MEBT status

A. Shemyakin
for the PXIE warm front end group

PIP-II technical meeting
January 20, 2015
Outline

• Overview
• Status of elements
• Configurations for RFQ beam commissioning
• Plans
Goals and status

• Main final goals stay the same:
  ▪ Demonstrate creating an arbitrary bunch pattern from initially CW 5-10 mA, 2.1 MeV H- beam
  ▪ Compatibility with SRF downstream
  ▪ Provide all modes that may be required for PIP-II

• The specifications and scheme did not change for ~3 years
• All major components are under development

• Parts of MEBT will be used to characterize the beam from RFQ
  ▪ A set of configurations is under design
MEBT elements

- Magnets
  - Quadrupoles and dipole correctors
- Kickers
- Absorber
- Bunching cavities
- Scrapers
- Diagnostics
- I will not cover LLRF and controls
- Mechanical design of the entire MEBT is expected to start in April 2015, when the LEBT is finished
MEBT magnets

- MEBT needs 2 doublet and 7 triplet assemblies
  - Each assembly includes a pair of dipole correctors
  - Design incorporates a BPM inside triplets/doublets

- Quadrupoles and dipole correctors have been developed and will be built at BARC, India
  - Prototype magnets have been built and measured both at BARC and Fermilab
    - Quality is within specifications

Transfer Function vs Current

BARC’s F-Quadrupole prototype

Quad field integral vs current. From M. Tartaglia, PX DB 1323
MEBT magnets - status

• Prototypes of the doublet and triplet are complete by BARC
  • Will be delivered to Fermilab after magnetic measurements
  • Will be re-measured at TD

• Quads will be re-arranged to make two doublets with dipole corrector sets
  • Prototypes of F-quad and corrector set that are already at Fermilab will be used
  • Covers a “short MEBT” configuration (see later) for RFQ beam characterization

• All dipole corrector sets are expected to be ready for shipment in Summer 2015

• The schedule for production of all quadrupoles is being discussed
MEBT magnets – power supplies

• MEBT magnets will be powered by power supplies from former Ecool
• Quadrupole PSs are LAMBDA (10A, 20V)
  • Have all (18+2 spares) on hands; need controls
• Dipole corrector PSs (4A, 10V) will be based on Ecool corrector PSs
  • Made in-house, G. Saewert. Test of combining four 1Amp PSs into one 4Amp was successful
  • Re-packaging is under way (R. Brooker)
• Power supplies have been tested with the magnet prototypes delivered by BARC
  • K. Carlson, G. Saewert
  • Current stabilization is better than specified
• All power supplies are planned to be ready by summer 2015

Correctors power supply testing.

Quadrupoles power supplies in a rack. K. Carlson. Photos: B. Hanna

PIP-II technical meeting, January 19, 2015
Kickers

- Developing in parallel two versions, “50 Ohm” and “200 Ohm”
  - The technology choice will be made after tests with beam
50 Ohm kicker - concept

- **Kicker**
  - 24 electrodes per plate connected in vacuum by 50 Ohm cables

- **Driver**
  - Commercially available linear amplifier
    - Do not plan to purchase yet
    - The concept has been tested with a similar lower-power amplifier

D. Sun, A. Chen
50 Ohm kicker - status

• One half of the kicker prototype was assembled and tested
  ▪ Excellent delay time
    ▷ 21.98 ns vs specified 21.97±0.1 ns
  ▪ Power test in vacuum with 250 MHz amplifier
    ▷ By the power left in the structure, 570 W applied to the kicker at 250 MHz is equivalent to specified 625 W at expected waveform
    ▷ Stayed 4 hours at maximum power. Vacuum 6·10⁻⁷ Torr. Temperature rise of an electrode (measured with IR camera) was 14°C. RGA scans did not indicate excessive organic components.

• The second half of the kicker is being assembled
  ▪ The complete kicker prototype is expected to be power-tested with 162.5 MHz amplifier in spring 2015
200 Ohm kicker - structure

- Helix as a travelling-wave structure
- One helix was manufactured and measured
  - The delay time is off by 5%, so the final helix winding needs to be adjusted for the beam tests
  - In addition, ceramics permittivity was measured (S. Kazakov)
- One helix assembly is being assembled for power tests in vacuum
  - First, test the design for handling of anticipated beam losses
  - Then, test with a 35 MHz, HV RF driver source for measuring the effects of RF losses

One helix is being prepared for power tests. G.Saewert, A.Chen, D. Franck
200 Ohm kicker - driver

- Driver is being developed at Fermilab (G. Saewert)
  - Broadband, DC coupled switches in push-pull configuration
- Push-pull driver was tested up to 200V
  - It was determined that the progress toward 500V requires different topology, which now is being pursued within LDRD
- Single switch was tested up to 500V
  - Being prepared for RF power testing the helix prototype

Output of 500V low-side switch. 4 ns and 20 ns wide pulses are superimposed. Leading edge is 2.0 ns, trailing edge is 9 ns (5%-95%). 1 MHz CW, 200 Ohm load. Resistive load/monitor is bandwidth limited resulting in the leading edge appearing to be 3.2 ns.
• 21 kW CW, 2mm 1σ beam; absorber of 50 cm length, 29 mrad grazing angle, 17 W/mm² of surface power density
• Features: Molybdenum alloy TZM, transverse slits to alleviate stress, shadowing steps to protect the slits
• Two ¼-size prototypes were successfully built and tested with an e-beam (28 keV, 0.19A) at comparable power density
  • Reasonable agreement with ANSYS simulations
  • Plan to test Prototype-II in full-length MEBT before proceeding to final absorber
Prototypes

- Prototype-I: monolythic design
  - Complicated manufacturing process; a possibility of a crack to water
  - Tested surface power density up to 17 W/mm$^2$ with surface temperature up to 1300 K
- Prototype-II: separate TZM plates pressed against a water-cooled aluminum plate
  - Sacrificed thermal properties (~25% higher temperature rise) for simplicity and reliability
  - Also, better management of reflected particles
  - Was tested with power density well above the expected at PXIE, to ~30 W/mm$^2$ with surface temperature up to ~1600K
  - Survived $>10^4$ thermocycles in 8 days
Bunching cavities

- 162.5 MHz, 100 kV max
  - Expected power in copper ~1 kW
  - Need 3 cavities

PIP-II technical meeting, January 19, 2015
Bunching cavities - status

• A prototype cavity has been brazed and is at Fermilab
  • Resonant frequency is good (T. Khabiboulline)
  • A big vacuum leak was found (D. Plant)
  • The plan is to seal the leak and proceed with high-power RF tests
  • 3 production cavities will be procured following the tests
  • The prototype cavity will be used in “short MEBT” configuration

• Five 3-kW amplifiers have been ordered (R. Pasquinelli) and expected to be delivered in Feb 2015
Scrapers

- 4 assemblies, 4 scraper jaws in each
  - To be used for beam scraping, machine protection, and beam size estimations
  - Max 50W per jaw. A prototype was tested with an electron beam up to 150W.
  - Radiation – cooled, electrically isolated, independently movable TZM plates
  - Linear drives from ECool
Scrapers - status

- The first set is being assembled
  - May test it at LEBT in spring 2015
  - Will manufacture 2 more in FY15

Model of the scraper set. C.Baffes

Assembling the scrapers. K. Kendziora
Diagnostics

- Will be mainly in two “diagnostics” sections of the final MEBT
  - The final set may include: 9 BPMs, 2 toroids, DCCT, 4 x 4 scrapers, emittance scanner, 2 wire scanners, Fast Faraday Cup, 2 laser wires, extinction monitor
- Because of resource limitations, the diagnostics will be installed sequentially over years
  - FY15: 2 toroids, 2 BPMs, 1x4 scrapers, Fast Faraday Cup, ToF. Should be enough for initial RFQ characterization
Diagnostics - status

• BPMs
  - One BPM is complete and measured
  - One more BPM is in production; have buttons for 2 more
  - Electronics for 2 BPMs should be ready by summer 2015
  - Buttons for all MEBT BPMs have been ordered

• Time-of-Flight monitor ("movable BPM") – being designed
  - To measure the beam energy by recording the phase as a function of the longitudinal BPM position, following an idea from SNS

• Fast Faraday Cup – being designed
  - Small portion of the beam is cut by a pinhole and collected to a strip line
  - Modifications to SNS design to improve robustness

2 toroids – on hands

Ring pickup – being procured
  - To estimate average beam current from RFQ for MPS purpose
Diagnostics – preparation for FY16 and beyond

• Emittance scanner
  ■ Will try to use slits in scraper jaws as double-slit scanner
  ■ Initial commissioning with the LEBT scanner (see later)
  ■ We also will measure the emittance by quadrupole scans

• If the scraper set assembly is found convenient, it may be used as a base for wire scanners

• Should have buttons for all BPM by summer 2015
  ■ To prepare all BPMs and triplet vacuum chambers by arrival of MEBT magnets

• Development of the laser wire has started
  ■ V. Scarpine, J. Ruan
  ■ Expensive and long – term work
  ■ General R&D in this direction within LDRD may help making the system less costly
Elements of vacuum system have been identified

- Purchased elements needed in CY15
MEBT in 2015

- In 2015, parts of MEBT will be used for the RFQ beam commissioning and characterization
  - Expected to be in steps
- So far, all elements are on the path to work with a short-pulse beam in the end of FY15 (next slides)
- Plan to have high-power beam tests toward the end of CY15
• Plan to start RFQ beam commissioning including MEBT section #0 fully assembled with prototype magnets and cavity
  ▪ Pulsed mode only (<1 ms)
  ▪ Protection from CW by MPS through a ring pickup signal
  ▪ Commissioning of toroids, BPMs, scrapers, FFC, ToF, magnets
  ▪ Measurement of beam energy, RFQ transmission, bunch length
  ▪ If ready with RFQ frequency stabilization, commission the buncher
“Short MEBT 1_2” (Oct- Nov 2015)

- Measurements of beam emittance, Twiss functions
  - Start with the LEBT emittance scanner, compare with measurements by slits/scrapers
- First high – power tests
  - SNS beam dump (from HINS)
  - 16 kW power test will be done with the “instrumentation” section removed

3σ beam envelope 3D simulation for high-power tests. A. Saini. 5mA.
LEBT scanner in MEBT

- Very attractive to try using the LEBT scanner for initial RFQ beam commissioning
  - The Allison scanner is much faster than double-slit
  - Commissioned at LEBT; could be used for cross-calibration of slits
  - H- energy is by 70 times higher => the kick angle is 70 times lower
    => ±180 mrad in LEBT corresponds to only ±2.5 mrad in MEBT
  - Conclusion: Can be used if emittance is not too large with a specially prepared envelope

3σ beam envelope 3D simulation for LEBT scanner use in MEBT. A. Saini. 5mA, transverse emittance 0.21 μm (rms, n). 3 σ beam angle in the proposed location of the scanner is 3.5 mrad.
16 kW power test may require a removal of the “diagnostics section”
- To provide larger beam at the dump
- The same components

3D model of MEBT 1_3.
C. Baffes, S. Oplt.
“Short MEBT” preparation

- 3D models of first configurations are prepared
- All components for “short MEBT 1_1” should be ready by July 2015 for RFQ beam commissioning
MEBT plan (technically driven, with no contingency)

- Aug 2015 – pulsed beam from RFQ
- Nov 2015 – CW beam
- Dec 2015 – Feb 2016 – installation of full – length MEBT
  - With prototype kickers (50 Ohm and 200 Ohm) and 5 kW prototype absorber
  - Final bunching cavities, final magnets, SNS beam dump at the end
  - Incomplete diagnostics (e.g. no wire monitors, extinction monitor, laser wire etc.)
- Mar – Jul 2016 - initial MEBT commissioning
  - The main goal is to pass the beam to the chopper to test its elements
  - Make decision on the kicker technology; start the final chopper design
- Aug- Nov 2016 – all cryo work and SSR1 installation
- Dec 2016- Aug 2017 – MEBT characterization
  - In parallel with SSR1 commissioning
- Sep – Dec 2017 – final MEBT installation (concurrent with HWR’s)
- FY18 – demonstration of bunch-by-bunch separation