Survey and Alignment of the Fermilab MuCool Test Area Beam Line

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MuCool Test Area (MTA) is designed to develop and test muon ionization cooling components using the intense Fermilab Linac beam.

MTA facility is part of the Muon Collider and Neutrino Factory R&D program.

MuCool stands for Muon Cooling experiment.

The MTA facility is located southwest of the Fermilab Linac. It consists of an experimental hall and a service building.

Fermilab Linac is a $H^-$ ion, 400 MeV accelerator which provides beam for the Booster operation.
MTA Experimental Hall and Linac tunnel are separated by 50 m long connecting (Linac-to-MTA) enclosure.

MTA beam line is located in the Linac-to-MTA tunnel enclosure.

MTA experimental hall is shielded and separated from the Linac by a 3.66 m (12 ft) long concrete block.

Beam line penetrates through the shield block to the Hall. The penetration has an inside diameter of 22.23 cm (8.75 in).
MTA Beam Line

- MTA Beam Line is a simple beam line to transport $\text{H}^-$ or proton beam from the end of the Fermilab 400 MeV Linac to the MTA.

- Beam Line design is based on using existing dipoles and quadrupoles and other equipment available at Fermilab from previous projects.
MTA Beam Line consists of 62 components, which include:

- 26 Components with Fiducials
- 10 Beam Position Monitors (BPMs)
- 4 Trim Magnets
- 4 Booster Correctors, and
- Other instrumentation
Establish a precision horizontal and vertical control network for positioning MTA Beam Line components in the Fermilab Site Coordinate System (FSCS) to ±0.5 mm at 95% confidence level.

- Bring horizontal and vertical controls into the
  - MTA Experimental Hall
  - Linac-to-MTA enclosure, and
  - Part of the Linac enclosure

- Tie the new MTA Horizontal and Vertical networks to the existing Linac network
Survey and Alignment of MTA Beam Line

- The 3.66 m (12 ft) long shielding block is removed before for the MTA network measurements

MTA Network consisted of:

- 25 Floor Monuments
- 34 Wall Monuments
- 12 Tie-Rods on the Wall
- 32 Pass Points
- 6 Brass Points
Survey Methodology

- All Survey and Alignment were done with:
  - Laser Tracker
  - Total Station for Stake-out
  - Electronic Level for Elevations
  - Gyro-Theodolite for Azimuths
MTA Network Results

Bar scale tick at $1\sigma$

Residuals (mm)
Gaussian Fit to Residuals

Residual Count = 4040
$\sigma = 0.080$ mm
Component Fiducialization

- Fiducial is a stainless steel (Shegjak) lug with a magnet in the center to hold SMR
- Shegjak = O’Sheg + Dijak
Component Referencing

- Components with Fiducials were referenced with Laser Tracker in a local magnet coordinate system.

- Referencing Methods used:
  - Plane Fits
  - Plane-Plane Intersections
  - 3- Plane Intersections
  - Line Fits
  - Plane-Line Intersections
  - Line-Line Intersections
  - Cylinders Fits
  - Circle Fits

- Magnets Referenced to better than ±0.15 mm
Magnet Reference - Method 1

- No dimensions of component
- Six planes are created from Laser Tracker measurements made on six sides of the component
No dimensions of component

Two planes are created from measurements made on upstream and downstream sides of the component

A cylinder is constructed from measurements made on the upstream and downstream circular pole tips in each quadrant of the component
Pre-Alignment
- Stand installation (±6 mm)
- Rough alignment (±0.5 mm)

Final Alignment
Alignment Tolerance:
- Magnets: ±0.25 mm
- Instrumentation: ±0.5 mm

Component Alignment

- 8 TQTB Quads
- 4 SQA Quads
- 5 Cooling Ring Dipoles
- 7 Multiwires
- C-Magnets
- Shielding Blocks
Error Analysis of Magnet Alignment

Total radial standard deviation of a magnet alignment ($1\sigma$) :

$$\sigma_{Mag\_Align} = \pm\sqrt{\sigma_n^2 + \sigma_m^2 + \sigma_f^2 + \sigma_s^2} = \pm0.165 \text{ mm}$$

$\sigma_n$ = standard deviation of the relative errors in the network = ($\pm 0.158 \text{ mm}$) (relative transversal errors between points)

$\sigma_m$ = standard deviation of the errors in measurement from control points to fiducials

$$= \pm\sqrt{\sigma_{nm}^2 + \sigma_{LT}^2} = \pm0.017 \text{ mm}$$

$\sigma_{nm}$ = standard deviation of nest to control monument repeatability = ($\pm 0.008 \text{ mm}$)

$\sigma_{LT}$ = standard deviation of the Laser Tracker measurement for aligning components from one setup = ($\pm 0.015 \text{ mm}$)

$\sigma_f$ = standard deviation of the errors in measurement from fiducials to magnet ($\pm 0.035 \text{ mm}$)

$\sigma_s$ = standard deviation of the errors in resolution of the stands adjustment ($\pm 0.025 \text{ mm}$)

The resulting standard deviation is within the specified accuracy of ($\pm 0.25 \text{ mm}$)
Challenges

- Stands are of poor quality. MTA used components from previous projects and very old stands.

- Time constraints. Network was done over a period of six months because access to Linac-MTA enclosure depended on the Linac downtime.

- High congestion in the Linac-to-MTA enclosure, too many jobs going on at the same time.

- Unstable floor at some locations. Stands were sitting over a metal ledge.
Status of MTA Beam Line

- The C-magnets has to be installed during a Linac downtime sometimes in 2008

- Since all the components have been put under vacuum and leak checked, a final alignment would be completed during a Linac downtime sometimes in 2008

- Full commissioning is expected to be sometimes in 2008
Conclusion

- The MTA beam line has been surveyed and aligned.
- The alignment methodology used has also been presented.
I would like to thank
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- Dr. Fernanda Garcia - MTA Beam Line Installation Manager

Domo Arigato !!!

ありがとうございます