HIE-Isolde Project Review (June 15-16 – CERN)

Final summary bullets: June 29, 2009

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- **General comments:**
  - The committee thanks the local team for the quality of the presentations and for their patient explanations
  - CERN has a tremendous amount of experience in niobium on copper sputtering technology developed during the LEP cavity preparation and an extensive experience in copper surface treatment
  - The choice of the biased diode sputtering technology represents a safe initial development stage of the program given that INFN-LNL is successfully operating Nb/Cu cavities produced with this technique albeit at a lower average gradient (Ep=22MV/m, Bp=44mT compared to 32MV/m and 58mT specified for the high beta and 32MV/m and 48mT for low beta). Achieving the specified gradient routinely may require refined procedures or new techniques. New techniques will require new prototypes. CERN has applied for EuCARD to develop quarter wave sputtering using a magnetron or other techniques and this R+D would benefit HIE-Isolde but also the world community as new material searches are ongoing to improve cavity performance while reducing production costs. Thin film technology is highlighting a number of new SRF development initiatives world-wide and it is forward thinking to maintain this expertise at CERN.
  - The choice of the sputtering technology for HIE-Isolde as specified would represent a state of the art demonstration of this technology; the anticipated high operating levels with reduced requirements on the fast tuner and rf systems and magnetic field suppression may represent a lower cost alternative to bulk niobium for some applications. It is well suited to this application and will represent a significant data point in the global SRF development
  - A clearer presentation of the anticipated gains of using sputtered Nb/Cu technology would help sharpen the focus of the R+D and motivate better the project goals and design choices.

- **Comment on R and D activities on-going**
  - Beam dynamics
    - The quadrupole asymmetry could be reduced and the TTF could be improved by adding a drift tube like structure at the end of the inner conductor. Some development may be required to optimize the shape for sputtering.
    - The beam steering compensation seems appropriate and the reduction in aperture is compensated by the racetrack beam port design.

    - Further study on the racetrack beamport design with realistic fields should be done with particular emphasis on the quadrupole asymmetry in the transverse rf fields
    - In parallel a comparison of TTF and shunt impedance as a function of bore diameter would be useful
- The first-order study shows the lattice design can provide beams with a minimal emittance dilution at the design energy of 10 MeV/u.
- Off line source for tuning would be a desired feature and/or the addition of improved diagnostics to help study the existing machine and commission the new machine
- The chosen linac transverse phase advance of 90degrees, residual field specification at the cavities and overall length limitation is driving a challenging solenoid strength. It is recommended that further studies be undertaken to reduce the maximum field strength to less than 9T so that NbTi technology can be employed.
    - The solenoid provides desired 90-deg phase advance for any $A/q \leq 3.5$. For $A/q=4.5$, the lattice can be tuned for 60-deg phase advance. While for $A/q \leq 3.5$ 90-deg can be applied even with 9-Tesla solenoids.
    - Generally, 60-deg lattice is less sensitive to the misalignment errors (probably, by factor of 2). In the proposed linac, the transverse emittance growth is likely due to the quadrupole component of the defocusing field, this can be canceled by introducing small drift tubes on the stem (like donuts as in TRUMF).
- Realistic field simulations of the high-energy section confirm the strength of the design and show the beam steering and asymmetric effects are not problematic.
- The stability of the cavity phase and voltage should be better than 0.5 degrees rms and 0.5 % rms in order to keep the longitudinal emittance growth less than 100 %. The LLRF specification should be much tighter than this, perhaps 0.1 deg rms and 0.1% rms (with peak values of 0.5 degree and 0.5 %) and these should be readily achievable. In any case the LLRF should be specified to keep the emittance growth to be no more than 20%.
- Element misalignments are quoted as requiring a static error of less than 0.5mm. This level of error can be corrected by imparting 6 mrad kick at the steerer positions. Since the sensitivities to cavity misalignment and solenoid misalignment are quite a bit different it is recommended that the specifications be given separately.
- The future recommended plan as presented is reasonable:
    - Study realistic low-beta cavity fields.
    - Introduce low-beta cavity fields into the simulations and assess error and misalignment tolerances of the entire linac
    - Introduce BPM errors into the correction routine.

        - Correlate cryomodule misalignment with the misalignment of the solenoid in order to account for a beam-based alignment of the cryomodule.
        - Cross-check error and misalignment study in TRACK

- Cavity development
    - The cavity parameter list represents a challenging but attainable specification and would represent the state of the art in sputtered heavy ion linac performance
        - In order to feel confident in the on-line performance an off-line test should show results 10-15% above these values
        - The high beta cavity is the most demanding of the two with peak magnetic field of 58mT along with a peak surface field of 32MV/m
    - A slightly reduced performance of the cavities would require more rf power (increased cryogenic load) or result in a reduced beam energy
    - The cavities are appropriately rounded at the peak rf current location to minimize Bp while improving the thin film surface quality
    - The beam port end of the cavity mirrors the approach taken at Legnaro where cavities have been successfully sputtered
        - Given that this is a relatively low current region and given the relative ease of fabricating the inner conductor end section it may be advisable to assume an end tube more like a drift tube. This may not be harder to sputter but would improve the transit time curve and help reduce the quadrupole asymmetry a source of transverse emittance growth due to coupling with the solenoid focussing.
    - Increasing the cavity length slightly would reduce the tuner sensitivity and the rf currents on the bottom tuning plate (see below)
    - A cavity passive damper should be studied to test whether a further reduction in microphonics may be gained
    - Plastic deformation of the finished cavity by pushing at the beam ports can be used to fine tune the final frequency removing the need for a large tuning range
- Rf ancillaries
    - The rf coupler range of motion seems adequate and the mechanical stability should be sufficient
    - The coupler as presented was defined as compatible with beta=200 but seems underdesigned for this factor. Thermal calculations of the heat deposited to the helium space should be done assuming various coupling factors; this would define the level of temperature staging that may be required

        - is the use of Macor standard for this application; the reviewers are familiar with AlNi or Shapel instead?
    - Rf tuner
        - The tuning sensitivity of the bottom tuning plate at 13kHz/mm should be adequate to meet the coarse tuning range required in the cavity. However it may be preferable to reduce this sensitivity somewhat to allow a reduced specification on the tuner resolution since in this case a tuner position change of only 1 micron corresponds to more than the expected full cavity bandwidth. A factor of two reduction would help. This would also reduce the rf currents on the tuning plate where thermal conduction may be limited due to a marginal pressed contact
- Solenoid
    - The solenoid specification is based on reducing the fringe field at the cavity to no more than 25μT at a maximum field of 12T. There are several comments:
        - The requirement that the residual field be less than 25μT is only required when the cavity goes through transition so as not to trap flux
        - It is possible that the Nb surface of the cavity could warm up above transition locally during a quench at high field. However:
            - Sputtered cavities are less likely to quench given their superior thermal stability
            - The quench would typically be at the high current region farther from the beam axis
            - A cavity quench is most likely to happen during cavity conditioning and in this case the solenoid can be off
            - Even if the cavity did quench and trap flux (extremely rare event) the cavity performance can still be recovered relatively quickly by attaching heaters to the cold mass elements
        - The sensitivity to the residual field at the cavity should be determined experimentally but in any case the TRIUMF cavities operate in a field of 40mT. The HIE-Isolde solenoid specification can be increased substantially without ill effect. This could result in an increase in solenoid length and lower the maximum field below 9T to utilize NbTi technology
    - It is advised to add a variable magnetic field in the TRIUMF cryostat and subsequently the Isolde test cryostat to test the Isolde cavity prototype during cooldown for trapped flux sensitivity

        - The current required in the solenoid is high compared to other similar applications. More windings would reduce this current and make the leads easier to engineer
    - Cryomodule
        - The cryomodule design as presented is in its early phase
            - Further attention should be paid to:
                - The side loading requirement presents engineering with a particular challenge; it appears solvable though a top-loading scheme seems more straightforward. In addition many labs are using the top loading scheme and so engineering solutions could be shared. The lack of a clean room with sufficient head room is driving this design choice.
                - The static load of 7W seems low compared to other cryomodules of similar size. It is recommended that the cryogenic system be designed for a static load of a factor of two higher.
                - The independently adjustable solenoid position is a nice feature and gives flexibility though may not be required if the solenoid dominates the positional tolerance
                - In general a thorough analysis of the heat loads and temperatures should be done
                    - Direct cooling of the main strongback may be required
                    - Heat load from the rf cable can be high; some thermal shielding may be required
        - Keep room in the overall layout for a cold trap at the entrance and exit of the linac
    - Cryogenics
        - The cryogenics scheme looks well thought out though complicated by the thermal shield circuit; it is recommended that a cooldown scenario be worked out for cooling the whole linac to determine whether the scheme works for the given expected heat loads and thermal masses
        - the addition of a storage dewar between the cold box and the main distribution system may add a useful isolation between the refrigerator and the linac for a modest cost
        - the active and static heat loads are 65% of the expected refrigerator power; this is at the optimistic end of design practices and may represent a vulnerability during periods of degraded refrigerator performance or if the cavity performance is below design specifications
        - a pre-cooling spider manifold can be employed for faster cooldown
    - Low level rf

        - The SEL implementation for cavity startup and conditioning is a good idea
        - The in house cavity cryostat can be used for LLRF development
        - Tighter specifications may be required on the LLRF performance after the beam dynamics study is completed
- **Comment on what is left to be done before moving to the construction phase**
    - Presented as a homework assignment to Matteo
        - Matteo's list
            - Beam Dynamics: Definition of all the optics parameters for the accelerator, matching section, beam transfer lines, alignment tolerance, cavity geometry and definition of easy tuning procedures.
            - Cavity development: high beta and low beta cavity prototypes fully equipped with tuner and coupler tested in the single cavity cryostat configuration. Tests on microphonics, external magnetic field sensitivity. New LLRF system developed and tested with the cavity prototypes.
            - Cryomodule: cryomodule prototype (demonstrator) to be equipped with 5 cavities and a solenoid. Definition of the assembly procedures, tooling and diagnostics for the cryomodule.
            - Beam diagnostic systems: Intensity, profile/position, phase and energy monitors, especially for the very low intensity beams.
            - Solenoid prototype and cold test
        - Committee reinforces the following:
            - Beam dynamics studies
                - Beam dynamics study of the room temperature linac during beam development periods to understand the machine. Should have priority as a required stage in the HIE-ISOLDE project
                    - match to beam tests
                    - off-line ion source may help here and/or improve the diagnostics to help diagnose the beam quality in the room temperature machines
                - full three dimensional beam dynamics with machine errors
                    - study 90 degree phase advance and 60 degree phase advance with errors
                - investigate 9T solenoid option be re-evaluating the solenoid fringe field specification
                - investigate the correction of quadrupole asymmetry by adding a beam drift tube; some hardware tests on the sputtering of the new shape will also be required

- First level of hardware priority:
    - Continue thin film R+D to improve surface characteristics and enhance rf performance by reducing surface resistance
    - Complete the prototype cavity and arrange a cavity test at TRIUMF
        - Recommend that the cavity test include provision to add a magnetic field to test the sensitivity of the cavity to trapped magnetic flux
    - Design and build a test cryostat and set up a small test lab
        - Initiate a small R+D program in cavity processing optimization, cavity conditioning, rf ancillaries including rf power couplers and rf tuners and the LLRF system as well as experience with helium transfer and cryomodule sub-systems
- second order priority
    - Cryomodule design with side loading capability; estimate of engineering issues
    - Beam diagnostics: weak beams, compatible with low-particulate clean assembly.
    - Mechanical design of the inter-cryomodule space: diagnostic box, steerer and valves.