Post A G1-2: a bit dirty
- U27 Post A G2-3: a bit dirty



10 Single Unit Conversion

The single unit conversion project is designed to electrically connect the middle electrode of the 8 gap tubes to the casting to eliminate any voltage disparity. It was decided to trial the idea on one unit with the idea to implement it throughout the machine if it proves to be good. Unit 1 was chosen to install the conversion on.

The system involves connecting an NEC style clamp to the electrode. The clamp is crimped onto a wire with a loop (so as not to influence alignment) which is then crimped to a plate feedthrough bolted to the casting and trimmed. Note that the plate connection is done in place to eliminate problems with varying distances.

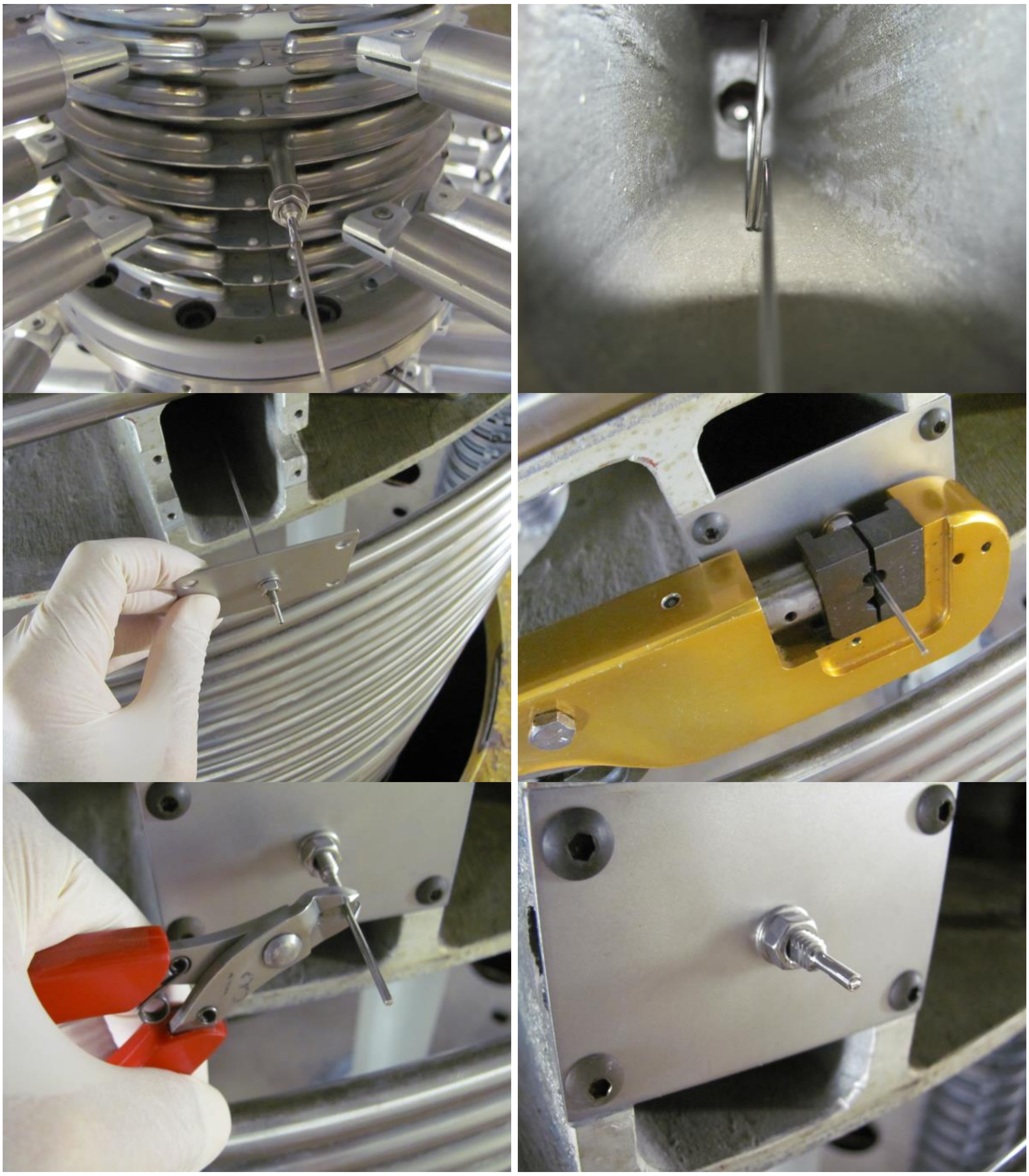


Figure 10-1 Single Unit Conversion installation.

11 Brass Fittings

When inspecting the terminal, it was noted that most of the brass Swagelok fittings on the back of the electronics boxes were discoloured brown. The fittings seem to be in good condition otherwise, with no apparent change to their integrity. It is not known if over what period this has occurred or why it has occurred (reaction with SF_6?), but it was thought that it should be noted if any issues with these fittings were to arise in the future.

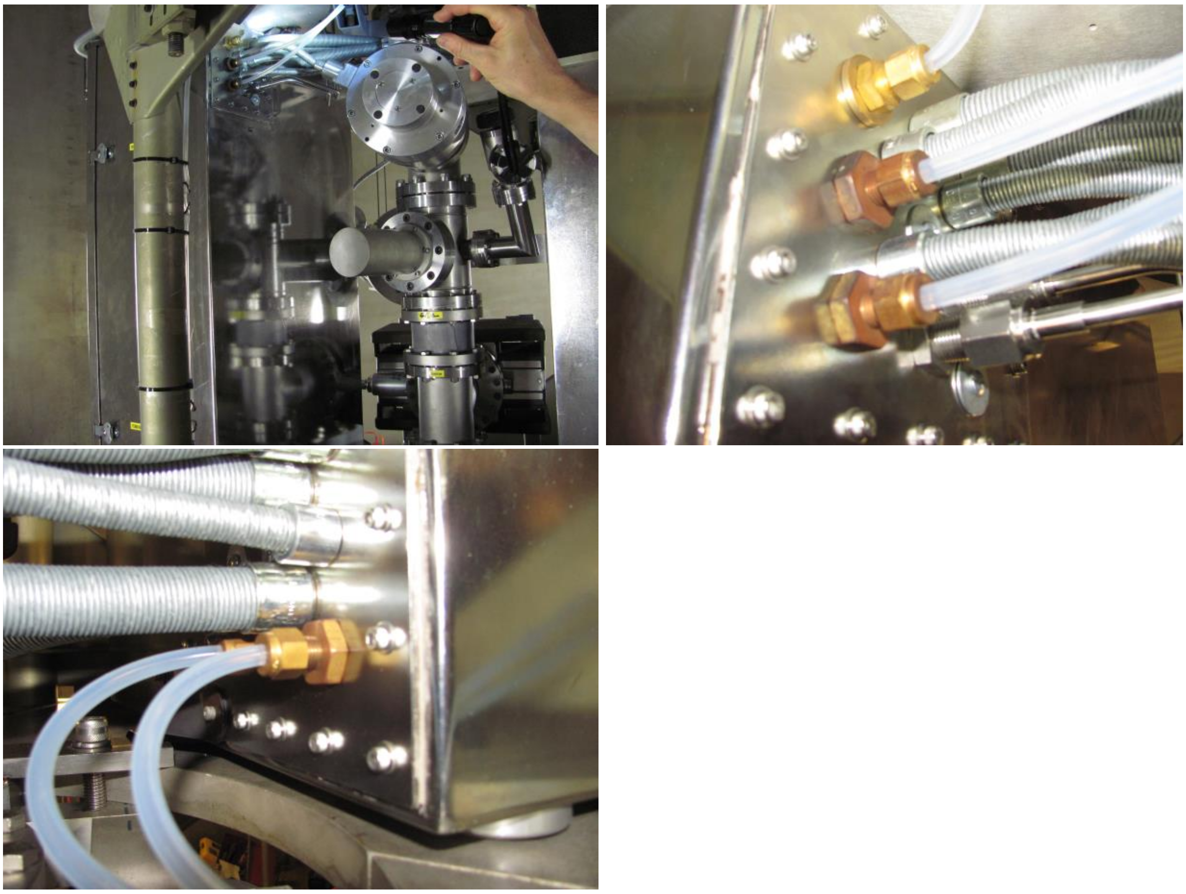


Figure 11-1 Brass fittings discolouration.

12 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

13 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
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

14 Machine hour meter readings

Table 3 Machine hour meter readings

Date compiled	15/02/2016					
Team member(s)	PL					
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	29886	29824	29973	49298	49291	31072
Previous reading (TO #124)	26965	26904	27052	45462	45460	28520
Change in hours	2921	2920	2921	3836	3831	2552
Previous total hours	5433	5372	9862			
Current total hours	8354	8292	12783			

15 Terminal voltage distribution for period of service

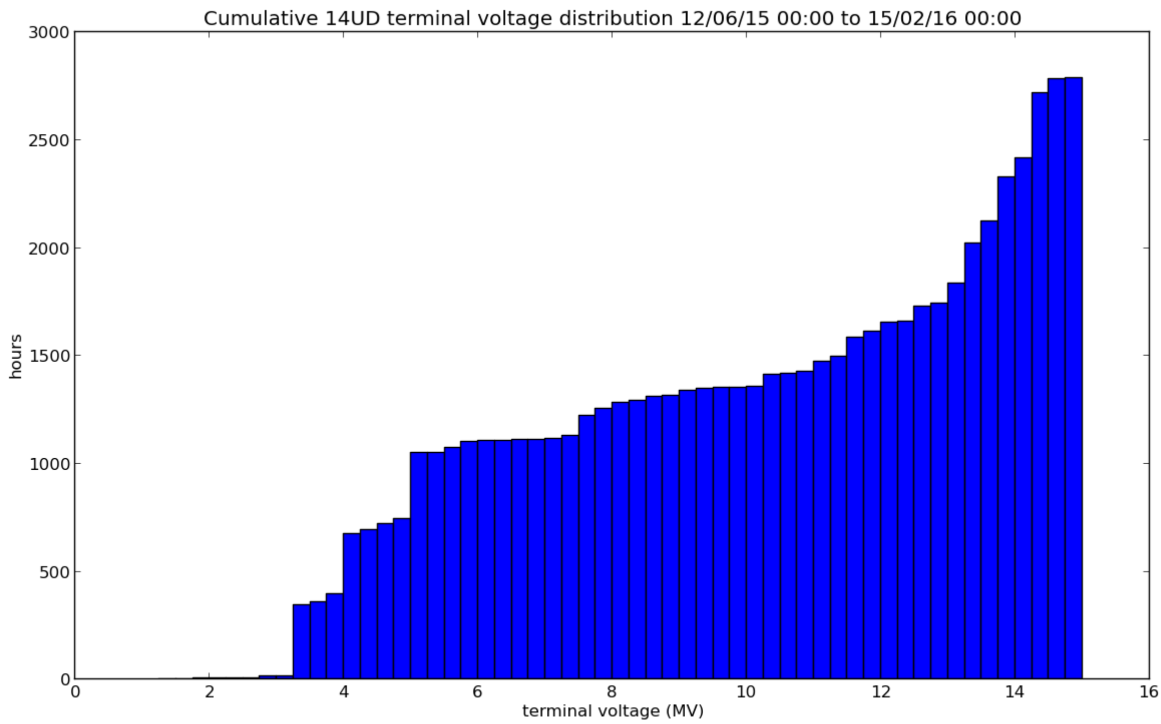


Figure 2 Cumulative terminal voltage distribution for period of operation from the end of tank opening 124 to the start of tank opening 125

The total hours with voltage on the terminal was 2787 hrs, which gives a utilization of 47% assuming a twenty-four hour, seven-day maximum.

If the shutdown over the holiday period and the time taken to remove, repair and reinstall the inflection magnet is ignored, then utilisation is 61% from the end of tank opening 124 until the 18th December 2015.

16 Initial performance

The accelerator was initially conditioned to 12.2 MV over a one week period in late March 2016 and it was a bit of a struggle. Spark activity was in the gas space and in the vacuum tube. The tank gas pressure was 102 psi.

During initial performance tests it was discovered that the HE sublimer vacuum pump did not perform to specifications. The sublimer was opened on the 24th March, old pellets were replaced and its body was cleaned in-situ from Ti flakes followed by outgassing to a sorption pump. With the refurbished sublimer the HE vacuum was down to 6×10^{-8} Torr by 20th April 2016.

The Super- e group running in the first two weeks of April at 3 MV terminal voltage did not report any problems.

14UD conditioning resumed on 19th April and achieved a terminal voltage of 13.3 MV. After conditioning of sections 15-21 and 22-28, machine was able to operate above 1.07 MV/unit corresponding to 14.6 MV full machine. Following this conditioning the terminal voltage was limited to 14.1 MV where the accelerator would repeatedly spark and conditioning events migrated to the LE end of the machine. Conditioning could not improve beyond this threshold. Tests were done by operating with pairs of units shorted out in an attempt to isolate the location of the problem at the LE end. The problem was isolated to Unit #10 where it was found this unit would only achieve 1.04 MV/unit whilst the average voltage per unit prior to this event was 1.07 MV. Unit #10 was shorted out and the 14UD operation voltage was limited to 13.7 MV. The stability of the 14UD is not ideal with small sparks disturbing the terminal voltages and occasional recoverable drop out reducing voltage to 13.3-13.7 MV with long reconditioning time.

The 14UD is turned over to the experimenters for another couple of weeks. Next Tank Opening is scheduled in the second half of May. More conditioning is to be done before TO to find out the cause of poor HV performance.