Alignment of Duke Free Electron Laser Storage Ring

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Abstract:

At present, Duke Free Electron Laser Laboratory storage ring facilities consist of a 50 meter long RF powered linac and a 107 meter circumference storagering which is designed to store 1 A of electron beam at 1 GeV. In this report, specifications and procedures for alignment of over 200 magnets, most of which must be positioned to achieve efficient injection and toobtain storage time of several hours, will be discussed. In particular tolerances of better than ±.05 mm in transverse position of ring quads and ±.1 mm for the linac quads were achieved. Some redundancy measurements such as a stretched wire method for all straight section components, wire offset measurements for the arc magnets and an invar tape designed by the Budker Institute of Nuclear Physics (BINP) for the distances between the floor monuments were used to verify the accuracy of our alignment method.

I. INTRODUCTION:

The Duke Free Electron Laser (FEL) Laboratory is housed in a 5100 square meter building located on the west campus of Duke University in Durham, NC. The building was designed to house the Laboratory's advanced infrared, ultraviolet and x-ray FEL sources, linac sections, their accelerator drives, all bending and correcting magnets and the instrumentation and setup space required by the researchers using these light sources.

The building is laid out to provide a central 2200 square meter experimental area with attached office and shop space, and a 143 meter long underground tunnel to house the linac injector required by the FELs.

To satisfy the extraordinary stability requirements for research in the ultraviolet and x-ray regions, a 1 meter thick floor slab for the storage ring area is supported on a series of 32 closely spaced caissons extended to the underlying bedrock. The spacing of the caissons and the thickness of the slab were specified to limit the deflection of the slab to less than 0.12 mm under static and dynamic load.

II. ALIGNMENT INSTRUMENTS AND TOOLS:

Several optical instruments and alignment tools were used to accomplish the alignment of the Duke FEL Laboratory storage ring. A list of these instruments and tools is as follows:

- Brunson 76-RH Telescopic transit square, used to align components in a vertical plane.
- Brunson 376-RHN Universal transit square, to perform the dual functions of telescopic transit square and linescope to turn right angles.
- Kern electronic theodolite model E2, performs angle measurements in both horizontal and vertical planes.
- Wild precision sight level model N3, used to sight in horizontal plane and set elevations of components.
- Wild precision optical plummet model NL, used for nadir plumbing.
- Brunson 803 invar scale extension kit, to measure linear distances of less than 7 meters.
- BINP invar tape, to measure distances of less than 25 meters.
- Specially made tools such as:
  - "Meterstick" assembly: used to measure horizontal transverse positions of quadrupoles in the arcs.
  - "Mirror assembly": used to measure azimuthal rotation angles about a vertical axis of arc quadrupoles, through retroreflection.
  - stretched wire-related tools: used to support wires stretched between two known points and measure transverse distances between it and intermediate magnet. Stretched wire has been used to ascertain that the floor monuments are in one straight line.

III. FLOOR MONUMENT LAYOUT:

A. Ring Floor Monument Network:

27 floor monuments (designated as Duke floor monuments) are installed in an array of 9x3 (Fig. 1). The intervals between these floor monuments are 5 meters in longitudinal and 5.2 meters in transverse direction. Transit square was used to align the monuments in a straight line. Perpendicularity of the lines were set with a theodolite and a 376 transit square. Precise distances between these monuments were measured with invar rod kit. Relative elevations of these monuments were then measured with reference to monument Mcc using the precision sight level. In order to use the BINP invar tape for verifying the distances between the monu-

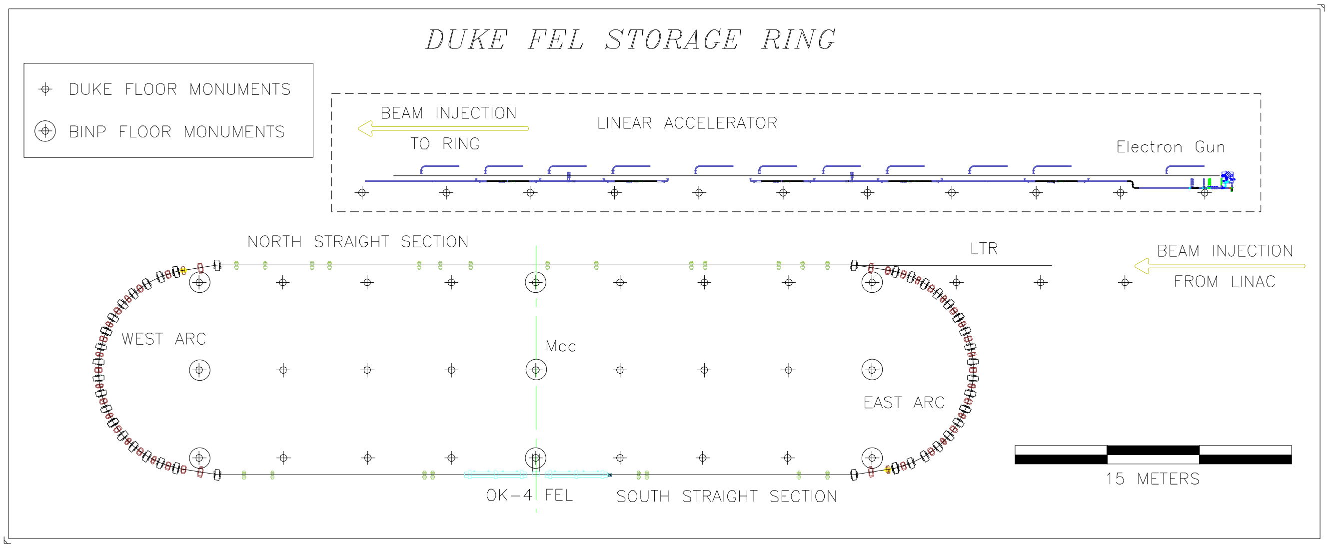

Figure 1

ments, a total of 9 specially made BINP floor monuments were adapted on the existing Duke floor monuments.

B. Linac to ring (LTR) and Injection linac Floor Monuments:

15 floor monuments are installed in a straight line as an extension from the north straight line of ring monuments at approximately 5 meter intervals. Distances and elevations of these monuments were evaluated with the same method as the ring monuments.

IV-NOMENCLATURE FOR ALIGNMENT POSITIONS AND ANGLES:

X = Horizontal (transverse) position.
X' = Angular Rotation about x axis (Pitch).
Y = Vertical position.
Y' = Angular rotation about Y axis, Yaw.
Z = Longitudinal position (in beam direction).
Z' = Angular Rotation about z axis (Roll).

V-ALIGNMENT TOLERANCES:

Installation tolerances on storage ring magnets:

	X mm	Y mm	Z mm	X' mr	Y' mr	Z' mr
Arc quads	.05	.05	.25	.5	.5	.5
Arc dipoles	.05	.05	.25	.5	.5	.5
Straight section quads	.05	.05	.25	.5	.5	.5

Installation tolerances on linac components:

	X	Y	Z	X'	Y'	Z'
Quads	.1	.1	.25	.5	.5	.5
Dipoles	.25	.25	.25	.5	.5	.5
Linac sections	.25	.25	.25			

VI. STORAGE RING ALIGNMENT

The alignment of the storage ring can be divided into 3 stages:

1. Injection Linac
2. Linac to Ring (LTR)
3. Ring

1. Alignment of Injection Linac:

At present the injection linac is comprised of 4 pairs of focusing and defocusing quadrupoles (quad doublets), 2 dipole magnets, 6 fluorescent screens, 4 current transformers, 6 steering magnets and eleven linac sections (linear accelerator sections). The theoretical electron beam path was transversely offset by 90.11 cm parallel the linac floor monuments. Relative positions and elevations of floor monuments were used as references for the alignment of the linac components. Quadrupoles and dipoles were aligned using fiducials near their extremities. Positions of these fiducials had been previously checked to a high accuracy. Linac sections were aligned in longitudinal direction with respect to fiducials that are placed at the entrance of RF input power and in X and Y direction using their outer ring and disk body.

2. Alignment of Linac to Ring (LTR):

LTR facilities begin at the end of the injection linac's high energy electron faraday cup and end at the entrance of the storage ring's septum magnet. It consists of 3 chicane (dipole) magnets, 5 quadrupoles and 6 steering magnets.

Basic principles of alignment of injection linac were applied to the LTR components.

3.- Alignment of the storage ring:

3a. Straight section alignment: The north and south straight sections consist of 22 quadrupoles, 14 steering magnets, a septum magnet, a kicker magnet and a 178 MHz RF cavity. In addition to the existing fiducials on these quads, a special BINP made fiducial is mounted on the side of each quad at exactly 25.40 cm away from its mechanical center. These fiducials are used as references for alignment of quads in the X direction. Initially, the first and the last quads on each straight section were aligned. To align these two quads in X, Z and Y' direction, A Brunson 376 transit square (placed at the nearest floor monument) and a conventional surveying scale with a proper length of invar rod were used. A Wild optical sight level and a high precision alignment level were used to set the elevation Y, and checking the roll and pitch of each quad. Once these two quads were aligned, a thin (about .06 mm thick) wire was stretched between the BINP fiducials of the first and the last quads. This wire was then used as a reference line for alignment of the Intermediate quads in transverse direction. The first and the last quad were also used to position their neighboring quads in longitudinal direction and set their ψ angle. Optical sight level and precision alignment level were subsequently used to set the elevation, roll and pitch of these quads.

3b. Arc alignment: Each dipole was mechanically aligned with respect to its companion quadrupole by pushing both magnets tightly against an accurately machined positioning jig, and then bolting and pinning both to a common aluminum base plate. Subsequently only this base plate was moved, in six degrees of freedom. Three leveling screws were adjusted to set the elevation, pitch and roll of the magnet cluster, using the precision sight level and precision alignment levels in the conventional way.

Then the remaining coordinates ρ, θ, and ψ (refer to figure 2) were set for each cluster in turn using the specially made "invar meterstick" system, which takes advantage of the fact that in our arc lattice each focusing and each defocusing quadrupole is equidistant from a common "arc center" point. A heavy hollow steel post was erected over this point and its upper end centered over the arc center monument using an accurate optical plummet mounted on the upper end. The post's adjustable diagonal braces are spring loaded to eliminate backlash.

The polar angle θ to the center of each quadrupole is set by moving the cluster plate along the beam direction until a target at the quadrupole center lines up with the crosshairs of a theodolite whose angle has been preset at the desired value, relative to the ring's arc-to-arc axis, defined as θ=0. The radial distance ρ is set using the invar-core meterstick pivoting about the center post. The tip of the micrometer head at the outer end of this "meterstick" contacts a hardened spherical button mounted on the inward-facing side of the quadrupole. The radius on this button was machined equal to the

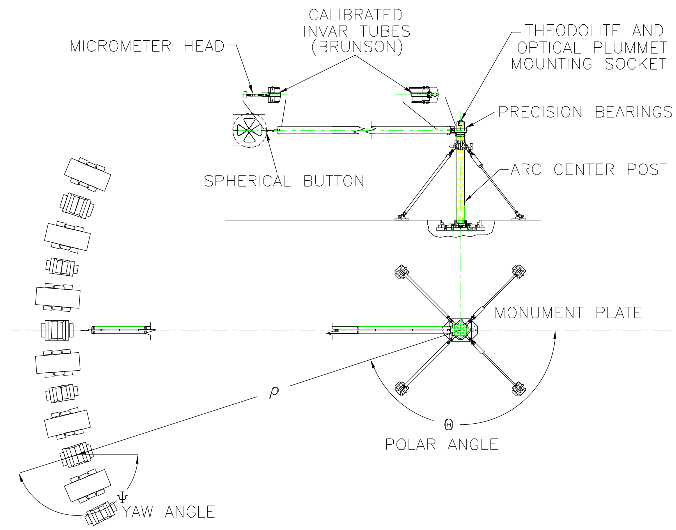

Figure 2

distance from the poletip center to the outer surface of the button, which means the meterstick is in effect measuring the distance to a sphere centered on the quadrupole. Thus the measured distance ρ is to first order independent of the Yaw angle, ψ, of the quadrupole.

This final coordinate ψ is then set to its desired value by setting the theodolite telescope's angle to the desired value, and rotating the cluster plate about a vertical axis through the quadrupole (which is possible due to the mechanical design of the cluster plate supports). This rotation is halted when the reflected image of the telescope's crosshairs line up with the crosshairs seen through the telescope. The reflection is off a plane mirror mounted on a fixture attached to the quadrupole in such a way that it is perpendicular to the flat end of the quadrupole. This perpendicularity is ensured using a pentaprism whose turning angle is specified to be within 3 arcseconds (.015 mr) of a true 90 degree angle.