PXIE MEBT status

A. Shemyakin
PXIE Program Review
January 16-17, 2013
• Goals and specification
• Main technical challenges
• Progress to date
• Milestones
• Medium Energy Beam Transport (MEBT) is a ~10 m section between RFQ and HWR
• The main goal is to demonstrate the capabilities required for the Project X
  – Form the bunch structure required for the linac
    • Bunch-by-bunch selection
  – Match optical functions between RFQ and SRF
  – Include tools to measure the properties of the beam coming out of RFQ and sent to SRF
  – Clean transverse halo particles
Main MEBT Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Nominal output energy (kinetic)</td>
<td>2.1 (+/- 1%) MeV</td>
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<tr>
<td>Maximum frequency of bunches</td>
<td>162.5 MHz</td>
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<td>Beam Current Operating Range</td>
<td>1- 10 mA</td>
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<tr>
<td>Nominal Output Beam Current</td>
<td>1 mA</td>
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<tr>
<td>Nominal Charge per Bunch</td>
<td>30 pC</td>
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<tr>
<td>Residual Charge of Removed Bunches</td>
<td>&lt; 10-4</td>
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<tr>
<td>Beam Loss of pass through bunches</td>
<td>&lt; 5%</td>
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<tr>
<td>Nominal Transverse Emittance</td>
<td>0.27 mm mrad</td>
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<tr>
<td>Nominal Longitudinal Emittance</td>
<td>0.8 eV-μs</td>
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</tbody>
</table>

- The MEBT allows for **bunch by bunch selection** to create the final time structure of the PXIE beam by chopping ~80% of the beam with a wideband chopper.
  - This requirement determines most of MEBT design features
Main challenges

- Wideband kicker performance
  - Temporal characteristics, stability, survival with the beam
- 21 kW beam absorber
  - Thermal characteristics, life time, blistering, secondary particles
- Vacuum management with the absorber in proximity of SRF
  - Gas flow, neutralization, dust particles
- Emittance preservation
  - Rms emittance growth, halo formation
- Effective extinction of the undesired bunches

- All these challenges can be addressed with a full-scale PXIE MEBT; preliminary solutions have been found.
- Main technical efforts now: kicker and absorber
  - Also, long lead items: bunching cavities and quadrupoles
• Transverse focusing by equidistantly placed triplets
  – A shorter section #0 with doublets
• 3 bunching cavities for longitudinal focusing
• Chopping system: two kickers and absorber

Full – scale MEBT completion date: Feb-2018
Kicker: scheme

- Two travelling wave kickers working in sync
  - ~180 deg phase advance between
  - Kicker length in one section is 50 cm
- Bunch dimensions (6-sigma) at kicker locations:
  - ~12 mm vertical (Y), ~16 mm horizontal (X), ~1.3 ns
- Any bunch of the 162.5 MHz CW train can either pass or be removed
- +/-250 V on each kicker plate for passing/removed bunches
- Flat top 1.3 ns, ±25 V

Two versions distinguished by the structure impedance are being developed: 50 Ohm and 200 Ohm.
The choice is to be made after tests with H-beam (Oct-2016)
50-Ohm version

- Driver: commercially available linear amplifier + signal pre-distortion
- Structure: Flat plates connected in vacuum by 50-Ohm cables
- Mechanical design of the structure is progressing
  - RF and thermal simulations are done
  - A 3D model is complete
- Prototype structure is to be tested by Sep-2013

3D model of 50-Ohm kicker
(the vacuum box is partly removed for presentation purpose)
A. Chen, D. Sun
A mockup with 8 plates and cables in their final RF configuration was manufactured, assembled, and successfully tested:

- RF tests
- Power tests in air:
  - Loss at 1.3 GHz, 400W signal is equivalent to the required form (at 1 kW)
  - Measured loss and temperature rise are close to expectations

RF measurement of a 8-unit mockup. Scope traces: yellow - input, cyan - output after the 8 delay units. The input trace consists of two consecutive pulses with different rise time. One is 1 ns rise time and the other is "0" ns rise time. (D. Sun, V. Lebedev, R. Pasquinelli)
50-Ohm version: driver tests

Test of the CBA 1G-150 amplifier with pre-distortion. (a) scheme of the test; (b) pre-distorted input signal and (c) corresponding output signal for a single pulse; (d) output for a CW pattern, corresponding to removal of four consecutive bunches followed by a one-bunch passage. Maximum voltage was 240 V ptp. (V. Lebedev, R. Pasquinelli, D. Peterson)

A 1-kW amplifier with similar characteristics is commercially available.
200 Ohm version

- **Structure:** two helixes wound around grounded cylinders
  - Preliminary mechanical conceptual design
  - Geometry was optimized in simulations, and several models were measured
    - Ready for mechanical design
  - Design of 200 Ohm hardware progressed
    - Design of transmission lines has been proven
    - Load tested; feedthroughs ordered
  - Prototype is to be tested by Nov-2013
- **Driver:** in-house developed fast switch (G. Saewert)

0.5 m model of the helix–based kicker with the 200 Ohm transmission line and load. (G. Saewert)
RF simulations

- Analysis in frequency domain (HFSS) and time domain (CST)
- Good agreement with measurements of a model
- The pitch and height of winding adjusted for the right phase velocity and impedance
- A recipe for end effect compensation is found

Simulation of the regular structure with the correct impedance and $\beta = 0.067$. Compensation for the end effects by a stepped inner conductor
200 Ohm kicker driver progress

- Prototyping verified the design of critical sections
- Designing a complete bipolar switch
  - The first step will be to make a fully functional 100V bipolar switch
  - PCBs have been fully designed and are in the production stage
- The driver prototype is to be assembled by Aug-2013

Results of testing of one switch prototype. Five 200 V rated GaN FETs in cascode scheme. The drop time of the output signal, 3 ns (10-90%), is close to the requirement.
• The absorber should withstand 2.1 MeV X 10 mA = 21 kW focused into a spot with 2 mm rms radius
• Difficulties:
  – Thermal load, mechanical stress
  – Outgassing, blistering, sputtering
• A preliminary conceptual design of the full-scale absorber is done
  – Molybdenum alloy TZM is chosen
  – 29 mrad grazing angle
  – Thermal and stress analysis
  – Analysis of radiation, secondary particles, sputtering
• The final absorber is to be completed by Aug-2015

C. Baffes
• Temperature distribution will be recorded with 6 thermocouples and compared with simulations
• All part have been machined, tested, and being brazed
  – a crack developed during the braze; attempting to repair
• Consider an alternative version of the absorber with no brazing
• Test of the prototype is to be completed by Jul-2013
Absorber prototype test bench

- **Goal:** to test thermal properties of a prototype with an electron beam at similar surface power density
  - 30 keV, 0.2A of e- to model 2.1 MeV, 10mA of H-
  - The same power density ~25 W/mm²
    - Because of a larger grazing angle, ~120 vs 29 mrad
  - Mainly re-using parts from the Electron Cooler
- **Commissioned with a “pre-prototype”**
  - A TZM brick with simple water cooling
  - Difficulties: ~50% of energy is reflected; cathode poisoning

Schematic of the test bench. K. Carlson, B. Hanna, W. Johnson, L. Prost, A. Shemyakin, J. Walton, A. Mitskovets

Beam OTR image at the TZM surface (R. Thurman-Keup)
• Conceptual design is done
• Production drawings are being prepared
• Tests of the prototype cavity are to be completed by Mar-2014

Frequency 162.5 MHz
Max voltage 100 kV
Gap 2x23 mm
Max power loss 1.5 kW

Couplers and tuners from HINS

G. Romanov, I. Gonin, T. Khabiboulline, M. Chen,, J. Coghill, I. Terechkine
Other subsystems

- Quadrupoles/dipole correctors
  - Magnetic design is done
  - Possible collaboration with India for production
  - Prototype quadrupoles and correctors are to be tested by Oct-2013

- Vacuum system – concept
  - Design to be completed by Sep-2015

- Diagnostics, machine protection systems, controls, infrastructure
  - Discussions

VI. Kashikhin

Simulation geometry of the triplet with adjacent dipole coils
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<td>MEBT Chopper R&amp;D 50 Ohm Prototype Tested w/ no Beam</td>
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<td>MEBT Prototypes Quad Tested</td>
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<td>Beam through the MEBT*</td>
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<td>MEBT Beam meets Specs</td>
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<td>MEBT Final Installation Complete</td>
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<td>MEBT Commissioning Complete</td>
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- MEBT Quads Ready for Installation 6-Oct-14
- MEBT Chopper prototypes Initial Testing Complete 17-Feb-14
- MEBT Final Absorber Complete 3-Aug-15
- MEBT Final Buncher Cavities Complete 11-Jan-16
- MEBT Kicker Technology Finalized 14-Nov-16
- MEBT Final Installation Complete 15-Dec-17
- MEBT Commissioning Complete 20-Feb-18
Backup slides

• Reasoning for developing two kicker schemes
## Project X

### Kicker: schemes comparison

<table>
<thead>
<tr>
<th></th>
<th>50 Ohm</th>
<th>200 Ohm</th>
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<tbody>
<tr>
<td><strong>Slow-wave structure</strong></td>
<td>Plates with cables</td>
<td>Helix</td>
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<tr>
<td><strong>Driver</strong></td>
<td>Linear amplifier with pre-distortion</td>
<td>Fast switch (in-house development)</td>
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<tr>
<td><strong>Signal bandwidth</strong></td>
<td>20 – 600 MHz</td>
<td>DC- 250 MHz</td>
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<tr>
<td><strong>RF power dissipated per kicker</strong></td>
<td>~200 W</td>
<td>~12 W</td>
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<tr>
<td><strong>Advantages</strong></td>
<td>Commercial amplifier</td>
<td>Potentially lower cost, lower power, DC coupling</td>
</tr>
<tr>
<td><strong>Drawbacks</strong></td>
<td>~100 soldered connections in vacuum; higher power and frequency</td>
<td>Driver development; custom-made feedthrus, loads, transmission lines</td>
</tr>
<tr>
<td><strong>Structure status</strong></td>
<td>Modeled; mechanical design</td>
<td>Modeled; ready for mechanical design</td>
</tr>
<tr>
<td><strong>Driver status</strong></td>
<td>240 V p-t-p tested</td>
<td>480 V tested (1 switch)</td>
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</tbody>
</table>
History lessons: importance of beam tests

- **LAMPF**
  - “helical kicker” (PAC’79, 3433): replacement of Teflon by ceramic
    - Worse temporal characteristics but improved robustness
    - “… a more rugged mechanical structure with better pulse-propagating characteristics.”

- **SNS**
  - “It took several iterations to build a MEBT chopper deflector suitable for high power beam operation” - MOPD063, IPAC’10
  - Completely different design
    - Worse temporal characteristics but improved robustness
  - It is difficult to judge whether the design will work until beam tests
    - While it is a critical element of Project X