Notes on IR Triplet Alignment Process/Alignment Table

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Part of the US contribution to the LHC accelerator project is the integration of the Inner triplet quadrupoles and dipoles. And an important part of this integration is the alignment of these magnetic elements. By “Alignment" I mean the whole process of placing these magnetic elements into the accelerator so that their magnetic axes are where they are suppose to be vis a vis the beam optics analysis. Thus a successful alignment is an interplay of accelerator physics requirements, construction mechanical tolerances and measurement and survey measurement.

In order to understand the interplay of the three, we have created an “Alignment table” version 1.0 as shown in figure 1. The major goal of the workshop is to agree on the format of this table and “fill in” the table. We will attempt to start filling in numbers over the next two weeks and modify the table format as comments are gathered.

The format philosophy is as follows: Columns are arranged by the three criterion for alignment: AP requirements, mechanical tolerances and measurement and survey accuracy.

> The **AP requirements** are goals set by the AP community for achieving the accelerator luminosity and dynamic aperture requirements.
>
> **Mechanical tolerances** refer to how well the various components can be aligned as a consequence of the construction process.
>
> **Measurement and survey** refers to the ability to measure the specified alignment. Measurements include magnetic field measurements, survey, mechanical measurements (levelers, micrometers etc)

Rows are arranged by alignment “events”, which have a direct correspondence to the assembly of the inner triplet. A brief description of each process is described below. It is arranged in order of the assembly, starting with single components and working towards integrated triplet. See figure 2

The general idea is to see which column is the limiting factor for a given alignment event. If, for example, the AP requirement is much tighter than the practical achievable mechanical tolerance, then we have to either revisit the AP goals or search for new ways

to build the cryostat. Also, it doesn't make sense to achieve a mechanical tolerance that is beyond the measurement capabilities.

The correlations between alignment events are complicated and so it is neither necessary nor desirable to "vertically" compare or cumulate uncertainties. This is particularly true in sections 1 and 2 which describe the construction of the cold mass elements. The process of relating magnetic axes to fiducials accelerator landmarks via cryostat fiducials is covered in events 3-4 and can be thought of as one alignment process.

Finally the alignment events are covered:

1a) Single MQX cold mass deals with the local imperfections within the cold mass. The average harmonic imperfections over a coldmass length are assumed to be corrected by the local correctors. We expect that as long as these imperfections do average to zero this will not be a significant source of problem. Average offsets are dealt with in steps 2-4

1b) Single multilayer corrector field is concerned with the relative angles and offsets of the nested coils are here. This is assumed to be performed at CERN prior to Fermilab assembly. CERN will provide mechanical fiducial keyed to the strong correctors for attachment at Fermilab.

2) Construction of the cold mass from single elements. MQX magnets and correctors come together to form a single cold mass. Location of these elements will depend largely on mechanical locators on the cold mass. MQXb magnets have an alignment key on the skin that locks into the yoke, which in turn looks into the collars. Multilayer correctors are expected to have a fiducial on the out side of the strong correctors. The elements will be joined together on a table in the Fermilab Industrial Center building. If mechanical measurements are not sufficient, we have the option to perform room temperature stretch wire measurements at any stage of the construction. Otherwise all of the elements will be measured warm and cold in the Fermilab magnet test facility after cryostating (step 3)

2a) Relative alignment of MQX magnets in composite Q2. For the case of the Q2 only, there will be two MQX magnets rigidly joined in one cold mass. The relative alignment cannot be modified once in the cryostat. In practice, the magnetic center of Q2a , Q2 b and the combined Q2a-Q2b magnet will be separately measured and the best magnetic axis will be determined Based on these determinations, the location of the Q2a-b cryostat in the tunnel should be adjusted as per AP requirements.

2b) Relative alignment of corrector in a composite Q2 and Q3 The corrector packages will be mounted on the front face of MQX magnets

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3) Placement of composite coldmass into cryostat and relating magnetic axis to external fiducial. This deals with the placement into cryostats of Q1, Q2, Q3, complete with correctors, absorbers etc. The magnetic axis will be determined warm and, for most magnets, cold and this axis will be related to external fiducials on the cryostat. This cold axis to external fiducial is just what is needed for tunnel installation.

The proposed method for determining the magnetic axis is to use a “stretched wire”. This procedure will be explained during the workshop. The stretched wire is placed in the bore tube of the cryostat and is left in place for both warm and cold measurements. The magnetic axis will be known relative to fiducials on the stretch wire platform. It is then required by survey or other means to transfer these fiducials to the cryostat fiducials.

Since not all of the magnets will be measured cold, it is important to understand the correlation between warm -cold measurements.

Since we are locating the magnetic axis to the cryostat fiducial, in principle, it is not necessary to understand how the relationship of the cold mass to the cryostat. In practice we must understand this to the extent that the cryostat would move during thermal cycle or between through transport. Further changes in the cryostat during tunnel installation could effect the alignment. Thus we need to understand how stable are the internal magnets supports so that the position does not shift with thermal cycle and transport? Will it be necessary to remeasure the magnetic centers once they are shipped to CERN?

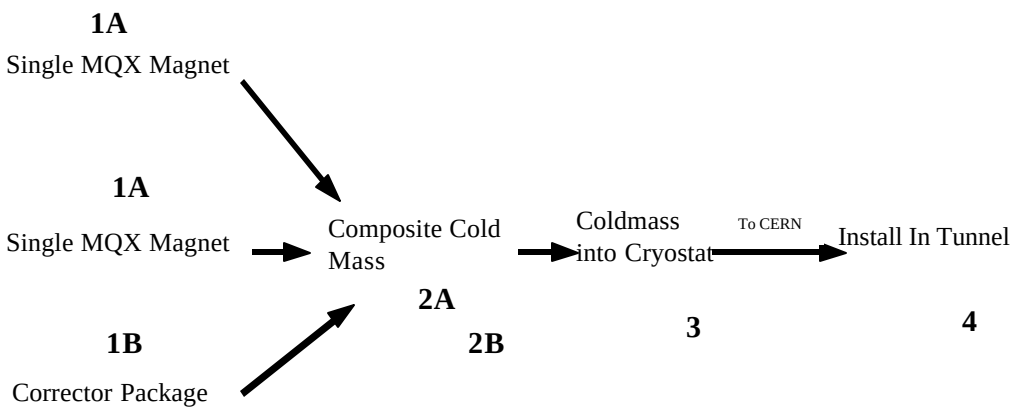
4) Alignment and Survey into IR This is largely the domain of the installers. What are the accuracies for the tunnel installation and how does this effect the AP requirements? In the case of Q2, how should the Q2a/Q2b misalignments be handled? What effect, if any, is the tunnel cryostat mounts on the sag and otherwise deformation of the cold mass.

Figure 1 Alignment Table for Workshop Version 1

Alignment Table	**AP Requirements**	**Mechanical Tolerances**	**Measurement and Survey Accuracy**	
			Warm	Cold
1a) Single MQX cold mass				
Straightness H and V				
Twist				
1b) Single multilayer corrector field				
Relative layer displacement				
Relative layer rolls				
2a) Relative alignment of MQX magnets in composite Q2				
Q2a/Q2b transverse alignment				
Q2a/Q2b relative roll				
Q2a/Q2b relative pitch and yaw				
2b) Relative alignment of corrector in a composite Q2 and Q3				
Corrector displacment				
Corrector roll				
3) Placement of composite coldmass into cryostat and relating magnetic axis to external fiducial				
Displacement transverse				
Displacement longitudinal				
Sag				
Roll angle				
Pitch/Yaw				
4) Alignment and Survey into IR				N/A
Triplet displacement				

Figure 2

Installation and Corresponding Alignment



1A Single MQX ColdMass Twist and Straightness
1B Single Multilayer Corrector Internal Alignment
2A Relative Alignment of MQX in Composite Q2
2B Alignment of Corrector to Composite MQX Magnetic Axis
3 Magnetic Axis to Cryostat Fiducials
4 Alignment of Cryostat to IR