THE NSNS FRONT END ACCELERATOR SYSTEM*

John W. Staples
Lawrence Berkeley Laboratory, Berkeley, California 94720

ABSTRACT

The National Spallation Neutron Source (NSNS) front-end accelerator comprises a 65 keV LEBT, a 2.5 MeV RFQ and a matching accelerating a 55 mA H^- beam with a 6% duty factor. Critical design issues are the 6% beam duty factor, the 5 free space-wavelength long 402.5 MHz RFQ, and nanosecond chopping of the beam before it enters the first DTL. The conceptual design of the front-end systems will be presented, with experimental validation of some of the proposed subsystems.

NSNS CONFIGURATION SUMMARY

The NSNS front end provides a 2.5 MeV, 28 mA H^- beam at 6% duty factor to the rest of the 1 GeV linac, supplied by LANL, which in turn injects a 1 GeV storage ring. Approximately 1200 turns of H^- beam is accumulated into the storage ring by stripping injection, then extracted in a single turn, supplying 1 MW of average beam power to a neutron production target at a 60 Hz pulse rate. Future options increase the front-end beam current to 55 mA for 2 MW power at the target, and then further double the beam power to 4 MW by funneling two injectors together at the 20 MeV point.

The Front End comprises the ion source, (described elsewhere in these proceedings [1],) the electrostatic LEBT, the RFQ and the MEBT including a fast beam chopper.

LEBT (LOW ENERGY BEAM TRANSPORT)

The LEBT will transport up to 70 mA of beam from an rf-excited volume ion H^- source to the RFQ operating at 6% duty factor. The LEBT comprises an electrostatic extraction gap, followed by two einzel lenses with a final output energy of 65 keV within a length of 10 cm.

To permit chopping in the ion source and the LEBT and to eliminate neutralization turn-on time, the beam will be fully unneutralized. The entire LEBT is electrostatic, with a high-voltage extraction gap followed by two sets of einzel lenses with a minimum aperture-to-beam diameter ratio of approximately two.

*This research is sponsored by the Lockheed Martin Energy Research Corporation under the U.S. Department of Energy, Contract No. DE-AC05-96OR22464, through the Lawrence Berkeley National Laboratory under Contract No. DE-AC03-6SF00098.

Figure 1 shows the trajectory of a 28 mA H- beam from the ion source plasma boundary (left) to the start of the RFQ vane. A transverse field at the split einzels deflects the beam up to 25 mrad with an emittance increase of less than 10% [2]. Beam chopping is included by applying a ±3 kV square wave across opposing quadrants of either einzel lens. Transverse steering is accomplished by moving the entire ion source-LEBT assembly on a sliding joint at the LEBT-RFQ interface while the LEBT is under vacuum.

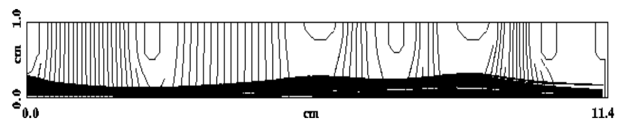

Figure 1. 28 mA Beam Envelope in LEBT

A five-segment Faraday cup, doubling as a beam stop, and a vacuum gate valve will be included in the 1 cm space between the last einzel electrode and the RFQ entrance flange. The Faraday cup will comprise a center button and an outer ring, divided into four quadrants. Half the beam will target the center button, and the rest of the beam will be divided on the other four quadrants. The last einzel lens will be brought to ground potential when the Faraday cup is swung in from the side, which will not significantly alter the beam size at the Faraday cup position. The vacuum valve will isolate the RFQ from atmospheric pressure during ion source maintenance.

RFQ

The RFQ accelerates the 35-70 mA H^- beam from 65 keV to 2.5 MeV. A 59 mA input beam with rms normalized emittance of 0.2 π mm-mrad results in 55 mA accelerated, a transmission efficiency of 93%. The long buncher section produces an rms longitudinal output emittance of 89 keV-degree at 55 mA output without increasing at the 28 mA level due to bunch overcompression.

The vanetip geometry uses a constant-transverse radius design with $\rho_T = r_0 = 0.336$ cm. This results in very low multipole error fields for this particular design, as the emittance blowup in the RFQ is less than 10% at 55 mA. The constant transverse radius vanetip is a great convenience, as it permits cutting the vanetip shape with a form cutter, reducing the risks of variable radius vane cutting. The minimum longitudinal radius is 1.49 cm, a very easy radius to accommodate with a form cutter.

The two most challenging aspects of the RFQ are the 6.1% beam duty factor, and the 3.7 meter length, corresponding to 5 free-space wavelengths.

Previous LBNL-built RFQs have strapped opposing vanes together with vane coupling rings (VCRs), which move the dipole frequencies away from the TE_{120} quadrupole mode, significantly relaxing the assembly tolerances. For this RFQ, the high duty factor prompted us to select pi-mode stabilizers, used successfully on the high duty-factor Japanese Hadron Collider RFQ injector, instead of VCRs.

The pi-mode stabilizer, pioneered at KEK, consist of pairs of rods placed through the RFQ, alternately in the horizontally and vertical planes [3]. Operating experience with the KEK RFQ using pi-mode stabilizers show that the maximum contamination of the desired quadrupole field configuration by both dipole modes and unwanted longitudinal tilt from high-mode longitudinal modes is less than 1%. That RFQ is four free-space wavelengths long, this one is five.

A power of 590 kW excites the cavity to 76 kV peak voltage between the vanetips, including an additional 50% margin for actual cavity losses compared to theoretical losses in the Glidcop© AL-15 cavity material. With 55 mA accelerated beam to 2.5 MeV, an additional 135 kW is required, for a total of 725 kW, with 19% beam loading.

A 1-MW 402.5 MHz klystron will provide power to a 21-inch waveguide, which will be split into eight 3-1/8 inch semi-flexible coaxial feeds, each driving the RFQ at 8 drive ports with loop couplers, located in pairs along opposing sides the RFQ.

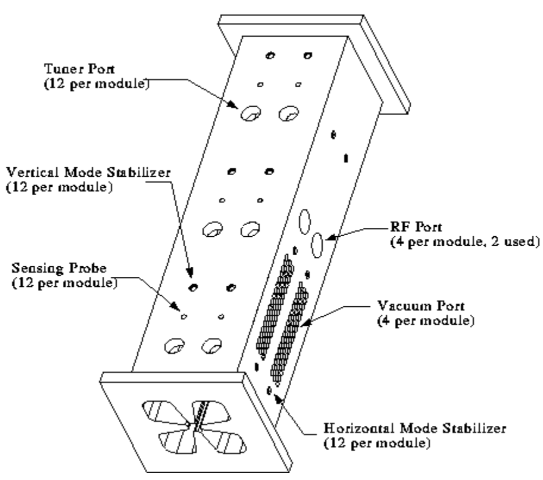

Figure 2. One 1-meter-long RFQ module

The high r.f. duty factor results in an average power dissipation of 1.9 watts/cm^2 in the outer wall of the cavity with hot spots at the ends of the vanes of up to 6 watts/cm^2.

Each module will have water cooling passages gun-drilled in the 93 cm long section from both ends, and then brazed shut at the ends. Connecting water passages will be bored radially from the outside. The steady-state temperature variation in the RFQ body is less than 3° C and the material stress is below 600 psi.

Four vane-cavity segments are brazed together to form a 93-cm long module Each vane-cavity segment is machined from a solid block of Glidcop, insuring that the vane tip and the joint to adjoining sections are in close dimensional tolerance with each other, a technique proven in a previous 400 MHz RFQ built at LBNL [4].

The mechanical design eliminates demountable r.f. joints in regions of high r.f. wall currents by brazing four Glidcop pieces together forming each RFQ module. The entire RFQ will be assembled of 4 of these brazed modules with demountable vacuum and r.f. joints. The four RFQ modules will be joined with a circumferential Helicoflex vacuum and r.f. seal, and the vanes themselves by sections of canted spring ring. The Helicoflex seal will be surrounded by a back-up O-ring vacuum seal. Figure 2 shows the intermodular joint.

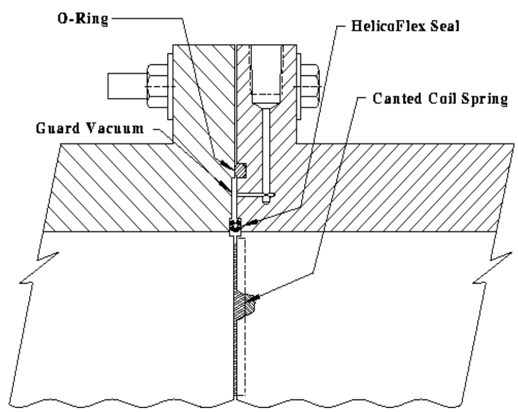

Figure 3. RFQ intermodule rf and vacuum joint

Vacuum ports are arrays of holes and will be machined symmetrically in all 4 quadrants to guarantee r.f. symmetry. Local tuners will be used to compensate the depressed cutoff frequency of the RFQ waveguide to level out variations in the vane tip voltage distribution. The RFQ vacuum will be in the 10^{-7} Torr region.

The RFQ will incorporate 48 tuners, 3 per quadrant in each of the four modules each with an active piston area of 2 cm^2 and a motion range of ±2 mm. The r.f. sliding contact will be similar to that of the PEP-II tuners, which operate at about 476 MHz with a 100% duty factor in cavities with similar wall power density as ours. Those tuners use silver-plated Glidcop r.f. contacts sliding on rhodium-plated surfaces of the copper tuner body.

A full-scale prototype RFQ will be built and operated at LBNL with beam for an prolonged test period to uncover any problems with the design. A production RFQ will then be made and incorporated into the actual NSNS injector system. The mechanical design is further discussed in a companion paper at this conference [5].

MEBT (MEDIUM ENERGY BEAM TRANSPORT)

The MEBT transports the 2.5 MeV, 402.5 MHz r.f. bunched and 1.2 MHz chopped beam from the RFQ to the DTL. A major MEBT function includes the 2.5-5 nsec, 1.2 MHz beam chopper. (Two slower risetime choppers are located upstream in the ion source and the LEBT.) The tandem operation of the choppers provides an on/off intensity ratio of $1:10^{-5}$.

The first traveling-wave chopper deflects the beam off the axis; the second chopper deflects the beam back parallel to the axis. This chopper-antichopper combination insures that deviation from perfect waveform in the chopper (ringing) will not cause axis shift of the beam itself as it enters the DTL. The traveling-wave choppers and their 2.5 nsec rise/fall, 900-volt power supplies will be designed and constructed by LANL.

The most stringent MEBT design requirement is preservation of transverse emittance from the RFQ to the DTL. The average linear external focusing force provided by the quadrupoles is strong in comparison to the nonlinear space-charge forces, making the MEBT relatively space-charge independent. The quadrupole filling factor in the beam line is high, requiring all the other MEBT equipment fit in narrow inter-quad gaps.

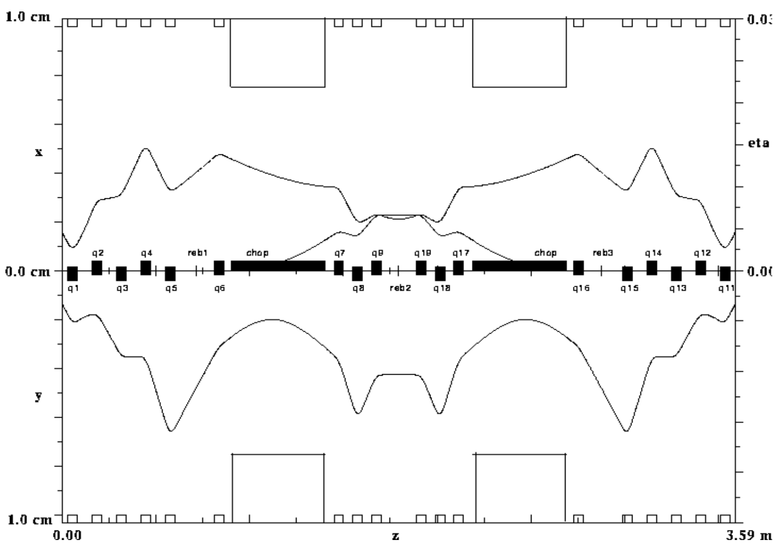

Figure 4. Beam Envelope in MEBT

The six quadrupole system at the beginning of the MEBT slowly relaxes the very rapid phase advance the beam experiences in the RFQ. The focusing system matches the beam size in the chopper by placing a waist in the transverse plane in the middle of the chopper, and minimizes the beam size at the exit of the chopper in the deflecting plane, producing a minimum beam size to maximum beam displacement at the chopping aperture (“chopper stopper”).

The quadrupoles have a 1 cm pole tip radius and an effective length of 5 cm. The quadrupoles will be of two types, and will allow at least a ±30% field variability. The quads with less than 3 kG poletip field will be simple iron-core, water-cooled EM design featuring end-clamps. The highest-strength quads will use permanent magnets with variable energization from additional PM material connected to a rotatable outer soft iron ring. Both designs must operate in vacuum, and six of the quadrupoles will provide beam steering by adjustable transverse offset.

Figure 4 shows the beam envelope in the MEBT. The two long objects are the chopper and the antichopper. Three 402.5 MHz rebuncher cavities are in the other large gaps. The peak gap voltage on the first and third cavities if 55 kV, with the central cavity operating at 35 kV. The peak r.f. power requirement is 15 kV at 35 kV gap voltage.

The beam line alternates quads and short beam boxes. Rather than combining all the quads together in a single package inside a common vacuum chamber (“coffin”), the quads are mounted around sections of vacuum pipe between short diagnostic beam boxes with some quads inside the short beam boxes. This technique isolates sensitive diagnostic equipment from the strong electromagnetic interference generated by the bunched beam in the environment of large beam boxes.

Diagnostic equipment will occupy the short beam boxes between the quadrupoles. These diagnostic devices will include slit-type emittance measurement equipment, Faraday cups, flying wires, beam toroids, residual-gas profile monitors and a beam stop.

ACKNOWLEDGMENTS

This work was aided by efforts of Rick Gough, Matt Hoff, Alex Ratti, Craig Fong, Ka-Ngo Leung, Daniela Wutte and Matthaeus Leitner with additional assistance from Steve Lewis, Martin Fong, Ross Schlueter, Mike Green, Dave Humphries, Sam Mukherjee, Greg Stover and Jim Hinkson.

REFERENCES

[1] Ka-Ngo Leung et al, this conference.

[2] J.W.Staples, M.D.Hoff and C.F.Chan, *All-Electrostatic Split LEBT Test Results*, Linac 96.

[3] A. Ueno et al, *Beam Test of the Pre-Injector and the 3-MeV H-RFQ with a New Field Stabilizer PISL*, Linac 96

[4] S. Abbott et al., *Design of an Integrally Formed RFQ*, 1989 PAC.

[5] M. Hoff et al, *NSNS RFQ Mechanical Design*, this conference.