INTEGRATION BETWEEN THE FRIB LINAC MECHANICAL CAD MODEL GEOMETRY AND THE ACCELERATOR PHYSICS LATTICE DATABASE*

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Abstract

This paper will summarize the systems engineering techniques utilized to translate the FRIB accelerator physics lattice file to actual three-dimensional CAD geometry for linac components. An automated approach of using the accelerator physics lattice database used for optics and particle simulation has been implemented to generate data points used to position the technical 3-dimensional CAD geometry. This coordinated method ensures consistency between the technical and scientific design domains throughout the project design phases. The FRIB configuration management used to control lattice and CAD model revisions is also discussed. In addition, the paper discusses fiducialization plans and tolerance stack up analysis to meet positional requirements for FRIB cryomodules, diagnostics, and the beam delivery magnet systems.

DATA MANAGEMENT

The layout of the FRIB accelerator physics lattice file is composed of the basic element layouts of the driver linac. This layout is accomplished using spreadsheet file to define the undeveloped geometry of ion sources, focusing and steering magnets, accelerating cryomodules, radio frequency quadrupole (RFQ), The alignment placement requirements of the accelerator components are summarized in [1,2]. An automated script imports the lattice points into our mechanical CAD software generating local coordinates for the centers of each component, called a skeleton file. The three-dimensional design geometry is then located to each coordinate in the skeleton file making up the complete linac geometry. The Survey and Alignment Group will develop and maintain a proprietal data handling system composed of a relational database and a workable simplified wireframe graphics model [3]. This system will be integrated with the FRIB project database currently under development within the Controls and Computing Group. All components requiring alignment will have associated fiducials. The fiducials are placed on the wireframe component model and these in turn are placed at the correct location in the design lattice based upon the data gathered during the fiducialization process. The wireframe graphical model is a single graphical representation of every point that the Survey and Alignment Group is given as a design location. The relational database provides functionality for archiving and retrieving data from various epochs of the project's evolution in order to keep abreast of revisions and network re-observation campaigns. In addition to coordinate data and associated uncertainties the database will hold information regarding nomenclature, instrumentation, tooling, fiducialization, and ideal component design lattice positions.

General Layout

As shown in Figure 1, the driver accelerator consists of Electron Cyclotron Resonance (ECR) ion sources, a low energy beam transport containing a pre-buncher and electrostatic deflectors for machine protection, a Radiofrequency Quadrupole (RFQ) linac, linac segment 1 (with Quarter-wave Resonators (QWR) of β=0.041 and 0.085) accelerating the beam up to 20 MeV/u where the beam is stripped to higher charge states, linac segments 2 and 3 (with Half-wave Resonators (HWR) of β=0.29 and 0.53) accelerating the beam above 200 MeV/u, folding segments to confine the footprint and facilitate beam collimation, and a beam delivery system to transport to the target a tightly focused beam.

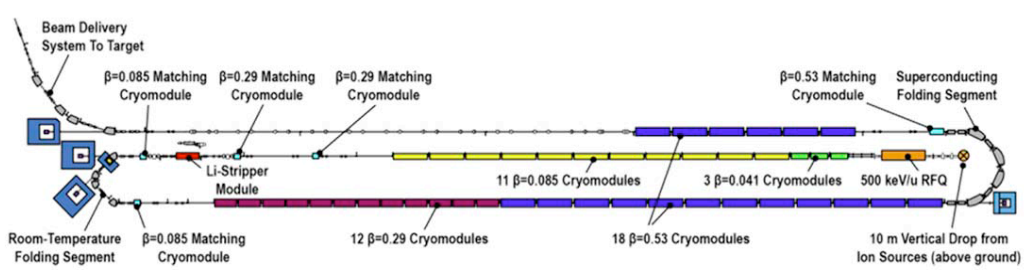

Figure 1: The FRIB accelerator layout at the tunnel level.

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ALIGNMENT NETWORK

At present the core processes are in the project-specific refinement phase. The FRIB global coordinate system (GCS) is the single cartesian site-wide reference system used by the Survey and Alignment Group to integrate the spatial information and placement requirements of the Accelerator Systems Division (ASD), the Experimental Facilities Division (ESD), the Conventional Facilities Division (CFD), and the civil construction effort. The network is an array of monuments permanently affixed in the floor and to walls to realize coordinate system. The Z-axis of the coordinate system is oriented to gravity at all locations, as the effect of earth curvature is to be regarded as insignificant with regard to project requirements. The floor monuments holes will be drilled and the monument bodies grouted in place when the concrete substrate is sufficiently cured, allowing the maximum time to elapse before the first network campaign begins. The monument body accepts a 1-1/2" spherically mounted retroreflector (SMR) the center of which is considered a geometric point and conceptually defines the monument location. The Spallation Neutron Source (SNS) floor monument design is to be adopted for FRIB. The SNS design requires no intermediate fixture for placing the SMR into the monument body. The wall monument design has yet to be chosen but several designs are under consideration with the main criteria being the method by which they are affixed and cost. Measurements are made to the SMR primarily by laser trackers and total station instruments. Digital level measurements are also made, but in that case the SMR is replaced by a solid sphere of the same dimension and measurements made to the sphere's uppermost point utilizing a bar-coded invar rod that are reduced to the sphere's center by its nominal radius.

Network observations are made to the monuments from a series of instrument stations. The series of instrument stations and observations through the front end, linac tunnel, target area and existing NSCL constitutes a network observation campaign. The objective of a network observation campaign will be the production of a triad of X, Y and Z coordinate values with the GCS.

The uncertainties associated with the monument locations represent an upper limit on the achievable global precision of alignment. The component-to-component tolerances are found in the FRIB Driver Linac Element Placement Requirements document and the Experimental Systems Alignment Requirements document.

The network path begins at the ECR ion source in the front end the beam transitions to the linac floor through a 13 m vertical drop. Monuments affixed to the walls through the vertical drop provide for the placement of instruments near the 6 m mark as well as above and below. In similar fashion, the nearby equipment hatch will also be utilized. Employing differential leveling techniques through narrow vertical passages is particularly difficult and special fixtures and aids will be needed. The linac is a folded design so there is no single corridor from which instruments may have lines of sight to all components within any particular cross section of the tunnel. Two corridors of linac floor allow for the necessary lines of sight. Along the length of the tunnel there will be monuments placed in 4 rows spaced 5 meters apart. Where available wall space will be utilized for monument placements. The rows will be spaced at 5 meter intervals along the beam path, resulting in an approximate total of 150 monuments.

COMPONENT ALIGNMENT SCHEMES

Vertical Drop Alignment

FRIB will write individual fiducialization procedure documents for each species of component in which unique or special considerations are addressed. The adjustment process should be fairly straightforward for many components, especially those spanning the linac floor. The vertical drop from the ECR to the linac floor offer significant challenges for the alignment process. The design makes use of two spaceframes, shown in figure 2, to which the individual components are affixed. In this region, the beamline components consists of 2 sets of 3 electrostatic quadrupoles residing in a common vacuum housing, vacuum pumps, profile monitor diagnostics. The individual components are mounted and aligned within the space frame in a horizontal orientation. Subsequently the individual component fiducial locations are verified and transferred to spaceframe fiducials. Alignment mounts are then placed in the drop and the spaceframe is installed and aligned. Using this method reduces alignment in the vertical drop to just two components.

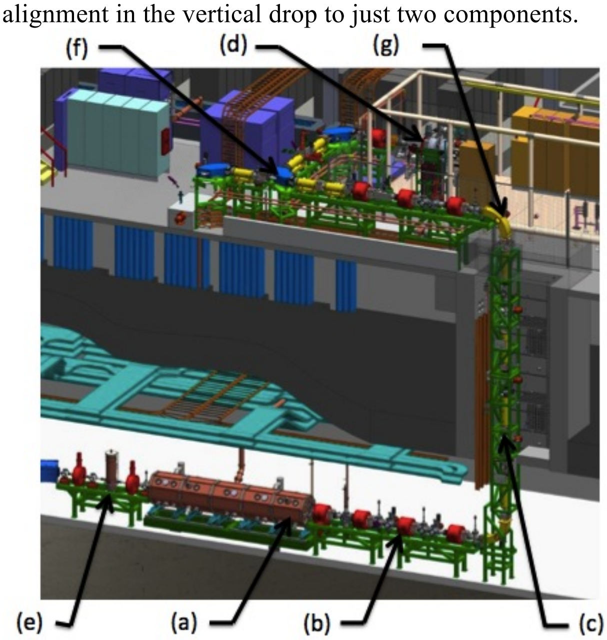

Figure 2: Vertical beamline transport section. (a) Radio Frequency Quadrupole, (b) RT solenoid, (c) vertical spaceframe, (d) SC ion source, (e) bunching resonator, (f and g) RT dipole magnet.

Cryomodule Alignment

Resonator and solenoid alignment of the cryomodule is accomplished using a mechanical axis line established from the entrance and exit 3-3/8" gate valves. The gate valves are part of weldments that are assembled with dowel pins to the vacuum vessel bottom plate which doubles as a strong back with external fuducials visible for tunnel placement. The bottom plate also supports the superconducting resonators attached to cold rail structures via G-10 thermal insulating support posts.

During assembly the inside of the resonator's niobium beam tubes are fuduciaIized to temporary SMR nests on the helium vessel. Once assembled to the bottom plate the vessels locations are logged with respect to the bottom plate fuducials in order to transform the local fiducialization coordinates into design lattice coordinates to be used for alignment in the GCS. The bottom plate fuducials are then used to place the mechanical beam axis orientation into the design lattice.

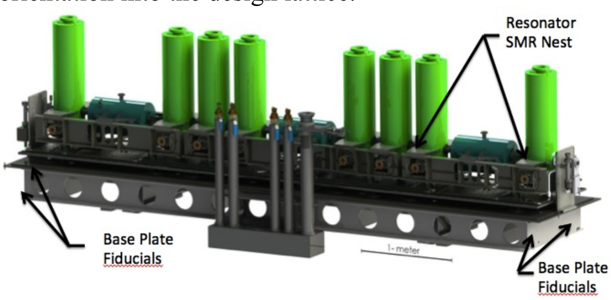

Figure 3: Cryomodule cold mass alignment setup.

Diagnostics Alignment

Beamline diagnostics located between cryomodules are integrated into the linac vacuum system boxes, shown in figure 4. These vacuum boxes and diagnostics assemblies consist of beam profile, beam current, beam position and the ability to house beam loss monitors.

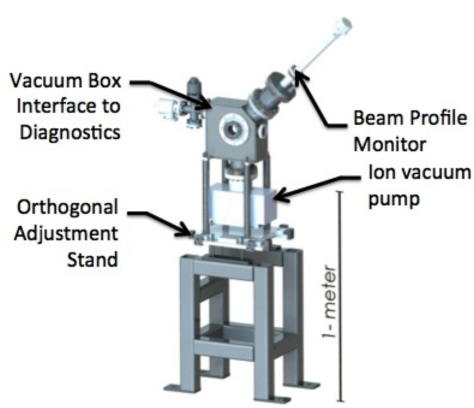

Figure 4: Integrated beam diagnostics, orthogonal adjustment and vacuum system.

Fidulization is performed during assembly and recorded into the alignment database. The diagnostic components are aligned via the vacuum box's external SMR nests. To do this efficiently the use of a coordinate measuring machine (CMM) arm may be used. The vacuum box is positioned to the tunnel network via the external SMR nests.

Magnet Alignment

The driver linac portion of the accelerator consist of room temperature (RT) X-Y correcting magnets, RT quadrupoles, super conducting (SC) dipole magnets, RT dipole magnets.

Magnetic field mapping is done with respect to 6.35 mm [.250"] holes in the pole tip steel, which are then fuducialed to SMR nests visible at tunnel installation. The SC dipole is shown in figure 5.

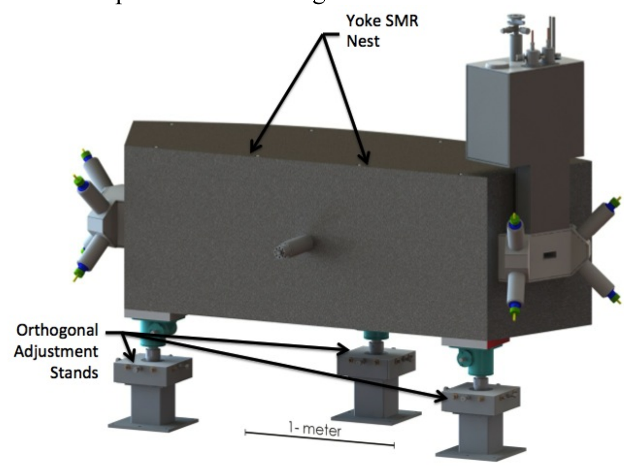

Figure 5: Folding segment 2 superconducting dipole magnet.

SYSTEMS ENGINEERING

The lattice file and corresponding 3D mechanical CAD geometry is stored in a read-only database after drafting checking and stakeholder approvals. The database is controlled using a commercial engineering software package [4]. Subsequent changes follow a formal engineering change order process that records the design history, requirements and subsequent specifications.

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