Proton Source Workshop

Wednesday Afternoon Session

Notes by Bob Zwaska

Session Summary

The fourth and final session of the Proton Source Workshop took place on the afternoon of Wednesday, December 8, 2010 in the Piano Room of the Fermilab User's Center. The session consisted of four prepared presentations, two discussion periods, and some closing comments to the workshop. Notes to the sessions in this document are organized in their chronological order:

- John Reid on Booster RF
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3749
- Trevor Butler on Linac RF Modulators and RF Power Systems
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3745
- Steve Hays on Electrical Utilities and Power Infrastructure
  - https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=3741
- Intermediate discussion (because Steve's talk ended early)
  - Primarily on the question of new Booster RF cavities
- Maurice Ball on Water Systems
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3750
- Bob Webber with Closing Remarks
- Final Discussion
  - Several issues with the Booster

The following notes are not exhaustive recitations of the talk contents. The talks are available in the DocDB. The notes do contain certain highlighted items from the talks, and try to capture as much of the discussion as possible

John Reid - Booster RF

John began with a description of the Booster RF system, interspersed with some details of changes that are part of the presently planned upgrades (solid state and modulators). The first item to come up for discussion was the issue of rack space – the new stations take up about I more rack width than the old. John said that had surveyed the galleries and found no issues in 85% of the cases, and they have relocation plans in the others.

The new RF stations presently being pursued have new solid state drivers and modulators using designs that were part of the MI RF upgrade. John described the modulator as a big programmable operational amplifier that also protects the anode in the case of the arc; the present modulators are original to the lab, and were already obsolete when they started operation. The 150 kW power amplifier is also being replaced. The ferrite bias supplies are not being replaced, they were already replaced in the 70s and are working reasonable well. Some of the controls are changed. The cavity itself is unchanged in the present plans, except that some cooling systems must be decommissioned and/or augmented.

Stations 12 and 19 have already been upgraded to the new scheme and are operating. One station is typically kept as hot spare, and two circuits of nine stations each are used for the RF. Two anode supplies provide the high voltage for the modulators. The RF cavities were originally designed to tune 30 to 52.8 MHz, but with 400 MeV injection have only to tune 37 to 52.8 MHz. The peak voltage per cavity is 50 kV over two gaps. The Q of the cavities is only ~ 300 at injection when detuned by the ferrites, and 1200 at extraction. The three separate tuners plus cavity body make a tight fit in the cavity, so that repair work is more time-intensive (~60 hrs for a PA) and requires close contact. With the SS upgrade, the repair time will be shortened to ~ 16 hours and the lifetime will be about three times as muc5.

The question of tube lifetime at higher repetition rate was raised. The chief tube of concern is the “big tube” in the PA (Y-567B) in the tunnel. It has an estimated lifetime of 36 months, and John says it is limited mostly by its peak voltage, and not the rep rate – so it is not expected to degrade more quickly.

John presented some statistics and discussion on downtime. Downtime due to RF increased substantially when MiniBooNE came online when rep rate and throughput increased substantially. Since then the failure rate has remained constant even though rep rate and throughput have increased further. Dominant failure modes are the modulators and amplifiers. In the amplifier the major weakness is the cascode tube: each amplifier has 20, and they presently have a lifetime of 9-12 months. The tubes are heat sensitive and water-cooled, so this lifetime will get worse at higher rep rate. John estimates that 1.5 PAs are replaced per month.

John went through some more details on the SS upgrade. The major components are 22 new modulators, 22 new 150 kW PAs, and 22 new 4 kW SS RF amplifiers. Two stations have been upgraded completely and various parts for the rest have already been purchased (some parts made sense to buy all at once. The 4 kW amplifiers are composed of four individual 1 kW modules using wideband MoSFET amplifiers. The modules were originally built by Intech for the MI upgrade, but are now being assembled in-house. The failure rate of these is very low, only 1 or 2 per year out of 200 in service; the failure mode is a water leak which may be fixed by

Particular modifications still needed to pulse at 15 Hz were next addressed. The present system operates at 7 Hz, but 15 Hz is way beyond the design considerations. John set the needed RF spec as 900 kV/turn plus 1 or 2 spares. An obvious point of discussion was whether those specs match the needs for efficiency. It was pointed out that the Booster operates more efficiently with more voltage up to 960 kV/turn (the maximum ever available), so the plateau in efficiency has not yet been reached. Plans for running beam at 15 Hz need to consider what can be done to maintain a voltage of 960 kV or higher.

Getting back to pulsing at 15 Hz, the SS upgrade is an absolute need to get there, the old modulators and PAs have no chance. The next item of immediate concern is the cones on the ferrite tuners. These are known to get hot already and have very few spares. An old cooling system had been in place, but so it has been out of use for many years. It was known to leak and was not needed at those levels of operation. This system may need to be recommissioned, which will involve the eventual removal and modification of all of the tuners. The concerns about runer failures and the lack of spares are what directly lead us to the 7 Hz pulsing rate. This is a critical item as it prevents testing of other systems in the Booster at higher rep rate. Those tests would be useful to identify the next round of failures that are likely to be encountered as rep rate is increased. The bias supply main rectifiers may need cooling and rejiggering. General AC distribution is a concern. LCW needs to be upgraded a bit to reduce pressures as solid state produces more heating in gallery. Anode supply transformers are old, and may be failing; their supply vacuum circuit breakers are also suspect.

The final discussion started with the question of what voltage is really needed. Dave M. concentrated on the capture process and questioned whether emittance measurements from the Linac and in the Booster could document the voltage requirements. Bill P. responded that the Booster capture is not very sensitive to Linac longitudinal emittance, but does have some bunch length dependence. The emittance of captured Booster beam is vastly larger than the Linac's due to the adiabatic capture / paraphase process. This than led to the question of how well paraphase works and whether it is the problem, and back to the question of what RF voltage is needed – capture being only one of the RF-sensitive issues . Bill P. has done scans of efficiency vs. RF voltage and claims that he sees gains all the way up to the limit of what the RF can produce on that particular day, suggesting that the Booster efficiency is chronically RF limited.

Trevor Butler - Linac RF Power

Trevor informed us, that in general, the high-energy linac is in good shape, while the low-energy linac has several issues. He described the LEL amplifier change having five stages taking the 2 mW LLRF signal to the 4 MW supplied to the tanks. The modulator control system uses a very outdated vacuum switches system. Within the modulator, the construction is not modular, so major components, like a power supply, cannot be simply switched out with a spare. The local failure needs to be found and repaired each time which makes the repair process very slow, and favors quick repairs over investigation. The repairs are made mostly on the opinion of experience as the available instrumentation is very limited. Much of that experience has been lost through retirements. More modern and modular components would obviate many of the problems.

The F1123 switch tubes were discontinued 10 years ago and are a liability. These tubes were custom for Fermilab, as being the best cherry-picked out of a more general line of tubes. That line was used by a Coast Guard radar installation. When the coast guard radar went out of operation they sent their inventory to Fermilab, but the usefulness of those tubes will be very limited as they are known to be inferior through the original QC process. Replacement would be very valuable. Several solutions to modulator were presented, comprising various levels of replacement. The advantages and costs need to be balanced. Fermilab buys up inventory from outdated equipment as it becomes available. Other outdated components (resistors, relays, power supplies) are only found through by buying up used inventory when available, otherwise kludges are necessary.

An upgrade in progress is the filament power supply for the 7835 tube (4 MW driver). The old inductrol system could not compensate for line voltage variations – a geared system was unreliable. As such, the tube set point is higher than optimal, shortening lifetime. The upgrades are relatively inexpensive and the first will be implemented soon; lifetime gains are expected. A PLC interlock system also produces readbacks which were lacking in the old system. Some discussion of this upgrade ensued, and the consensus was that the upgrade would likely help, but they were curious as to what the real results would be.

A final item in the discussion was that more LLRF work was probably necessary, and that it had to be made clear that the Proton Plan LLRF upgrades only fixed so much.

Steve Hays - Electrical and Power Infrastructure

Steve started with power distribution, where he said that LINAC house 13 needs harmonic filtering from NTF operation perturbations. There was a little discussion on whether all the noise on the power system was actually causing any problems.

The Booster house power was cited for being in poor shape. Steve proposes replacing Booster oil-filled transformer with a dry one, and to refurbish the breaker. Reliable and replaceable parts would then be in use

The Cross Gallery transformer also needs replacement, along with switch gear. In discussion it was pointed out that this was not directly Proton Source related.

The Motor Control Centers (MCCs) are old, high-maintenance items. There is actually some danger in maintenance. They control mechanical systems around the linac (pumps, fans) They should be replaced with modern, safer ones.

The LINAC house power has an old transformer that runs hot, and further is captured by cable tray. The captured situation means that an emergency replacement could take weeks, whereas a planned replacement could probably be done in a few days. A new one would run cooler and be more reliable.

Steve laid out the general problem as being that we have limited spare parts for ancient equipment.

There was a discussion of priority for these upgrades. The linac house power (captured transformer) is high risk because it is inaccessible.

Another discussion was on collapsed duct banks to the Booster. This was found recently when installing a new feeder between the Master Substation and Booster West. The crew was unable to remove the old feeder and had to use one of the spare ducts. If more feeder work is needed the duct will have to be dug up. The opinion was that this would have to be dealt with when confronted with failure.

Intermediate Discussion on Copper

Steve's talk ended early, so there was a short discussion before Maurice's. The discussion was whether cavities should be included in the plan. A rough consensus is that it may be too expensive to be picked from the menu; however, it should still be presented as a reliable option to get to higher efficiencies and throughputs. New cavities would relieve significant aperture restrictions, have higher reliability, and produce more voltage which is expected to improve throughput. Of course, a set of new cavities would be expensive and disruptive.

Dave M. wanted more evidence that RF voltage is an actual limitation (continuing the discussion from John's talk). He was most concerned with injection and capture. Bill P. agreed that he could better quantify the expected benefits from studies he has done.

Another issue with the question of new cavities would be that it would consume resources from the RF department. We would want any cavity effort to not jeopardize the SS upgrade which is imminent and crucial.

Maurice Ball - Water Systems

Maurice started by saying that there are a lot of different skids for different purposes from the Pre-acc through Booster. There are correspondingly varying levels of uncertainty throughout.

In the Pre-acc all skids are of concern. Particularly, there is a lot of PVC, which is risky for carrying pressurized water.

For the Linac, the LEL is in trouble. PVC piping is an issue again. It is degraded by UV light and heat. There are known repairs needed. Some of those are in tight locations. There was discussion that some of the LEL LCW had been upgraded, but there still seemed to be work to do. The HEL is in mostly good shape, being recently upgraded.

In the Booster, the LCW is a trouble spot. Many valves are inoperable, meaning that drain-downs are excessive. Strainers are in bad shape. Heat load looks good (running DT = 3.3 F out of 10). Flow rate is in trouble: bypasses are stuck open and lots of LCW is used in test areas. In many tech areas the LCW is permanently bypassed so that when test items are valved in they avoid stagnant water. This means that the pumps have to keep up much more flow than is generally need; however, in discussion, there was no alternative seen: most of those bypasses must remain in place. So, the return pumps are failing as they are operating over design point. Some pipes also need upgrading to deal with the flow. The instrumentation is also antiquated.

For other small skids, the anodes and 400 MeV are marginal. The debuncher is in good shape, having been recently upgraded.

Bob Webber - Closing

Bob thanked everyone for providing lots of information and new perspectives. He commented again on how helpful it was to have numerical targets from management.

Bob, Bill P., Dave M., and Valeri L. will get together and make a list of potential studies and upgrades. A lot of the hardware items were already covered in the Task Force report.

To produce a menu that management can choose from, we will need to develop reliable costs, durations, and efforts for all the items.

Stuart wants something by the end of January.

Final Discussions

The first question to come up is what is the Proton Source's capability now? The Booster has done 1.1e17 p/hr, Bill P. believes we are good to 1.2-1.3 without further improvement. 9-10 Hz pulse rate is also in reach with the Solid State upgrade, with the caveat of concern for spare tuners keeping us to 7 Hz.

One apparent issue is that these upgrades need greater priority for/from the RF group. They are major players in several high priorities already: SS upgrade, tuners / cones, cavities, and other RF work. How much have they been distracted by other new efforts? What can be done to mitigate this?

The discussion turned back to concern for the Booster tuners and cones. We need to build up an inventory of spares (where there are essentially none now). Already one is being replaced about every three months. Will the mean failure rate go up with rep rate? or will you kill the weak ones, so that the failure rate bumps at first and then drops? Eric P. felt that we will kill the weak ones. Spares production has been taking months because the RF group has other items on their table. They have already qualified the ferrites for tuner replacements. On the failure of one, they would probably replace all three on a cavity. New tuners have cooling, so doing it as a package has advantages.

Injection painting was suggested as a route for improvement. Painting has the capacity to reduce space chare effects at low field. Nobody has seriously looked at it yet. The Booster already has some uncontrolled painting already by default. However, the Linac beam almost fills the injection aperture, so until we get smaller emittance it doesn't make sense to pursue. Hopefully, the Linac beam will be smaller with the source upgrade.

Next, the discussion turned to the general question of what needs to be achieved in the Booster to allow higher throughput. There was a distinction made between controlled loss and uncontrolled loss, with no consensus on how much controlled loss could be allowed to reduce uncontrolled loss. The question of whether we make the tunnel hotter in general came up – meaning that we accept greater beam power loss. This could only be acceptable in the model where there is substantially less hands-on maintenance required, which is a challenge when everything is being pulsed and irradiated more. So, is there a dose limit we have to conform to? We weren't too sanguine on getting solid answers to any of the above. Regardless, the strategy is the same, just the level of performance changes: the aperture should be opened up, notching losses should be reduced, and RF voltage should be increased.

The next question was why are the cavities the limiting aperture in the first place? By design, the beta functions are small there, so even though there are small they should not limit the beam. Valeri L. says that 25 pi should make it through, but the beam is only 15 pi at its largest. Still, beam is definitely lost there. The hottest cavity is 120 mrem/hr at a foot, and clearly from data, harder collimation reduces cavity activation. One possibility raised is that we are necessarily talking about the tails of the beam which may not follow the default optics as well as the core.

Finally, there was discussion of collimation effectiveness. Bill P. stated that the collimators are not effective as designed. They do have an effect, but it has little to do with the originally proposed scheme, and is not optimized. The jaws need to be redesigned for low energy. Copper is in use now, optimized for mid-cycle losses. But, collimation is performed entirely at low energy. The primary needs to be changed to thin graphite. Presently, the secondary collimator is doing the bulk of work. Nikolai M. indicated that the actual operational system could be simulated.