Half Current Option: Impact on Linac Cost

Chris Adolphsen

With input from Mike Neubauer,
Chris Nantista and Tom Peterson

Aug 23, 2006

Assumptions

- In the service tunnel, only every other rf unit would be fully built and installed. Thus there would be an essentially empty 36 m long space between rf units that could be filled later as an upgrade. For this 'empty' unit, the penetrations would be built and would include the three waveguides that feed the three cryomodules in this area. These waveguides would connect via a three-way splitter in the service tunnel to a waveguide that runs 36 m to the neighboring rf unit, where it would connect to one of the two 5 MW ports on the 10 MW klystron.
- Because of the lower beam current, the cavity fill time would increase from 0.565 ms to 1.130 ms, but the 1.0 ms long stored energy 'flat top' would remain the same. The rf pulse length would thus increase from 1.565 ms to 2.130 ms, and all power and water cooling requirements would scale accordingly.

Cost Impacts (1)

- Klystrons
  - The number of klystrons would decrease from 628 to 314, but the per unit cost would increase by 13% due to the smaller number, and by 8% due the modifications required for the longer rf pulse. The net savings would be 71 M$, which is a 39% reduction.
- Modulators
  - The number of modulators would decrease from 628 to 314, but the per unit cost would increase by 9% due to the smaller number, and by 17% due the modifications required for the longer rf pulse. The net savings would be 115 M$, which is a 36% reduction.
- LLRF
  - The LLRF system would basically remain unchanged. The associated electronic racks would be located in both the 'filled' and 'empty' sections of the service tunnel, just as in the baseline design. However, the LLRF stabilization of the cavity gradient during the pulse would be more challenging due to the two-times larger cavity Qext.

Cost Impacts (2)

- RF Distribution
  - Except for the short waveguides runs between the tap-offs and couplers, WR770 waveguide would be used instead of the baseline WR650 waveguide. This larger waveguide has a lower power loss per unit length (0.14%/m versus 0.21%/m), and with the added 36 m length of waveguide, the average power loss is compensated to 0.1%. That is, in the baseline, the average length of the three waveguide runs in each rf unit is 37 m, so the average loss is 0.21*37 = 7.8%. With the half current option, the average loss is 0.14*(37 + 36/2) = 7.7%. Thus, the number of rf units would not need to be changed to maintain the same final beam energy.
  - The total length of WR650 in the baseline design is about 628*3*37 = 69.7 km while that of WR770 in the half current option would be 314*6*55 = 103.6 km. The cost of WR650 is about $210 a meter - assuming it scales as the perimeter length, the additional cost of waveguide for the half current option is 103.6*.21*(77/65) - 69.7*.21 = 11 M$.

Cost Impacts (3)

- Cryogenics
  - The longer fill and discharge times increase the rf heat load while the lower beam current reduces the HOM related heat loads. To account for the rf heat load during the fill and discharge times, an effective rf pulse length is used that equals the bunch train length plus 1.11 times the fill time.
  - For the half current option, the main linac plant sizes for each of the five plants per linac would have 5.02 MW installed power (equivalent to 22.9 kW of 4.5 K refrigeration, which is below the ~ 25 kW plant size limit). This is to be compared to 4.41 MW installed power (equivalent to 20.1 kW of 4.5 K refrigeration) for the baseline design. The cost of the main linac cryo plants scale as the installed power to the 0.6 power, so for the half current option, the plants would cost about 8% more, or 27 M$ in total.

Cost Impacts (4)

- Civil
  - The AC power load in the service tunnel would scale by a factor of ((168 - 15)*(2.13/1.57)/2 + 15)/168 = 71% where 168 kW is the baseline power load per rf unit, 15 kW is the rack related power load per rf unit (assumed to be all LLRF related) and 2.13/1.57 is the rf pulse length ratio. The water and air cooling load would scale by a factor of 0.5*[(168 - 15)*(2.13/1.57) - 37]/(168 - 15 - 37) = 74% where 37 kW is the power transferred to the beam per rf unit in the baseline design. Assuming the electrical costs and the air and water cooling costs scale by these factors, the half current option would result in a savings of 149 M$.
- Installation
  - Assuming the cryomodule and rf system installation costs are roughly equal, halving the rf system would save about 50 M$ in installation costs.
- Net Savings
  - Summing the above cost savings yields a total of 71 + 115 - 11 - 27 + 149 + 50 = 347 M$ for the half current option.

Other Linac Cost Savings

- Decrease TESLA Cavity Aperture to 60 mm
  - Harder to tune cavities and 2-times higher wakes
  - Lower cryo-load and faster fill (50+ M$ savings)
- Half Diameter Quad and BPM
  - Wakes 10% higher, use superferric quads everywhere
  - Save 35 M$
- Second Generation RF System
  - Marx modulator (120 M$), sheet beam klystron (60 M$) and circulator-less rf distribution (15 M$), larger waveguide (60 M$).
- Soft energy limit (let uptime decrease as approach within a few percent of 500 GeV).
  - Save ~ 60 M$ per percent overhead
- Assume lower overhead for cryogenic system.
  - Save ~ 60 M$