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# MECHANICAL DESIGN OF THE SNS MEBT\*

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## Abstract

The Lawrence Berkeley National Laboratory (LBNL) is presently designing and building the 2.5 MeV front end for the Spallation Neutron Source (SNS). The front end includes a medium-energy beam transport (MEBT) that carries the 2.5 MeV, 38 mA peak current, H<sup>-</sup> beam from the radio frequency quadrupole (RFQ) to the drift tube linac (DTL) through a series of 14 electromagnetic quadrupoles, four rebuncher cavities, and a fast traveling wave chopping system. The beamline contains numerous diagnostic devices, including stripline beam position and phase monitors (BPM), toroid beam current monitors (BCM), and beam profile monitors. Components are mounted on three rafts that are separately supported and aligned. The large number of beam transport and diagnostic components in the 3.6 meter-long beamline necessitates an unusually compact mechanical design.

## 1 PHYSICS REQUIREMENTS

The SNS is an accelerator-based user facility that will produce pulsed beams of neutrons for use in scattering experiments. LBNL has designed and is fabricating the Front-End Systems (FES) comprising an ion source, low-energy beam transport (LEBT) with a pre-chopper, 402.5 MHz RFQ, and MEBT. The FES will accelerate a 38 mA, 6% duty factor, H<sup>-</sup> ion beam to 2.5 MeV for injection into the 1 GeV linac [1].

The MEBT lattice matches the beam from the RFQ through two fast traveling wave choppers into the first tank of the DTL. The 35-cm long choppers perform the final beam chopping that prevents beam from intercepting the septum of the extraction kicker magnet in the accumulator ring during its rise time. A closely spaced lattice with strong focusing is required to minimize emittance growth, due to the nonlinear charge distribution of the beam and the 62-cm drifts required for insertion of the choppers [2]. The layout of the beamline has been optimized to minimize emittance growth while taking into consideration the mechanical implications of closely spaced transport components and diagnostic devices.

The MEBT lattice consists of fourteen quadrupole magnets, four rebuncher cavities, two traveling-wave choppers, and a chopper target that intercepts the deflected beam (see Figure 1). Four quadrupoles, one

rebuncher, and one chopper are mounted on the first and third rafts, with the remainder of the components arranged symmetrically on the second raft. Six quadrupoles, the first and last magnets on each raft, incorporate dipole steering to correct for misalignments between rafts. Diagnostic devices located between transport components monitor beam quality during operation and enable tuning of the MEBT itself.

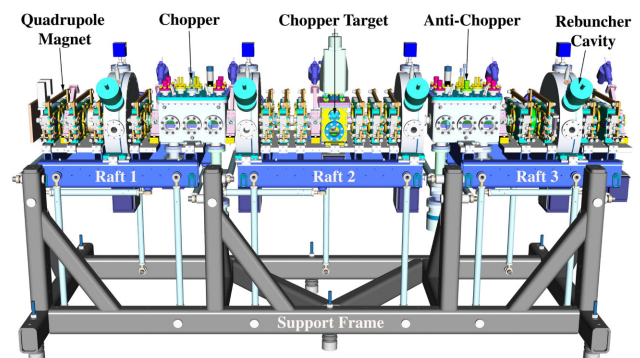


Figure 1: The MEBT beamline layout.

While the beampipes have clear bore diameters of 3 cm on the first and third rafts, those on the second raft have diameters of 4 cm in order to accommodate the vertically displaced trajectory of the chopped beam.

## 2 TRANSPORT COMPONENTS

Physically compact devices have been devised, with careful consideration for mounting and alignment features in order to accomplish the positional accuracy and tight longitudinal spacing necessitated by the goal of minimal emittance growth.

### 2.1 Quadrupole Magnets

The physical envelope of the quadrupoles was tightly constrained by the available longitudinal space and the fit with the beam position monitors (BPM) and beampipes that it surrounds. The design of the MEBT quadrupole is derived from the Los Alamos National Lab (LANL), prototypes developed for APT [2]. The six magnets on the second raft have bore diameters of 4.2 cm. The remaining magnets on the first and third rafts have bore diameters of 3.2 cm. The magnet cores consist of quadrants machined from 1006 low carbon steel. Dowel pins and bolts, spanning the horizontal and vertical centerlines, index and hold together the four quadrants. After conventional machining of the quadrants and surface grinding of the length-wise planes of each core

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assembly, the pole tip surfaces, mounting feet, and fiducial notches in the outer corners are cut by wire EDM to a profile tolerance of 0.076 mm. The epoxy impregnated quadrupole coils fit closely around the quadrants with power and cooling water connections on both horizontal sides of the core. Six of the fourteen magnets contain back-leg dipole steering coils. The design of the core and coil connections (see Figure 2) allows the magnet to be disassembled into two halves and reassembled around a beampipe or BPM, without changing the position of the magnetic center with respect to the fiducial surfaces.

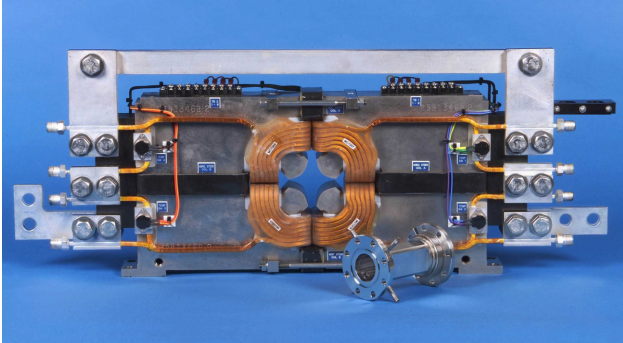


Figure 2: 3.2-cm bore quadrupole and 3- cm BPM.

All quadrupoles have been fabricated at LBNL, and magnetic measurements have shown the field quality and integrated focusing strength of all magnets to be well within specification.

## 2.2 Rebuncher Cavities

The 402.5 MHz rebuncher cavities have beam aperture diameters of 3 cm on the first and third rafts and 3.6 cm on the second raft. JP Accelerator Works, Los Alamos, NM, is designing and building the type-TM010 pillbox cavities. Each cavity assembly consists of a copper-plated 304 stainless steel body and lid. The bolted connection between these two parts contains stainless steel spacers, a silver-plated inconel C-seal to ensure RF contact, and a viton O-ring that creates the vacuum seal. Coarse frequency adjustment is achieved by varying the thickness of the spacers. Stepper motor driven slug tuners will achieve finer tuning with continuous adjustment during operation. All power, water cooling, and vacuum pumping connections are located on the outside diameter of the cavity, enabling the assembly to fit within the 13-cm beamline insertion length. One 3-cm cavity has been delivered and is currently undergoing testing at LBNL.

## 2.3 Chopper Structures

The fast traveling wave chopper assemblies, to be supplied by LANL, consist of two meander-line structures spaced 1.8 cm apart [4]. The meander-line pattern is chemically etched in the copper coating of a dielectric plate that is epoxy-bonded to an aluminum backplate. Water cooling dissipates approximately 19 watts of heat generated per assembly. Vacuum chambers mounted on

the first and third rafts contain the chopper structures. The assemblies are hinged at one end and mounted to an adjustable micrometer feedthrough at the other end to enable pitch adjustment during tuning.

## 2.4 Chopper Target

During SNS operation the deflected beam will deposit an average power of less than 400 watts on the chopper target. However, the peak power density in the core of the beam will exceed  $200 \text{ kW/cm}^2$ . This high instantaneous power and the limited longitudinal space available in the beamline to spread out the chopped beam posed significant thermal and mechanical design challenges [2]. Material selection was limited by the fact that copper and its alloys could not be exposed to the beam, as copper-65 has a neutron production threshold of 2.1 MeV for incident protons.

The design utilizes a grazing angle of  $75^\circ$  from normal to decrease the instantaneous heat flux. The TZM (Mo-0.5Ti-0.1Zr) faceplate contains cooling channels 1 mm wide by 4 mm deep, machined by EDM on a 2 mm pitch. The TZM backplate contains water inlet, outlet, and exchange plenums that circulate water through the cooling passages at a flow velocity of 15 ft/sec. The faceplate is brazed to the backplate and cut by wire EDM to create a 1-mm thickness of material between the front surface and the bottom of the cooling passages (see Figure 3).

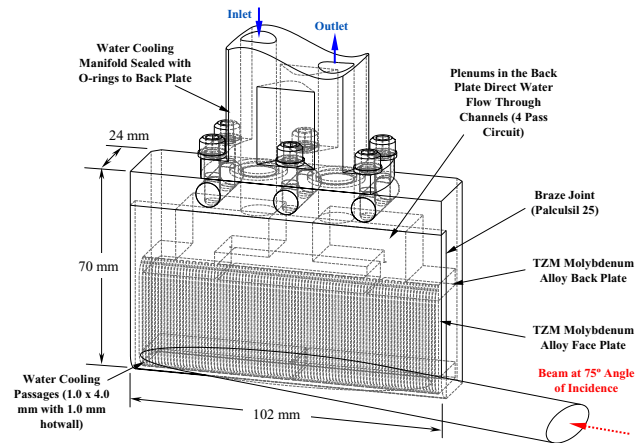


Figure 3: The MEBT chopper target.

The target was designed for a peak operating current of 52 mA. At a peak current of 52 mA, a 1-msec long beam pulse would raise the front surface of the target to a temperature of  $206^\circ \text{C}$ . Differential, transverse, thermal expansion would create a Von Mises Stress in the faceplate of 271 MPa, 65 % of the yield strength of TZM, including a derating for temperature and fatigue loading. The reduction of the FES peak current requirement to 38 mA by the SNS collaboration should reduce the peak surface temperature to  $106^\circ \text{C}$  and the peak surface stress to 93 MPa [3]. The target assembly is suspended in its vacuum beambox from a stepper motor driven bellows feedthrough and can be vertically adjusted during tuning by increments as small as 0.02 mm.

## 3 BEAM DIAGNOSTIC DEVICES

### 3.1 Beam Position Monitors

Six quadrupole magnets in the MEBT will contain shorted stripline BPM's (see Figure 4) [5].

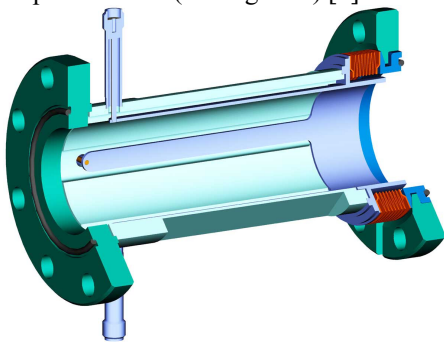


Figure 4: A sectional view of the BPM assembly.

The 316 stainless steel assemblies are externally TIG welded. The TZM central conductors of the SMA microwave feedthroughs are spot welded to the ends of the striplines. Radial shims between the quadrupole pole tips and precisely machined flats on the outside of the bore tubes will center and hold the BPM assemblies in the magnets. A welded bellows, on one end, enables insertion of adjacent beampipes and prevents the assembly from becoming over-constrained during bolting. All 3-cm and 4-cm bore diameter BPM's have been fabricated and tested.

### 3.2 Beam Profile Monitors

Dedicated beamboxes for beam profile monitoring are provided in five locations in the MEBT [5]. Measurements of beam profile will be made at low duty factor with crawling wire scanners. Run-time measurements may be made at full duty factor by laser-based photodissociation (LP). The MEBT beamboxes include provision for both types of diagnostics and have a longitudinal dimension of only 5 cm. A slot machined at a 45° angle by wire EDM guides the traveling wire scanner frame. Four 25 mm aperture viewports provide two orthogonal lines of sight to the beam for the LP system. Brookhaven National Lab (BNL) will provide flange mounted wire scanners for acceptance tests at LBNL and calibration of a possible, future LP system. Prototypes of both systems are currently under development at BNL [6].

### 3.3 Other Diagnostic Devices

The MEBT includes two current transformers to measure beam current, one before and one after the chopper target [5]. Both BCM's have been fabricated.

LBNL is currently designing other diagnostics devices to be utilized during commissioning, including a full power beam stop and a low-duty-factor emittance scanner. The beamstop and emittance slit designs will allow temporary installation of either device in the anti-chopper beambox on the third raft of the MEBT.

## 4 MECHANICAL SYSTEMS

### 4.1 Support and Alignment

The MEBT raft design utilizes tight fabrication tolerances and coordinate measuring machine (CMM) fiducialization to achieve accurate positioning of transport components. The bores, mounting feet, and fiducial targets of quadrupole magnets and rebuncher cavities are mapped by CMM prior to installation on the rafts. Bolts and shims fasten and align components to the precision ground mounting surfaces of the raft weldments. CMM measurements will verify the alignment of elements on the assembled rafts to an accuracy of 0.025 mm. In the event that removal of a magnet or cavity is required for maintenance or repair purposes, the shims will remain fixed to the raft to enable repeatable assembly.

A six-strut system kinematically mounts each raft to the carbon steel support frame. Flexible bellows spools between rafts allow separate alignment of each raft, under vacuum, to an RMS accuracy of 0.04 mm. Fiducial targets on individual components will remain accessible for the verification of stability or location of elements after replacement.

### 4.2 Vacuum System

The limited conductance down the MEBT beampipe necessitates a distributed pumping strategy. Eight VacIon 55 Starcell® ion pumps are expected to achieve an average vacuum in the mid-10<sup>-7</sup> Torr range [2]. Two V300HT turbo pumps backed by TriScroll™ 300 scroll pumps on the chopper beamboxes will pump the beamline to a rough vacuum adequate to start the ion pumps.

## 5 CONCLUSION

The mechanical design of compact beam transport and diagnostic devices has accommodated the challenging physics requirements of the MEBT. Most elements have been fabricated, and assembly work will begin this summer in order that the MEBT can transport beam during acceptance tests at LBNL in early 2002.

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