Input Q for CEBAF cryomodules
Jay Benesch 15 February 2021

Abstract

I summarize the reason for the input Q chosen for C20/C50 modules with stub tuners to increase Q. The pptx file also in this TN folder is an analysis of input Q for C75/C100 modules done by Tom Powers, correcting a simple minded analysis done by me.

Original modules C20/C50

The original CEBAF input Q spec was 6.6E6. Interatom came in consistently low and C. Hovater recommended we not ask them to change it. When vertical test results indicated that it should be possible to run CEBAF at 6 GeV and 1 MW and the lab director made the commitment, being able to push each cavity to maximum gradient the LLRF (low level RF) and klystron allowed became more important. The problem with cold window charging with field emission became known during the North Stub test. This resulted in the creation of lem by Larry Doolittle and I began modeling each cavity. Cavities with greater gradient capability were limited by klystron power given low input Q so the installation of stub tuners to increase input Q began. As a result of the 1990s application of Reece procedure for helium processing many more cavities became capable of ~12 MV/m. The LLRF system input drive level maxes out at 7.5 MV/m so a 3db attenuator was added to the input from the probe to allow higher gradients. This changed the allowable LLRF range from 1.5-7.5 MV/m to 3-15 MV/m.

Lorentz force detuning for the CEBAF cell shape is about 4 Hz*$(MV/m)^2$ For 11.6 MV/m, 540 Hz. It was empirically determined that setting the stub tuners to provide an input bandwidth of ~180 Hz, Q 8.3E6, allowed for automatic reset of cavities after a fault without manual intervention. This is the standard still in place for the original cell shape and allowed for 164 μA at 6.0675 GeV/c, 820 μA in the linac, during a test and ~750 μA in the linacs for Physics (900 kW limit).

As C50 modules with up to 14 MV/m capability were installed, the LL software group wrote code to walk up GSET if auto-reset failed due to the detuning being 4.4 bandwidths (at 8.3E6) instead of 3 BW. This code is available from the RF captain for all C50 modules.

Since setting Qext in the sheet metal is difficult, it is suggested that a target of 7E6 be used. Assuming a resulting range of ±30%, this would allow the existing stub tuners to set Qext in the range 8.3E6 to 9.1E6, allowing for ~800 uA current in the linacs. Qext > 1E7 does not interact well with the old LLRF system (again empirical).

12 GeV era

As a result of the egos of those making the decision, the C100 cryomodules were designed with high input Q to allow high gradient but limited current with 13 kW klystrons. This was perhaps justified by the desire to keep beam power below 1 MW in 2005, but the 2007 Environmental Assessment allows 1 MW <u>each</u> to Halls A and C and the spec should have been revisited. Since the Spreader/Recombiner and arc power supply designs imposed by 12 GeV Project Management do not allow for an increase in energy, unlike the Accelerator Physics Group design which provided 12 GeV to A/B/C and 13 GeV to D, the only way to increase the physics output of CEBAF is to increase beam power. Since the EA allows beam power to be 2 MW, there are only minor regulatory paperwork changes needed (in progress.) The high input Q of the C100 and C75 modules should therefore be lowered to allow more

of the available klystron power to be devoted to the I^2R term and less to the V^2/R term. The MIT Radiation Lab series shows that by making a stub tuner with the stubs in the narrow waveguide wall, as opposed to the wide wall as in all those now installed, one can lower input Q. This finding led to the simple analysis I did a year ago and the corrections Tom made in that analysis (pptx file in this TN folder.) One sees in the two graphs at the bottom of slide 4 that an input Q range of 8E6-10E6 for C50s and 10E6-12E6 for C100s would allow for 800 μA in the linacs if the klystrons meet spec. It is unlikely that both Halls A and C will want 80 μA fifth pass at once. If Halls A and C each take 70 μA and Hall D 5 μA, 730 μA would be required. Per a Tom Powers spreadsheet also included, 13 kW klystrons which provide 12 kW will allow this current with 40 Hz detuning at 17 MV/m or 95 MeV per C100 and 68 MeV in C75 modules. These energy gains are consistent with past performance of refurbished modules and are the values used in backup to the recent CEBAF Performance Plan submission to DOE. Geoff Krafft has a spreadsheet which suggests higher input Q than Tom's; these have not been reconciled. If higher input Q is better, the stub tuners will not need to compensate for as large a ratio.

Email with Physics Division on topic

From: Cynthia (Thia) Keppel <keppel@jlab.org>
Sent: Tuesday, February 9, 2021 5:20 PM
To: Rolf Ent <ent@jlab.org>; Camille Ginsburg <ginsburg@jlab.org>; Jay Benesch <benesch@jlab.org>
Subject: Re: high current

Hi Rolf,

It is certainly true that many if not most of our users will go for the max allowed thinking their science is the most important!

Nonetheless, we have a lot of high current running in A/C on the books and I'm nervous. Do you support the suggestion to go for 730 uA (70 uA each to A and C five pass, 5 uA six pass to D)?

Thanks (and thanks again also to you Camille and Jay),

Thia

Cynthia Keppel, PhD
Hall A and C Leader

Rolf Ent
Tue 2/9/2021 5:25 PM

Yes, of course I do as it will make scheduling much easier and gets more science for the buck. Of course it also comes with scheduling issues as higher currents may impact the highest energies, but overall one still wins!

I am just not sure about the formal process.

Conclusions

1. Sheet metal input Q target for C50 cavities should be 7E6 with stub tuners used to take actual up to the range 8.3E6 to 9.1E6 (assumes ±30% spread around target.)
2. If target input Q of C75 cavities sheet metal can be lowered to ~ 15E6, this should done. Stub tuners would then lower input Q to 13.25E6 (BW 110-115 Hz)
3. Stub tuners should be used to lower input Q of C100 cavities to 13.25E6 (BW 110-115 Hz)