Fermilab/AD/TEV
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Tevatron BPM Project Closeout Report

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1. Scope and background

Since the Tevatron Beam Position Monitor (TevBPM) project concluded, this document aims at providing a general overview of the status of the project as well as the lessons learned during the project execution. The goal is to use these experiences to improve the execution of similar projects in the future.

This document covers the design, fabrication including integration, installation, and commissioning phases of the TevBPM system development. In the context of this document, system verification and validation activities for the project are generally defined as follows:

The net outcome of the validation process is the assurance from the experts and users of the system that the integrated, installed and commissioned system with hardware and software/firmware and documents:

- Meets or exceeds expectations of users
- Solves the right problems
- Is adequate to hand over to the TevBPM system operations team who can conduct routine operations and maintenance

Detailed documents referred here are available on-line:

1. All documents are accessible through DocDb database for Accelerator Division. Document numbers refer to the Beams-doc numbers

2. Large files related to "as built" (http://projects.fnal.gov/tevbpm/wbs/VnV/Asbuilt/) documents including archived software and firmware file and test data (http://projects.fnal.gov/tevbpm/wbs/VnV/Test_Data/) are archived on the project web site on Fermilab's AFS space. (http://projects.fnal.gov/tevbpm/wbs/VnV/).
3. Electronic system configuration files are available at: \\Cdserver\cd_shared\EVERYONE\TeVBPM\Project\Hardware\System_Crate_Config
4. TevBPM project related information is available at http://projects.fnal.gov/tevbpm/wbs/index.html

2. Checklist for the closeout review

The following checklist was used to verify that the project is complete. Incomplete issues and planned completion dates are listed in the last section of this report.

Requirements validation

Verify that the system fulfills requirements specified in the TevBPM requirements document.

The Tevatron BPM upgrade was completed in June, 2005. Many but not all of the requirements have been achieved. Some have been achieved but not documented. Others have neither been achieved nor documented. This is sometimes true because no attempt has been made to do so. Or the system is not yet capable of handling the requirement. This document is meant to describe what has been achieved as of the end of August, 2005.

A. Measurements required (taken from P.24-26 of the requirements document, beams-doc-554-v4). The required measurement capability is listed here:

I. Standard store
   A. Closed orbit
II. Collider shot setup
   A. Closed orbit during ramp and squeeze.
III. Injection Commissioning
   A. Uncoalesced single turn
   B. Uncoalesced closed orbit
IV. Injection Tune up.
   A. Uncoalesced single turn
   B. Uncoalesced closed orbit
V. Lattice Function Measurements
   A. Uncoalesced closed orbit
   B. Coalesced closed orbit
VI. Lattice and coupling measurements
   A. Uncoalesced TBT
   B. Coalesced TBT
VII. Aperture Scans
   A. Uncoalesced closed orbit
   B. Coalesced closed orbit

VIII. Abort buffers
A. Closed orbit

All of the above are part of the functioning Tevatron BPM upgrade as of June 30, 2005.

B. Key Specifications (Protons) (taken from Table 2 of the requirements document, beams-doc-554-v4):

Measurement Range: +-15mm	
Absolute Position Accuracy: < 1.0 mm	YES (1893)
Long Term Position Stability: < 0.05 mm	YES (1925)
Best Orbit Position Resolution: < 0.02mm	YES (1753,1752)
Position Linearity: < 1.5%	YES (1893)
Relative Position Accuracy: < 5%	Not demonstrated
Intensity Stability: < 2%	Not demonstrated

The requirements listed above have either been shown to be satisfied in some very specific measurements or have not yet been looked at. In general the system looks like it has the capability to make the measurements with the precision required. In many cases it will take more work to disentangle real beam motion from measurement errors as well as making corrections for non-linearities or off-axis positions to provide the accuracy and precision required

The documentation for each of the requirements is listed above. For each one a short description of what has been done is described in the following paragraphs.

The document (beams-doc-1893) shows that the system can provide 1.0 mm absolute position accuracy as long as one is not measuring very far off-axis in the orthogonal coordinate.

In beams-doc-1925 a study was made of 32 stores taken over a period of 6 weeks. Proton position is shown to be stable better than an average of 0.038 mm (see figure 6). Some BPM's are somewhat worse but on average they do better than 0.040 mm.

The orbit position resolution is difficult to disentangle from real beam motion, among other things. However, the work referenced here in beams-doc-1752 and beams-doc-1753 provide plausibility that the system does in fact meet this requirement. Slide 7 of beams-doc-1752 and slide 7 of beams-doc-1753 indicate that resolutions of 5-7 microns (1 sigma) are likely to be achieved with this system.

Linearity was shown in the context of looking at measurements across the aperture of the BPMs. Figure 4 gives support to this, but is not an absolute proof that the system satisfies this linearity requirement. Further studies by Accelerator Division scientists will give more information.

Key Specifications (Pbars):

Measurement Range: +-15mm	
Absolute Position Accuracy: < 1.0 mm	YES (1863)
Long Term Position Stability: < 0.05 mm	YES (1925)
Best Orbit Position Resolution: < 0.05mm	YES (1752)

Position Linearity: < 1.5% Not known yet
Relative Position Accuracy: < 5% Not known yet
Intensity Stability: < 2% Not known yet

The anti-protons' requirements are either satisfied as documented in the referenced notes or will likely be satisfied but no evidence exists for it yet.

Figure 1 of beams-doc-1863 shows that the position accuracy for measuring antiprotons is better than 1.0 mm.

In beams-doc-1925 a study was made of 32 stores taken over a period of 6 weeks. Anti-proton position is shown to be stable better than an average of 0.048 mm (see figure 6). Some BPM's are somewhat worse but on average they do better than 0.050 mm.

Slide 9 of beams-doc-1752 shows a resolution of approximately 0.012 mm (1 sigma). Multiplying by 3 one gets a pbar resolution of 0.036 mm in this particular case.

C. Requirements from table 3 of the requirements document (beams-doc-554-4)

Measurement Purpose	**Measurement type**	**Beam Structure**	**Position accuracy and resolution**	**Status**
Protons during a store.	Closed Orbit	36x36.	Position resolution of 0.05 mm.	YES (1753,1752)
Pbars during a store.	Closed Orbit	36x36.	Position resolution of 0.05 mm.	YES (1752)
Protons during ramp and LB squeeze	Closed Orbit	36x36. Prot coal. Prot uncoal.	Position resolution of 0.05 mm.	Not yet
Pbar during ramp and LB squeeze	Closed Orbit	36x36. Pbar coal.	Position resolution of 0.05 mm.	Not yet
Injection commissioning.	Single Turn	Prot uncoal.	Position resolution of 0.1 mm.	YES
Injection commissioning.	Closed Orbit	Prot uncoal.	Position resolution of 0.05 mm.	Not yet
Injection tune up.	Single Turn	Prot uncoal.	Position resolution of 0.05 mm.	YES (1753)
Injection tune up.	Closed Orbit	Prot uncoal.	Position resolution of 0.02 mm.	Not yet
Closed orbit circular buffer.	Closed Orbit	36x36. Prot coal. Prot uncoal. Pbar coal.	0.02 mm (proton) 0.05 mm (pbar)	Not yet
Aperture scans	Closed Orbit	Prot coal. Prot uncoal.	0.02 mm 0.02 mm.	YES (1902) YES (1902)
Lattice measurements	Closed Orbit	Prot uncoal. Prot coal.	Position resolution of 0.05 mm	YES (1880)
Lattice and coupling measurements	TBT	Prot coal. Prot uncoal.	Position resolution of 0.05 mm	YES (1880)

Many of the requirements listed above have not been verified. This is expected to change as more users of the system collect and analyze data and are able to measure the capabilities of the system. For those cases where the requirements have likely been met the details are given in the following paragraphs.

Slide 8 of beams-doc-1753 indicates that a resolution of 50 microns (1 sigma) has been achieved in TBT measurements.

Slide 14 of beams-doc-1902 shows errors (1 sigma) of approximately 12 microns. These measurements were made while measuring the lattice of the machine for the purpose of measuring low beta.

An error of 20 microns is asserted on P.3 of beams-doc-1880. The analysis that follows is consistent with this error estimate. Though not a proof this is an indication that the error in TBT measurements (for protons) is sufficient for making lattice measurements, in this case low beta functions.

Verification of the as-built status of the design

- Are as-built drawings available? Yes. All as-built drawings are available at http://projects.fnal.gov/tevbpm/wbs/VnV/Asbuilt/
- Are as-built design specifications for the hardware and software available? As-built specifications for the major hardware components and the front-end software are available. Hardware components built in-house are TFG module, Filter card, and the terminator card. VME crates and Digital Receiver boards, model ECDR_GC814 were purchased. The vendor documentation is available, but will be retained offline.
- Are all as-built software installed, released, frozen, archived and accessible? All as-built software are installed and released. The front-end software, the component specifically built for the TevBPM project is controlled by the CVS software on Accelerator Division's Nova machine. The installed version of the front-end software (end of June, 2005) is 1.61. A frozen tar.gz software is available on the project AFS space under "Asbuilt" directory as well as in CD/DVD format. Please contact CD division office. This software continues to change during operations phase and will be managed in the same CVS repository. Due to the specific nature of the Online software, it is maintained under the control of Accelerator Division's MECCA code management system and is not archived here. Offline software issue - Incomplete
- Are all as-built firmware, procured and developed in-house installed, released, frozen, archived, and accessible? A frozen version of the TFG firmware is available on the project AFS space under "Asbuilt" directory as well as in CD/DVD format. Please contact CD division office. The version number is 2.1.1. The Echotek board driver software is available, but will not be made available publicly.
- Is an adequate description of the installed systems at each service building available? Yes. Original system crate configurations are available. However, these configurations may change during the operations phase.

Fabrication/implementation/installation

- Are adequate user documents for software and hardware available for the users to continue operations? Incomplete**.** See the plan for completion in the last section.
- Is there an adequate maintenance document available to maintain the system? Incomplete. See the plan for completion in the last section.
- Is there a programmers' guide available to update the system in the future? See the plan for completion in the last section.
- Is there a list of incomplete issues for this phase that must be addressed during the operations phase? Yes. See incomplete issues section.
- Is there a concern about the performance for the hardware? There were issues with three DAWN VME crates within last two months of completion of the project. The solution to the metal screw problem is to replace the screws with nylon screws. Replacement screws are available and will be replaced as soon as possible. An investigation is on-going

Commissioning and decommissioning

- Is there a list of incomplete commissioning issues? Yes. See the plan for completion in the last section.
- Is the decommissioning of the old system complete? Yes.

Operations

- Is there a high-level plan for the operations phase in place? Yes. See the TevBPM Operations MOU for Electronics (Beams-doc 1504) and Software (Beams-doc 1503).
- Is the operations team identified? Yes.
- Is there a plan for storing and distributing replacement hardware items? Yes.

Project management

- Is there a plan for closing the project WBS and related charge codes? Yes. All project charge codes were closed formally during the month of August.
- Are there new charge codes for the operations phase of the project? Yes. A new charge code was established and it is being used. We are working on the issue of equipment maintenance cost charging.
- Is there a list of lessons learned for the project execution, including scheduling and allocations? See below.
- Surety: Are there any incomplete quality, reliability and maintainability issues? No. Three Dawn crates failed unexpectedly. Investigation of this issue is on-going. To mitigate the brass washer problems, all washers were replaced with nylon washers. However, any steady pattern of failure could not be established.

3. Lessons learned from the project management point of view

Positive experiences gained

- The delivered system was successfully validated against the requirement. Defining requirements early in the project and refining it during the pre-shutdown commissioning was useful. See details of requirements validation in the project manager’s report.

- The cost of electronic components, after the detailed estimation, was accurate. The final cost was $1,736K where as the estimate in the first baseline version of the project was $1,764K. It should be noted that the initial fixed cost estimate in the RUN II WBS for the project was only $900K. This accuracy of estimation can be attributed to the cumulative experiences of participating engineers
- Initial effort estimate for the project was 15.9 FTE. The project used 17.3 FTE. The project completion was delayed by three months. Considering the complexities involved with the project, it can be counted as a positive experience. However, it is important to note that it is necessary to dedicate efforts early on to the project, particularly in the area of requirements definition and design.
- Installing a bare-bone prototype system to the Tevatron before shutdown and collecting pre-shutdown data was useful.
- The schedule for the design phase was estimated optimistically. TevBPM system turned out to be more complex than originally estimated

Issues resolved and lessons learned

- Most significant issues are associated with the delays in the project schedules. Lessons learned from these issues provide insights into the nature of system upgrade projects in the Fermilab environment, which might be useful during the planning of future projects:

    - Technology choices: It took a significant effort and time to decide on the Echotek hardware. After much deliberation, it was decided that buying the Digital Receiver boards from Echotek made more sense than using in-house boards.
    - Timing card design: There was a delay of close to seven months (11/18/04 instead of planned 2/13/04) in placing the PO (Task: Timing card PO complete). This was due to the complexities of the timing card and the need to upgrade of the firmware to standard VHDL format. However, it appears that the delayed placement of the purchase order is not the cause of the slip in the final commissioning.
    - Software implementation: Some delay in software implementation can be attributed to the complexities of the system. Consequently, proper requirements were not always available and that led to difficulties in designing the software. It took longer than expected time to understand new algorithms for necessary software functionalities. Being conservative in initial estimations for software design, implementation and debugging efforts will be useful for future projects.
    - Commissioning: Commissioning of the system at the first house A3 took much longer than expected. Some of the problems were associated with the Turn by Turn (TBT) mode data collection and 6000 turn problem. Once these problems were resolved, the commissioning process progressed according to the schedule. Delays due to these issues are reflected in the house commissioning status report available at http://projects.fnal.gov/tevbpm/wbs/VnV/CloseserviceBuildingConfiguration.htm

- At Fermilab, due to general demographic reason, man-power availability drops during months of July, August, December and January. It will be wise to plan for general shutdown during these months.

Note that the schedule slips are calculated by comparing the first baseline (Baseline 1 Finish) finish date with the actual finish (Finish) date entered in the MS project file at the conclusion of the project (TBPM Run_II_June05).

4. Incomplete issues

- System maintenance guide and software user guide are not yet available. System maintenance guide will be available by November 5, 2005. The front-end software documentation will be complete by October 15, 2005 Documentation for the offline software and analysis will be complete by October 30, 2005.
- Diagnostic software. Jim Steimel may lead the work to complete the diagnostic software issues with the help of others, after he finishes his work with the Rapid Response Team. Jim Steimel indicated that he will be able to devote time to this effort from October 14 and plans for commissioning this feature by Nov. 14, 2005.

5. Future work

Although the performance of the Tevetron BPM system is validated by users over the past two months, enhancements to the calibration software may be implemented in the future. However, it will require adequate resources and access to the Tevatron.

Rob Kutschke may lead the work to complete the calibration software with the assistance from Luciano Piccoli, Brian Hendricks and Marc Mengel. According to Rob, calibration software consists of two tasks. For both tasks, Accelerator Division needs to initialize two activities: a) Verify pbar position calibration up the energy ramp, through the squeeze and initiation of collisions. These tasks may be accomplished during the next shutdown; b) Remeasure the differential attenuation in the cable pairs with better precision and correct for this effect.