Accelerator Engineering Geometry

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Purpose

- What is Dimad / Optim
- Coordinates / Coordinate Systems
- Bending Magnet Geometry
- Why the Accelerator Alignment group needs to be involved
- General historical observations

What is Dimad?

DIMAD is a program which studies particle behavior in circular machines and in beam lines(1). Trajectories of particles are computed using this program. One of the end results from the software is that an output file for mechanical use is created. This output consists of coordinates and angles which we can then relate to a “real world” coordinate system. This is a very simplified definition of what the program is used for, but for our mechanical purpose, think of DIMAD as a beamline designer software whose output is a series of coordinates and angles based on a specific machine coordinate system. Dave Douglas of CASA and FEL fame has been heavily involved with DIMAD’s development.

1 . Users Guide to the Program DIMAD, Roger V Servranckx et al, Dec 24/2003 Version 2.9

What is OptiM

For our mechanical purposes, OptiM, a program developed by Valeri Lebadev, also generates beamline coordinates. Many of the members of CASA are using OptiM to investigate and optimize beamline data. The output available for mechanical engineering is similar to that of Dimad, but the output is in centimeters rather than meters.

Both OptiM and DIMAD use the SI system of measurements, except for the pitch angle which is defined by the accelerator physics community as always being positive for a pitch up and negative for a pitch down. Accelerator physics pitch angle does not follow the right hand rule convention.

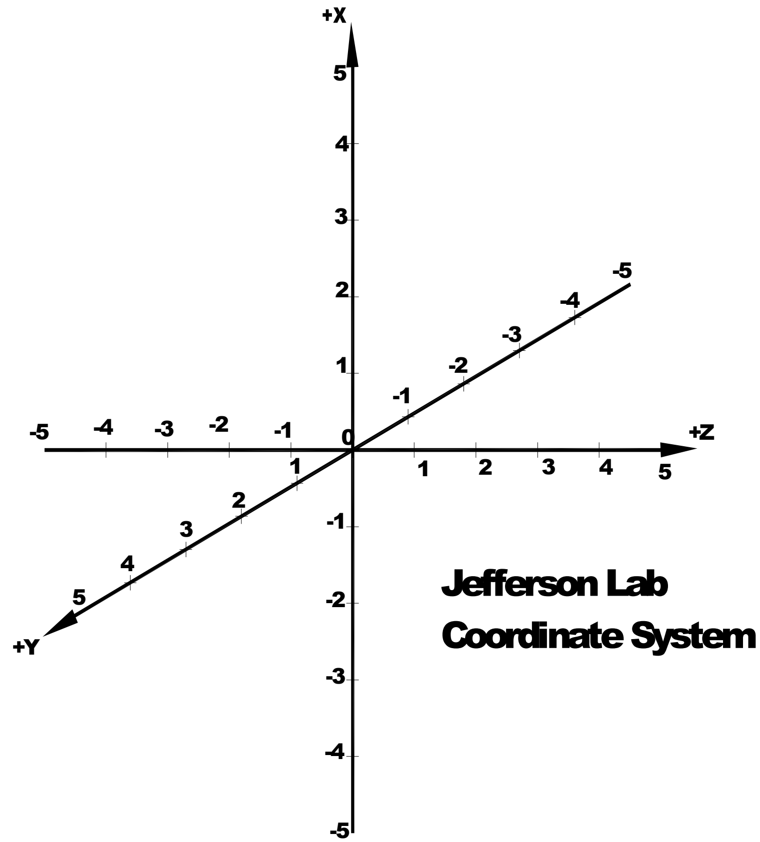
Coordinates

- What is a coordinate? Relative position in 2 dimensions is expressed as 2 coordinates per point. These can be expressed as x and y coordinates such as that in a sheet of graph paper. These are Cartesian coordinates. Points can also be defined by a polar system to a point (P) that consist of a distance from a defined origin and an angle from a reference axis.

- A 3rd coordinate can be added to a point to describe a location in space. The one to one correspondence between points in space and ordered triples of real numbers is called a rectangular coordinate system in three dimensions. Cylindrical coordinates can be used to describe the point in 3 dimensions. Cylindrical coordinates consist of a set of polar coordinates, plus a height coordinate from a level plane. Spherical coordinates consist of 2 angles (one in the horizontal (x,y) plane, one in the vertical plane (relative to the z axis) and the vector distance to the point. Physicist's often use cylindrical or spherical coordinates to describe particle motion in detectors. For most mechanical work, we use the rectangular coordinate system.

Coordinate Systems

- For our mechanical engineering purpose, a coordinate system is defined as, a method of locating points or positions by assigning numbers to them.
- A three dimensional coordinate system has 3 axes and is used to locate a point or object in space.
- There are both right-handed and left-handed coordinate systems.

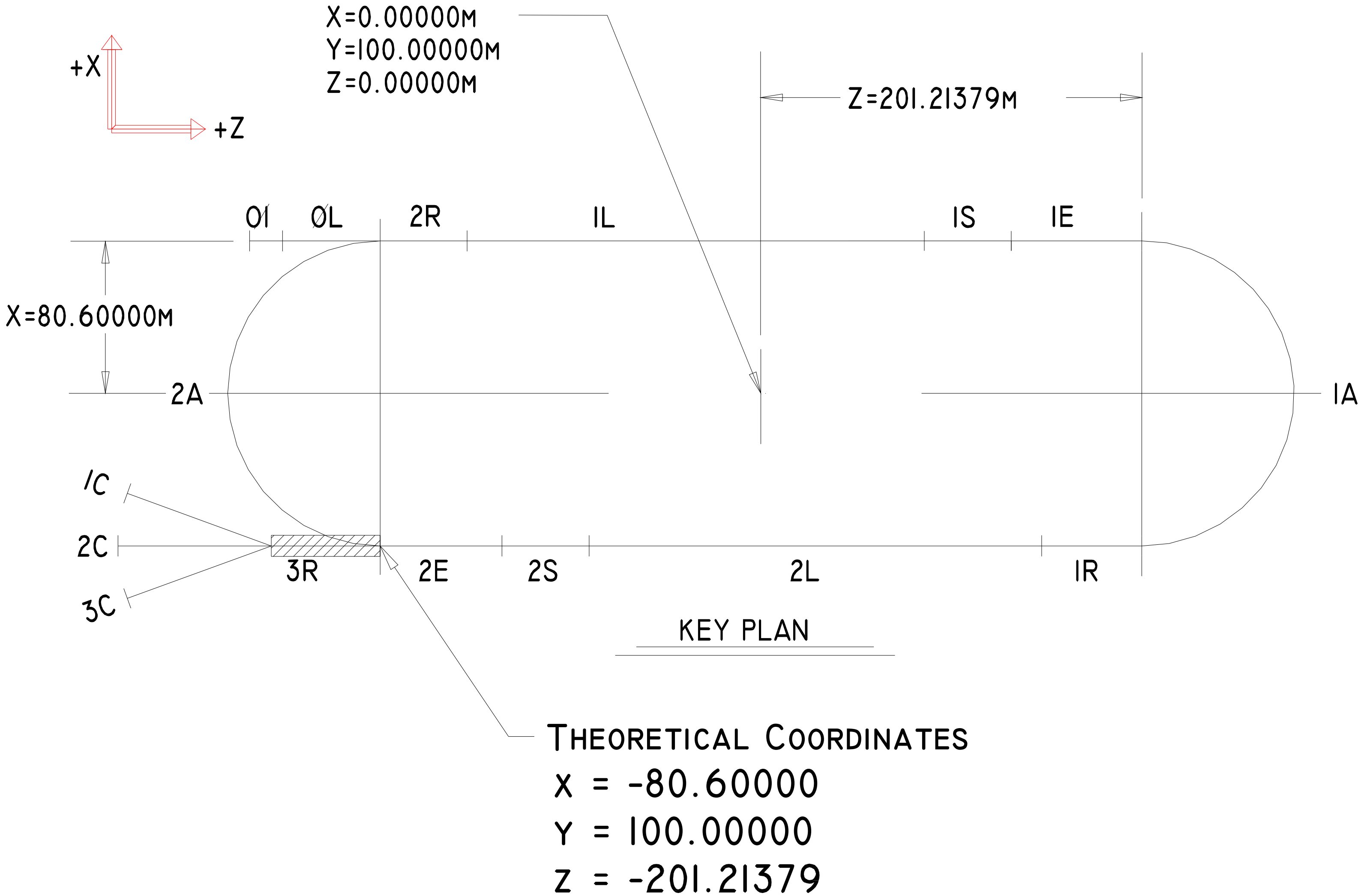


Coordinate Systems At JLab

- At Jefferson Lab, there are many coordinate systems. There are separate hall systems, surface site system, FEL system, geodetic system and the overall CEBAF machine system.

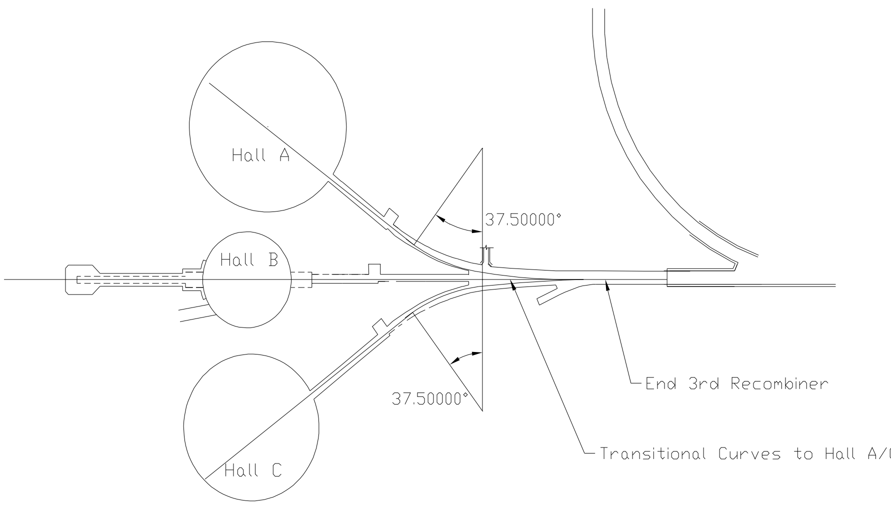
- The main coordinate system for mechanical engineering is the CEBAF machine system. This system is a right handed coordinate system with the principle axis in the direction of the North Linac (positive z axis). The y axis is transverse to the z axis in the opposite direction of the gravity vector. The x axis is again transverse to the z axis, and in the horizontal plane. The origin for this system is defined as being the mid-point between the north and south linacs in x, and the mid-point between west and east arc radial points.

CEBAF Coordinate System



BSY Coordinate System

- The 3 tunnels leading to the halls all have unique features to be aware of. Halls A and C each have a series of bending magnets that bends the beam approximately 37.5 degrees in order to hit the hall targets. Every girder / bending magnet has it's own yaw angle.
- Hall B's beam is a straight shot from the South Linac, but the line is pitched upwards to achieve a height approximately 3.35 meters above the nominal 100.0 elevation.



Hall Coordinates

The 3 experimental halls reference points are shown below, relative to the machine center. Halls A and C reference center coincides with the "ideal" target. In Hall B, ideal Clas center is used as a reference. Also note that Hall B's y value has changed vertically due to settling of the hall.

Units are Meters / yaw angle is decimal degrees, with the primary axis being the beamline in the north linac. The coordinates are in a right handed system.

name	s (meters)	x (meters)	y (meters)	z (meters)	yaw (decimal deg)
HallA	6460.59975	-32.95843	100.02200	-393.03108	142.50000
HallB(clas)	6453.76922	-80.60000	103.34326	-400.09480	180.00000
HallC	6455.63763	-124.62200	100.00000	-388.29410	-142.48324

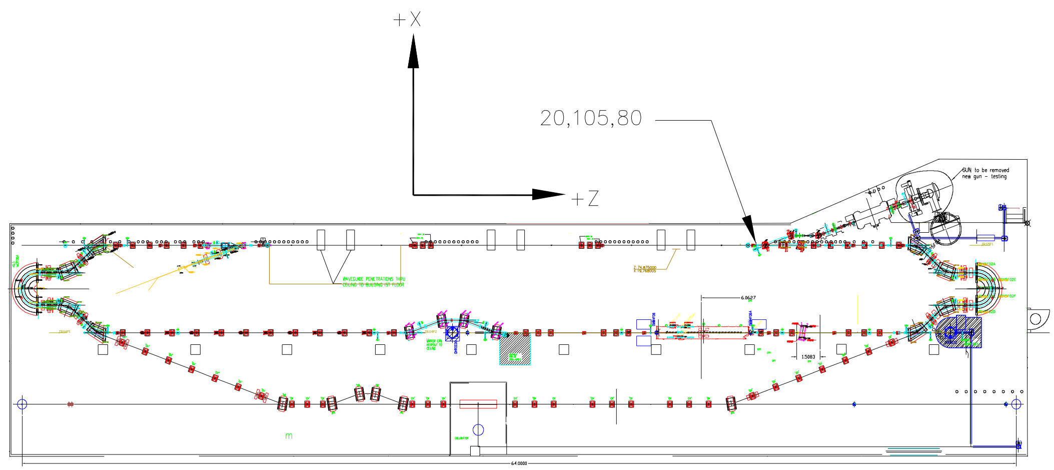
Note that the hall designers use their own coordinate system, based upon the hall centers for their designs. Note also that both Hall B and C are not at their CEBAF design centers, due to problems in construction and physical movements since 1990.

Hall Coordinate Systems

- Each hall has it's own system for their coordinate system. We must be aware of the differences.
- Hall A's coordinate system's origin is at the target center, with the principle axis following the beamline towards the dump. The units typically are inches. Related to CEBAF coordinate system, the principle axis is at a angle of 142.5°.
- Hall B's coordinate system origin is the center of CLAS, which is NOT the center of the hall. The principle axis follows the beamline towards the Hall b dump. The relationship to CEBAF coordinate system is at an angle of 180.0°.
- Hall C's coordinate system's origin again occurs at the target. Due to design errors and construction difficulties, the origin has changed since the original installation. For reference, the principle axis in the hall is at -142.48324° relative to the CEBAF system.
- Be aware, different installations within the halls have had their own individual coordinate systems, which can lead to a great deal of confusion…..

FEL Coordinate System

- The FEL coordinate system is different in that the machine runs counterclockwise. The origin is an arbitrary point.
- A reference point for all calculations is at the center of the flange upstream of the 1st cryomodule which has a coordinate of 20.0000 ,105.0000, 80.0000 meters (xyz).
- The primary axis is running positive in the direction of the ultra-violet line, with x being transverse in the horizontal plane. The y axis is vertical, in the opposite sense of gravity.

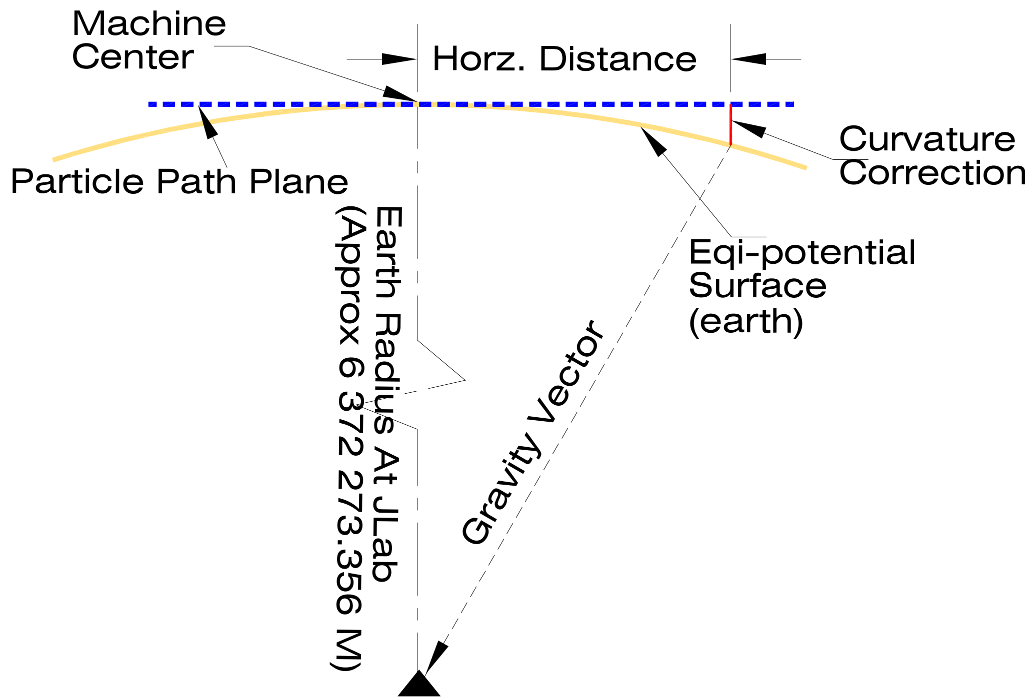


Alignment Coordinate System

- Just to be difficult, the alignment group wanted it’s own coordinate system….
- Particle physics – the beam is not affected by gravity – it travels in a plane.
- We use meters for distances and gons for our angular measurements.
- To avoid confusion over whether a point’s coordinate are in the mechanical (CEBAF) system, or any other system, alignment adds a bias of 60000.0 meters in the x direction, 2000.0 in y and 80000 in z. This was also done to allow some historical software to run without using negative values.
- To account for the beam traveling in a plane, we must add a curvature correction to all of our y dimensions (elevations). This varies as you get further from the center of the CEBAF coordinate system.
- JLab was fortunate (or the alignment group was…) that we could approximate a sphere for the site curvature correction. If the site was much larger (100m or so), an ellipsoid would have to be used for all of the curvature corrections, which entails much more difficult calculations.
- Note that mechanical and civil design and construction is in a flat (pre – Columbus) world. You do not have to account for the beams travel in it’s plane.

Alignment Curvature Correction

- How quickly do the elevations change? From the machine center (CEBAF) to Hall C target, the effect of curvature is 13.05 mm. Because alignment surveys along the earth's surface, we must account for the curvature correction for everything installed in the machine.

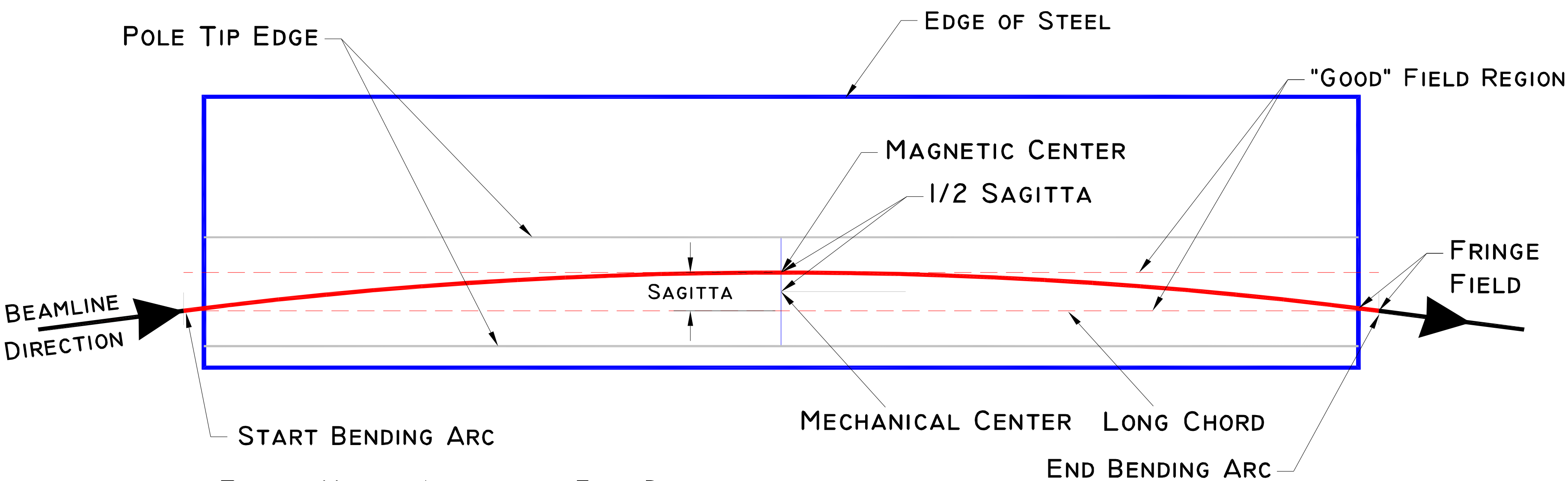


Bending Magnet Geometry

Typically Dimad supplies 4 pieces of information for a bending magnet that we are interested in for mechanical positioning. This information is the entrance coordinates, exit coordinates, bending angle and bending radius. Below is an example (Optim) for the 1st arc beamline.

N	name	S[cm]	X[cm]	Y[cm]	Z[cm]	TetaX[deg]	TetaY[deg]
136	qMQB1A02	35663.801	8060.000	10200.000	20412.120	0.0000	0.0000
137	oD126	35932.043	8060.000	10200.000	20680.362	0.0000	0.0000
138	gMBE1A01	35932.043	8060.000	10200.000	20680.362	0.0000	0.0000
139	bMBE1A01	36032.204	8050.198	10200.000	20779.880	-11.2500	0.0000
140	GMBE1A01	36032.204	8050.198	10200.000	20779.880	-11.2500	0.0000
141	oD127	36553.724	7948.455	10200.000	21291.380	-11.2500	0.0000
142	iIPM1A03	36553.724	7948.455	10200.000	21291.380	-11.2500	0.0000
143	oD102	36583.689	7942.609	10200.000	21320.769	-11.2500	0.0000
144	qMQB1A03	36598.689	7939.683	10200.000	21335.481	-11.2500	0.0000
145	oD115	36645.113	7930.626	10200.000	21381.013	-11.2500	0.0000

Bending Magnet Geometry



<u>Typical Magnet Information From Dimad</u>

Magnetic Entrance
Magnetic Exit
Bending Angle
Bending Radius

Bending Angle is the angle formed by the intersection of the entrance and exit beamlines

Sagitta Correction

- Sagitta correction is applied to bending magnets only.
- For mechanical purposes, sagitta correction can be defined as the distance between the center of the arc that a particle makes through a magnet and the midpoint of the chord formed by the entrance and exit into the magnet.
- We want to take advantage of the “sweet spot” or “good field” of a bending magnet, and therefore place the mechanical center of a magnet at the midpoint between the chord and the magnet center at the middle of the poletips.
- DIMAD / OptiM generally define only the entrance and exit points of the beam geometry, but we need to find the mechanical and magnetic centers of a bending magnet.
- The alignment group “fiducializes” bending magnets based upon the pole tip centers, hence alignment has a real link to tie in the magnet to the Cebaf coordinate system.

Bending Magnet Geometry

Taking the given beamline information and the entrance / exit coordinates for the bending magnet MBE1A01 :

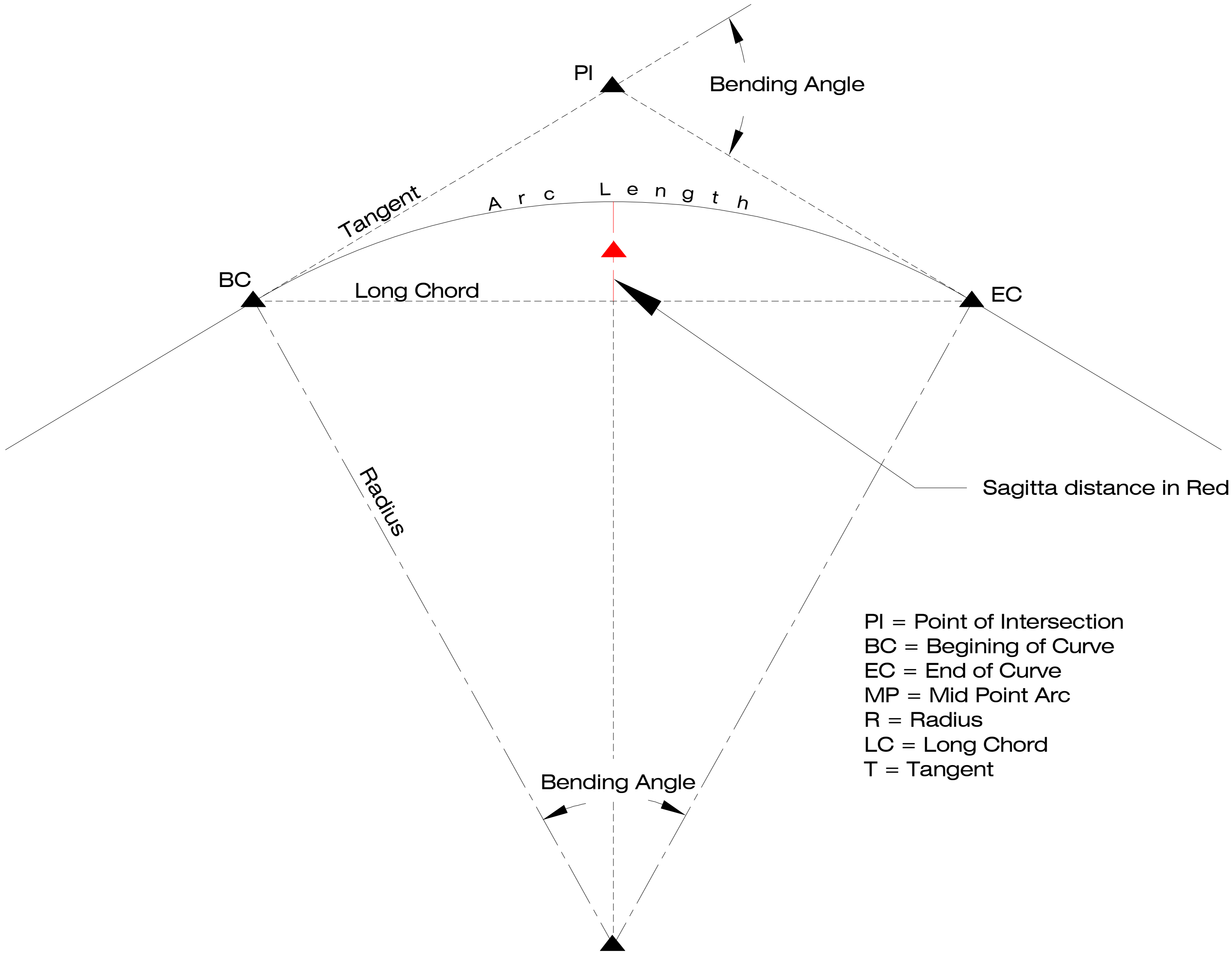
n	element	s (cm)	x (cm)	y (cm)	z (cm)	yaw(deg)	pitch (deg)
138	gMBE1A01	35932.043	8060.000	10200.000	20680.362	0.0000	0.0000
140	GMBE1A01	36032.204	8050.198	10200.000	20779.880	-11.2500	0.0000

From this information, you can derive some basic curve geometry equations, namely the radius, delta, long chord and arc distance and from these values, the sagitta correction. The long chord is the 1st value you can calculate from these coordinates. Using the distance formula, inverse the between the x,y, and z coordinates :

$$LongChord = ((x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2)^{1/2} = 1.00000m$$

The delta (bending angle) is derived from taking the yaw angle out (-11.25 °) from the entrance yaw (0.0°). Hence bending angle is 11.25°.

Curve Definitions



PI = Point of Intersection
BC = Begining of Curve
EC = End of Curve
MP = Mid Point Arc
R = Radius
LC = Long Chord
T = Tangent

Sagitta Correction

After obtaining the delta angle and long chord, and applying some basic geometric equations, the bend radius and sagitta correction can be obtained.

$$radius = \frac{LongChord}{2\sin\frac{\Delta}{2}}$$

$$ArcDist = R*(\frac{\Delta * PI}{180})$$

$$sagitta = R - R*\cos\frac{\Delta}{2}$$

We are interested in finding the mid point of the sagitta distance (1/2 sagitta correction) which in most cases will define the pole tip center of a magnet. This is also referred to as the mechanical center. The midpoint of the arc path is defined as the magnetic center.

Mechanical group relationship to Alignment

- Alignment places your designed equipment in the physical world. Data from Physics is translated into the geodetic coordinate system, and our goal is then to place your equipment into this real space.
- We are usually involved in the actual "fiducialization" of this equipment by measuring / locating the poletips, then relating this to a series of marks, or fiducials on the outside of the equipment.
- By relating these marks to the mechanical center, we can then determine where the physicist's designed magnetic centerline is to be placed in real space.
- This process starts with the bolt locations for the pedestals and stands which support the equipment.
- There are 4 processes to align equipment….

Alignment Processes

- Step 0 – Alignment's step 0 process involves the layout of the bolt patterns for the pedestals and stands. The layout is usually done to ± a few millimeters.
- Step 1 – The stands or pedestals are then aligned. Due to the crude construction of many of these stands, our alignment tolerance is done to approximately ± 3 millimeters. Typically cartridge adjusters are then placed in the stands and aligned. A typical cartridges has about 10 mm of adjustment and must account for the build up of tolerance errors.
- Step 2A – The equipment is installed on the cartridges. We do an alignment called step 2A which is done to a tolerance of ± 0.28 mm transverse to beam, and about ± 0.5 mm along beam. This allows for vacuum and other mechanical hook up.
- Step 2B – 2B alignment is our final alignment. The equipment is aligned to it's design tolerance. Alignment should be the last group to touch the equipment (in theory) and are usually the last group of people to exit the accelerator during the installation process.

Alignment Process

- If there are any mechanical / design errors / problems – it will show up when we try to match the physics locations to your bolt / cartridge coordinates.
- This is why it is vital that design data starts off on the right foot by ensuring that you are designing from the beam location specified by CASA.

What Alignment needs from the Design process

- If it has been determined that the center of a poletip is not to be used as the magnetic center point, the alignment group must be made aware of this. The poletip center is almost always used as the reference point for our fiducialization process.
- Signed off and checked drawings. It worked for the installation of CEBAF. A drawing needs to be checked for dimension stack-up at the very least before it should be signed off.
- If there is a question you can ask for as-found or built information, and if a survey is required to ascertain this data, some lead time may be required, so plan accordingly.
- Accurate bolt locations. It is the foundation of the installation, just like a house, it is the basis for what follows.

Historical Practices

- During the design of any type of unique equipment issues that have to do with alignment such as – “How are we going to align this particular piece of equipment in the Hall???”. We may have a way of assisting you that can ease the task of placing equipment in it’s proper location.
- You should not start your installation drawing without consulting with CASA as to the validity of the coordinates. Make sure it is also the most recent data.
- ALWAYS design from the beam elevation – it avoids embarrassing errors at installation.
- All CEBAF accelerator drawings should show beamline direction from the left side of a drawing to the right. This is the historical basis and should be followed for clarity.
- FEL is different ….. Jacki???
- Show beamline direction with an arrow.
- Alignment will discover errors in design when installation cannot match either existing or mating components. Please do not use us at this stage to “check” your designs.

Involve our group in your design process. If you have any questions about the installation, coordinate systems or the alignment of a piece of equipment, ask me, Chris Curtis or Jim Dahlberg early on in the process.

Thank you!