SUPERCONDUCTING SUPER COLLIDER LABORATORY SSCL RFQ to DTL Input Matching Section

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Abstract

SSCL has completed the preliminary design of the RFQ to DTL matching section for the SSC. The matching section matches a 2.5 MeV H⁻ beam to the acceptance of the DTL. The design is comprised of two double-gapped bunching RF cavities, four variable field permanent magnet quadrupoles (VFPMQ), two primary diagnostic chambers, and a vacuum beam line which integrates other diagnostic instruments such as beam position monitors and beam current toroids. The entire design is integrated in a limited longitudinal space of 54 cm. The double-gapped cavities operate at 428 MHz at a power of 25 kW. Their compact size permits integration into a standard-sized chamber. Four VFPMQ's, developed by Los Alamos National Lab, are used as the beam focusing and steering elements. The magnets achieve a maximum GXL product of 4.0 Tesla. Gradient variability is achieved through a rotating outer magnet ring. Linear actuation of each magnet in its focus degree of freedom permits beam steering. The two diagnostic chambers can accommodate up to eight actuated instruments. One chamber is located after the second quadrupole magnet; the second is located after the fourth quadrupole magnet. The vacuum beam line is achieved using bellows, beam tubes, and various seals. Ion pumps located on the RF cavity chambers achieve the required 3.3E-7 Torr vacuum.

RFQ/DTL Matching Section Requirements

Sethi et. al.[1] establish the primary goals for the matching section design as:

- Match the 2.5 MeV beam to the acceptance of the DTL
- Experience a minimal growth in beam emmittance
- Accommodate changes in the beam and its parameters
- Provide the necessary beam diagnostic devices

The physics design of the matching section resulted in a section which spans 580 mm from the last radio frequency quadrupole(RFQ) vane to the leading edge of the first fixed-field permanent magnet quadrupole(PMQ) housed in the drift tube LINAC(DTL) endwall. The endwall of the RFQ is an octagonal chamber which houses a vacuum gate valve and four ports for beam diagnostics. This chamber extends longitudinally 46 mm. The remaining 534 mm is the longitudinal space available for the matching section. Within this distance, the section must integrate several components:

- 428 MHz Buncher RF Cavities(2)
- Variable Field Permanent Magnet Quadrupoles(VFPMQ) (4)
- Diagnostic Chambers(2)
- Vacuum Gate Valve(1)
- Beam Position Monitors(BPM)(3)
- Beam Current Toroids(2)

Only six of these devices, the two bunchers and four quadrupoles, affect the dynamics of the 2.5 MeV H⁻ beam emanating from the RFQ. From an engineering standpoint, these components become the limiting design factors since their position size and parameters are driven primarily by beam physics.

The two buncher cavity gap centers are located 165 mm and 415 mm respectively from the end of the last RFQ vane. The required buncher operating frequency is 427.617 MHz, and the maximum required cavity voltage is 230 kV.

The longitudinal centers of the quadrupole magnets are located 100 mm, 230 mm, 350 mm, and 480 mm respectively from the RFQ vane. To limit emmittance growth, each quadrupole has an effective magnetic length of 40 mm and a GXL product variability of 0.8 - 4 Tesla. Each quadrupole magnets translates ± 2 mm in one degree of freedom to achieve beam steering. Thus, the four magnets form two focus/defocus pairs. Other important requirements for the matching section are summarized in Table 1.

Table 1
Matching Section Requirements

Buncher Frequency	427.617 MHz
E_0TL	140 Kv
Cavity Operating Temp.	40.5 ± 0.5 °C
VFPMQ GXL Product	0.8-4 Tesla
VFPMQ Translation	± 2 mm
Effective Magnetic Length	40 mm
Beam Line Vacuum	3.3 E-07 Torr
Component Transverse Alignment Error	± 0.1 mm

Meeting these requirements achieves the primary goals of the matching section. However, the restrictions on beam

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emmittance growth severely limits the available longitudinal space for the necessary components. This has proved to be the primary engineering design challenge of the matching section.

Alternate Designs

Two preliminary designs were considered for the matching section. The first design uses single-gapped, pillbox-type buncher cavities with a Q of 20,000 and maximum pulsed power of 30 kW. The VFPMQ's have an effective length of 40 mm and a mechanical length of 38 mm. The bore is kept to a minimum value of 18 mm to accommodate a 16 mm beam aperture and a beam tube with 1 mm wall thickness. The beam tube must translate with the VFPMQ's which are supported by the buncher cavities using cross slides. The beam tubes are connected by bellows.

One difficulty with this design is the pressure deflections of the 454 mm diameter bunchers. The axial load on each face of the buncher is nearly 16.76 kN resulting in large static pressure deflections which would unacceptably shift the cavity resonant frequency. So, the cavities were reinforced using steel ribs. With these ribs, a finite element analysis of the structure predicts a cavity frequency change of 240 kHz. Moreover, the ribs and supporting ring reduce the available longitudinal space for VFPMQ integration and actuation.

The design was further modified by placing the buncher cavities in a vacuum vessel. This eliminates the pressure loads on the buncher as well as the need for vacuum beam tubes; however, several problems are encountered with this design. First of all, 26 vacuum feedthroughs are required for VFPMQ actuation, water lines, electrical lines, and RF drive lines. Secondly, due to the limited longitudinal space, the vacuum vessel exit endwall serves as a diagnostics chamber. The design becomes quite complicated with the addition of the vacuum vessel. Installation and removal of the section would be difficult. Also, several components are inaccessible after installation, necessitating removal of the entire section for access. In addition to cost and schedule concerns, the overall maintainability and reliability of the section was in question

Therefore, a second design option was pursued wherein a significant change was made to one of the design-limiting components. The second preliminary design employs a rectangular slabline quarter wave resonator as a double-gapped bunching cavity. The volume for this cavity is one tenth of that required for the pillbox cavity originally considered. Accordingly, pressure loads on this cavity or any chamber housing this cavity are greatly reduced. The buncher can be more easily integrated in the limited longitudinal space of the matching section. This eliminates the need for the large, encompassing vacuum vessel.

Additionally, it was found that the bore diameter of the VFPMQ's need not be maintained at a minimum of 18 mm. Los Alamos National Lab(LANL) has developed a magnet design which achieves the desired VFPMQ performance using a 24 mm bore. In this way, the VFPMQ's may be translated independently of the beam tube. We have judged this matching section design to be superior to the other preliminary designs in performance, maintainability, reliability, and cost. This design is currently being developed for installation in the SSCL LINAC.

Double Gapped Buncher Cavities

The double-gapped buncher consists of a 12 mm diameter center-conducting shaft supporting a cylindrical ring. The outer conductor is a rectangular box with the minor axis along the beam line. "MAFIA" simulations of the cavity indicate that the required value of E_0TL can be achieved with a peak power of 20 kW.

With the significant reduction in cavity volume, the cavity can be integrated to the beam line as a stand-alone device. Preferably, the bunchers may be housed in a small vacuum chamber eliminating pressure deflections completely. Serendipitously, the resulting dimensions of the cavity are such that it fits in an octagonal diagnostic chamber designed for several sections of the LINAC. The chamber serves as a vacuum vessel and permits a thin wall thickness for the buncher outer conductor. The bunchers may then be installed and removed from the beam line as a module. If desired, the bunchers could be removed and replaced with additional diagnostic instruments. A level of commonalty in beam instrumentation is thus achieved between the various LINAC sections.

The buncher assembly features a manually actuated slug tuner with a vacuum feedthrough for in-situ capacitive tuning. The cover plate supports the center conductor as well as a loop coupler and a phase monitor probe both with vacuum windows. Water channels will be brazed to the cap and extend the length of the center conductor for temperature stabilizaton of the cavity. Preliminary material choices for the buncher fabrication include: Oxygen-free Cu for the buncher cap and outer conducting box for improved heat transfer and a Cu- plated steel center conductor for strength and reduced vibration. The bunchers will be installed at 45° with respect to the vertical.

Temperature and Frequency Stabilization

The aforementioned cooling channels will stabilize the operating temperature of the bunchers. However, this operating temperature will not be regulated by use of a separate temperature control unit(TCU). Instead, water flow will be extracted from the TCU of the RFQ. The temperature of the bunchers will then float with the setpoint of the inlet water supplied to the RFQ. Since the Q of the buncher cavities is relatively low and the impedance bandwidth high, small fluctuations in the buncher operating temperature will not effect the performance of the buncher. The expected worst case change in the supply water temperature based on the fluctuations in the ambient environmental conditions surrounding the RFQ is 0.4° C. This causes a change in buncher frequency of 2.85 kHz. In this way, there is no need for a separate TCU for the matching section.

VFPMQ's

Los Alamos National Labs(LANL) is developing the VFPMQ's as well as the integrated slide and motor package for the matching section. Kraus and Campbell[2] describe the design and fabrication of VFPMQ's at LANL. For this design, SSCL requested a 24 mm pole tip bore in order to achieve magnet steering without moving the beam tube. The magnetic design developed by LANL employs Neodymium Iron Boron magnets and soft magnetic pole pieces(C-1006). The magnetic outer diameter is 124 mm, the effective magnetic length is 40 mm. This design has a multipole content of less than 1% of the field.

The preliminary mechanical design calls for a stepper motor-driven worm gear to rotate the outer ring. Translation will be achieved through a linearly actuated slide mechanism integrated with the VFPMQ housing. LVDT's and RVDT's may be used for supervisory control feedback. The motor and slide package will be integrated external to the space between the octagonal chambers.

Buncher and Diagnostic Chambers

There are essentially five chambers comprising the matching section. The first are two tiered cover plates which interfaces to the RFQ endwall. The evacuated volume defined by these plates provides enough room for a BPM and a beam current toroid. The next three chambers are nearly identical octagonal chambers all sharing a common support. Each chamber has four flanges oriented at 45° with respect to vertical. The flange openings are rectangular and measure 50 mm X 93 mm. Two pin holes are available for precision location. The first and third of these chambers house the buncher cavities and provide connection flanges for vacuum components. The center chamber dedicates all four ports for diagnostic instruments. The cover plates on each box permit access to components and ease of assembly. Metal vacuum seals are compressed by each cover plate. The cover plates on the chambers housing the buncher cavities may be used to support the VFPMQ's . The three chambers share a common support plate.

The last chamber at the exit end of the matching section is cantilever-supported by the first DTL tank. This design is necessitated by the limited longitudinal space available between the fourth VFPMQ and the leading edge of the DTL endwall. A cover plate provides access to this chamber. Again, four flanges located at 45° with respect to vertical are available for diagnostic instruments. This chamber has a narrower flange opening of only 20 mm X 93 mm. An internal plate downstream from the diagnostics chamber provides a seat for a pneumatically actuated gate valve. The chamber bolts to the DTL endwall compressing a metal vacuum seal. With this design, the RF conducting surface of the DTL endwall experiences reduced deflection from pressure and seal loading.

Vacuum System

The preliminary design of the vacuum system calls for two ion pumps, one manifolded to each of the chambers housing the buncher cavities. Vacuum gauges will be located on available flanges on these chambers as well. The aforementioned gate valve isolates the matching section and DTL vacuum. This vacuum seal is achieved using an elastomer seal compressed by a wedge. The shaft is offset due to longitudinal space constraints and is coupled to the pneumatic actuator prior to installation.

The beam line is composed of four sections of beam tube. Each section has bellows on one end and a demountable, three-point metal seal on the other. The bellows provides for misalignment and thermal expansion. The demountable seal permits assembly of the beam tube through the 24 mm bore diameter of the VFPMQ. The seal is achieved by threading a nut to the cover plates and displacing a keyed bushing to compress the metal seal. A lock nut on the end of the beam tube prevents slippage.

Support and Alignment

The two tiered cover plate, inlet BPM and toroid are all supported by the RFQ. The exit diagnostics chamber is cantilevered from the DTL endwall. The only matching section components requiring independent support are the middle three octagonal chambers housing the cavities and the center diagnostics. The chambers will share a common support plate. The base plate will be keyed longitudinally, so chambers may be longitudinally positioned with transverse position fixed. The alignment of the chambers on a common beam axis will depend upon the machining tolerances of the octagonal faces and flanges of the chambers as well as the flatness of the base support. By wire EDM machining the octagonal chambers and grinding the base support, we expect to hold tolerances well below the required 0.004" absolute allowable error. This is necessary since random fiducialization and geodetic alignment errors will add in quadrature to establish the total positional error.

The base support will be adjusted using a six strut support system similar to that used throughout the LINAC. The rod ends are oppositely threaded with one rod end coarsely thread and the other fine. The resolution is determined by the difference in pitches. By using spherical rod ends, the system is uniquely constrained and cannot stress the structure. Likewise, no thermal stress can be developed in the matching section as a result of constraint. The six struts attach the support plate to a base plate which will connect to the LINAC facility floor by a support stand.

Status and Schedule

The preliminary design has been completed for the matching section. We are now working to develop fabrication drawings for a critical design review in mid October of '92. Fabricated hardware is to begin arriving at SSCL by mid March '93.

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References

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