NCSX Modular Coil Assembly Fixture (MCAF) Reference Design
Design Update and Response to Information Meeting Questions

A lot of good comments and suggestions came from the MCAF information meeting and through feedback received from vendor's responses to the questionnaire circulated by PPPL Procurement. When the information meeting was held, the basic design approach for the Reference Design was fairly well characterized for the installation of the Modular Coil Half Period (MCHP) from the right hand side, however the details required for the Turning Fixture to manipulate the MCHP from the left hand side had not been investigated and the MCHP interface with the gantry crane was only partially defined. This document is intended to provide updated design information on the Reference design and answer questions received concerning the Reference design and the MCAF design specification document supplied at the information meeting.

1.0 Turning Fixture: The Reference design (see Figure 1.0-1) has been updated in four areas: 1) in order to provide the same motion of the Turning Fixture from the left side the 6.125" x-axis offset was eliminated and an I-beam was added to the left side base guide rail, raising the vertical placement position for the left side Turning Fixture; 2) two of the Turning Fixture linear support structures were resized to provide greater stability; 3) the interface between the turning fixture and the gantry crane has been further developed and 4) preliminary concept models were developed to evaluate bolt access to the installed MCHP's. Figure 1.0-1 shows the final configuration for the MCAF where MCHP's are supported from the gantry crane on the right side and off a repositioned Turning Fixture on the left side.

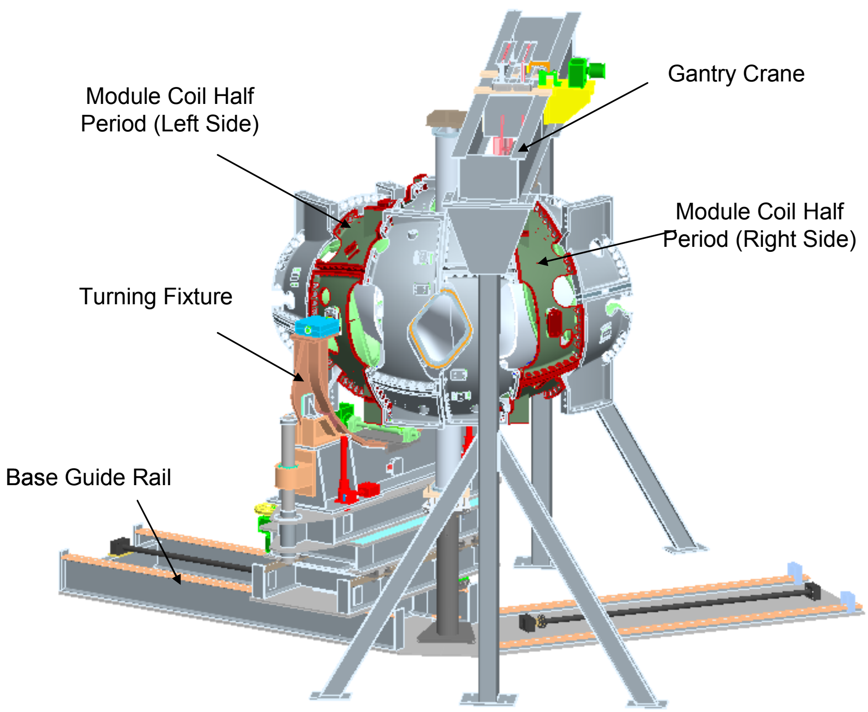
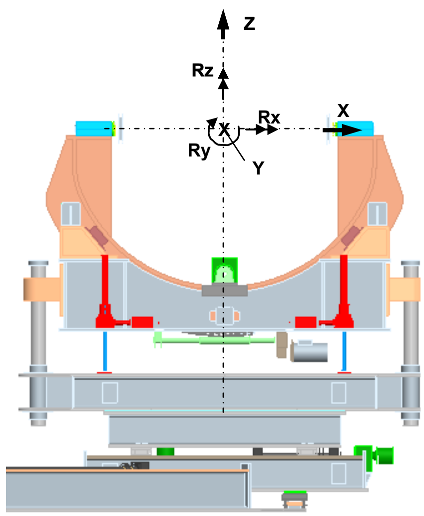
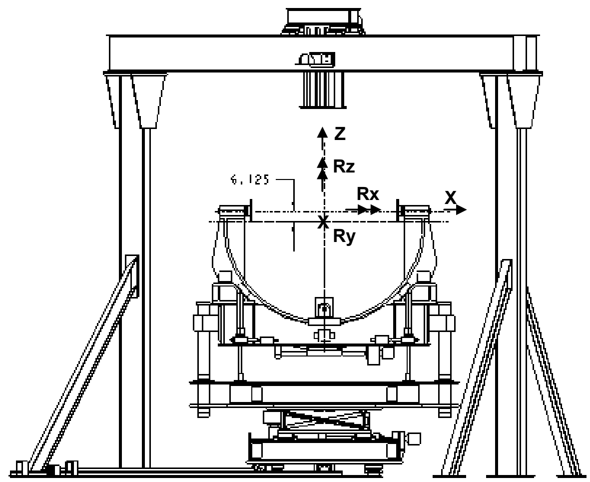


Figure 1.0-1 Reference Design Modular Coil Assembly Fixture

1.1 X-Axis Offset: To retain the same motion on the left side the 6.125” offset of the x-axis from the machine coordinate centerline has been eliminated. This was accomplished by expanding the overall width of the turning fixture and reducing the height of the gimbal structure. A comparison of the change in axis is shown in Figure 1.1-1.



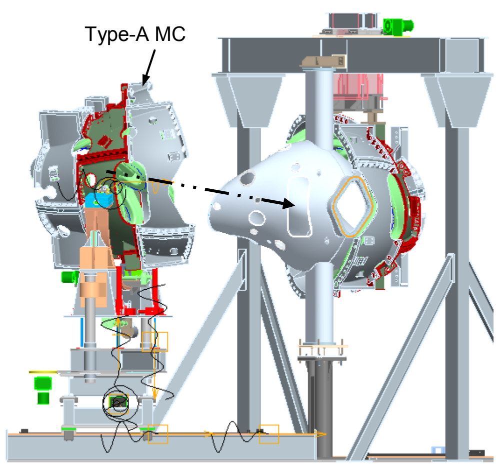
Updated Reference Design



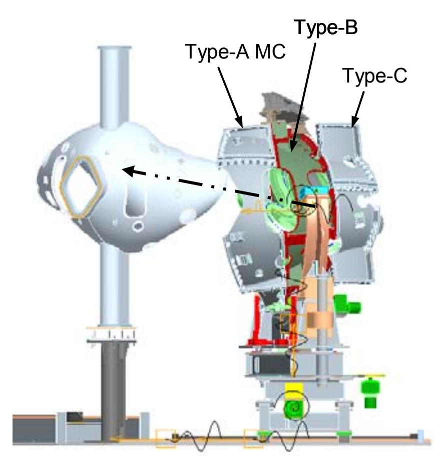
Reference Design as presented at the Information meeting

Figure 1.1-1 Turning Fixture Reference Axis

1.2 Base Guide Rail Revision: An I-beam was added to the left side of the base structure to raise the placement position of the Turning Fixture. This enables the jack screws providing z-direction motion to be sized to provide the minimum vertical lift needed to raise the MCHP from either the right or left side. It should be noted that the vacuum vessel shell geometry forces the MCHP to move from a low-to-higher position on the right side and from a high-to-lower position on the left side (see figure 1.2-1).



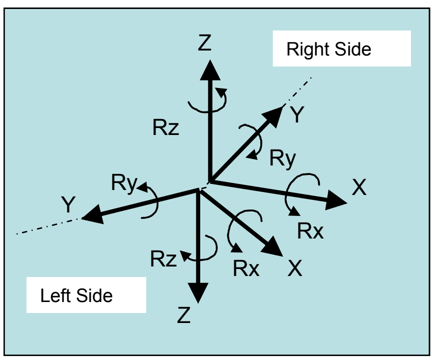
MCHP moves from a high-to-lower position on the left side



MCHP moves from a low-to-higher position on the right side

Figure 1.2-1 Motion of MCHP on Left and Right Side

1.3 Coordinate System: With the revision in the x-direction offset and the addition of an I-beam on the left side the coordinate system that defined the MCHP path on the right side could simply be rotated about the Machine Coordinate System x-axis, allowing one servo table drive system to operate both the left and right side. Figure 1.3-1 shows the relationship between the left and right coordinate systems and the Reference Design 247 step servo table. For clarification, it should be noted that the servo table is set up to "disassemble" a MCHP over the vacuum vessel. We have defined the starting position on the servo table (Step 0 – all values are at 0) as the position where the MCHP is located when the left and right sides are bolted together (their final position). Step 3 is the position where the MCHP is beneath the gantry crane ~ 0.54" from the final position (Step 0). The phantom box in the servo table indicates that only motion in the y and x direction occurs during Steps 1 thru 3, allowing the MCHP to move perpendicular to the interface parting plane between the left and right hand MCHP's. Step 247 defines the position where the MCHP Type-A MC will start to pass over the vacuum vessel (moving toward the gantry crane, see Figure 1.2-1). Additional steps beyond Step 247, that will move the MCHP to a position at the end of the guide rail, have not been added to the servo table at this time.



FPA Coordinate System

Reference Design Servo Table

Step	t	dy	dx	dz	rx	ry	rz
0	0.00	0.000	0.000	0.000	0.000	0.000	0.000
1	0.01	0.043	0.025	0.000	0.000	0.000	0.000
2	0.02	0.220	0.127	0.000	0.000	0.000	0.000
3	0.03	0.468	0.270	0.000	0.000	0.000	0.000
4	0.04	0.637	0.058	-0.386	-0.171	0.219	0.210
5	0.05	0.806	-0.154	-0.772	-0.341	0.439	0.421
6	0.06	0.975	-0.366	-1.157	-0.512	0.658	0.631
7	0.07	1.144	-0.578	-1.543	-0.682	0.878	0.841
242	2.42	72.505	-10.274	-14.387	3.072	-11.587	12.834
243	2.43	72.869	-10.274	-14.387	3.072	-11.587	12.834
244	2.44	73.234	-10.274	-14.387	3.072	-11.587	12.834
245	2.45	73.598	-10.274	-14.387	3.072	-11.587	12.834
246	2.46	73.962	-10.274	-14.387	3.072	-11.587	12.834
247	2.47	74.327	-10.274	-14.387	3.072	-11.587	12.834

Figure 1.3-1 Turning Fixture Reference Axis

1.4 Trajectory Validation: We have reviewed and validated the three dimensional motion that the MCHP takes in passing over the vacuum vessel. The motion was developed using an in-house code that selectively orients the MCHP at stepped increments to optimize the spacing between the MCHP and vacuum vessel surface, given the selected trajectory (or path) shown in figure 1.4 -1. We have performed interference checks of the MCHP and VV following the derived path using a Pro/Engineer Mechanism software package. The solution that we have used is not unique; alternate paths can be selected. We chose the MCHP path with the position and orientation of the Y-axis, shown in Figure 1.4-1, to minimize the extent of motion of the MCHP as it passes over the vacuum vessel. This enables us to make incremental moves in one direction (dx, dy, …, rz) if necessary. Alternate paths may require larger MCHP motions, potentially limiting the ability of incremental motion. Our plan is to offer the Reference Design as one possible solution for assembling two MCHP's over the vacuum vessel and provide all data that supports it (models, drawings, servo table, etc.). At the same time we will support any vendor initiated modifications to the Reference Design or alternate proposed solutions that would provide a lower cost system.

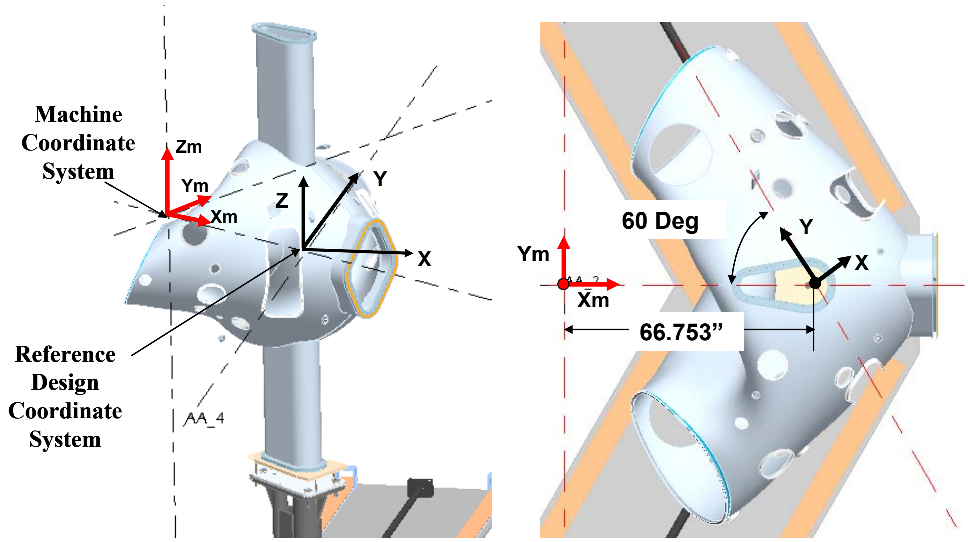


Figure 1.4 -1 MCAF Coordinate System

1.5 Travel Distance and Speed: For the Reference Design the turning fixture on the right side will manipulate the MC over the vacuum vessel to within ~½ inch of its final position and then stop. To reach this point the turning fixture will have traveled ~110 inches along the base guide rail (y-direction) over an elapsed time of about 60 minutes. The travel rate while moving over the vacuum vessel is very slow (~1.5”/min) in the Reference Design, governed by the mechanisms needed to position the spherical seats and the desire to view the movement of the MCHP over the close fitting vessel. The maximum rate of speed for the Reference design is ~2.25”/min. With the slow velocity it is expected that a sudden stop condition will not create an acceleration force in excess of the requirement for seismic forces.

1.6 Resized Linear Support Structure: To improve the stability of the Turning Fixture against seismic and sudden stop conditions the first two support bases of the Reference Design were enlarged in the y-direction of motion (see Figure 1.6 -1).

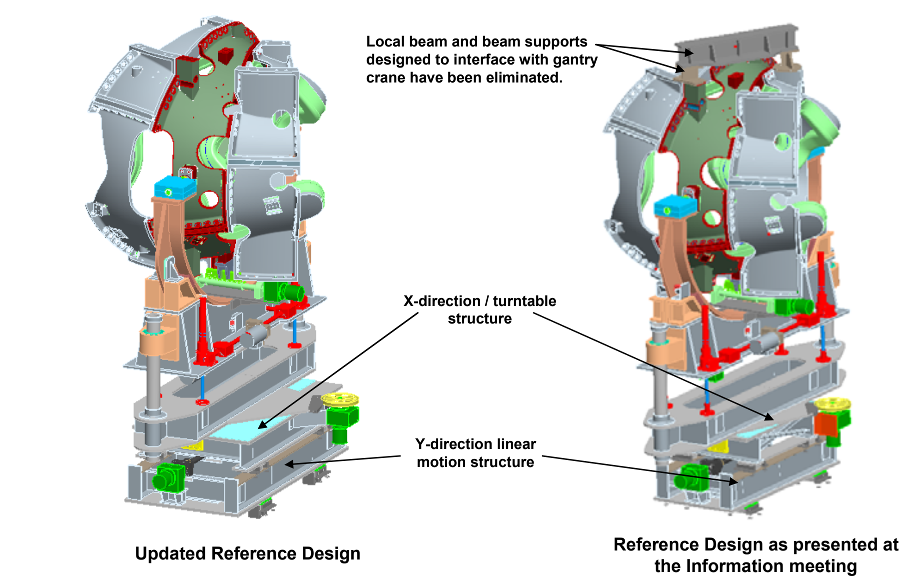


Figure 1.6-1 Resized Linear Support Structure

2.0 Gantry Crane: The Reference design gantry crane serves two purposes: 1) it supports the right side MCHP when it is ~ 1/2" from the final position (moving from step 247 to step 3 in the Ref servo table listed in Figure 1.3-1); and 2) it provides support to a linear mechanism that moves the right side MCHP into its final position (~ 1/2" of linear motion). Because of the geometry of the Type-A MC the MCHP's would interfere with each other if we were to simply place the right side in its final position and then manipulate the left side to reach its final position. With the right side supported off the gantry crane, the left side can be moved to its final position (reusing the turning fixture); then the right side can be moved to its final position using the local mechanism that is mounted off the gantry crane. The Reference design gantry crane has been updated to better define the MCHP attachment method and to identify service access for attaching the MCHP to the crane and bolting the MCHP's together. Figure 2.0-1 highlights the latest arrangement of the gantry crane showing an updated MCHP support system.

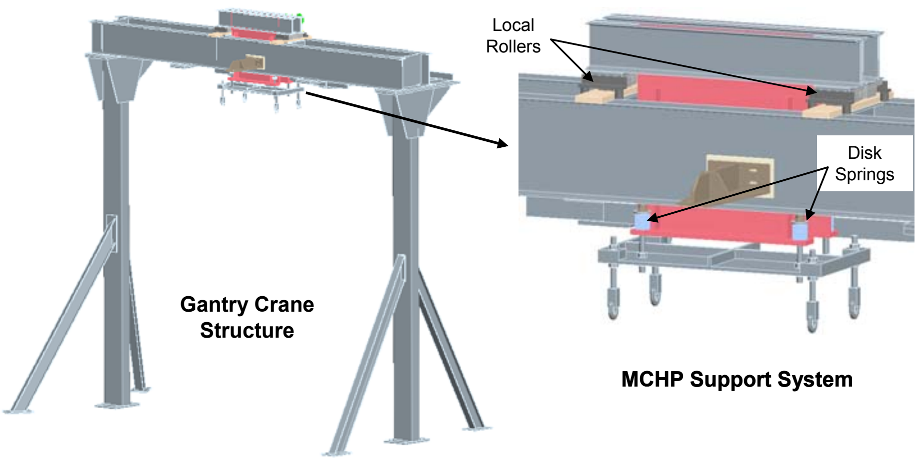


Figure 2.0-1 MCAF Gantry Crane

2.1 MCHP / Gantry Crane Attachment Method: The Specification document reviewed at the information meeting called out a requirement to limit the vertical deflection of the gantry crane to .050" inches (defining a relatively stiff system). When the MCHP is transferred from the turning fixture to the gantry crane there can be no interference with the vacuum vessel insulation system due to deflections of the gantry crane. Contrary to this "stiffness" requirement there is a desire to have some degree of "float" in the support of the right side MCHP support (off the gantry crane) in an

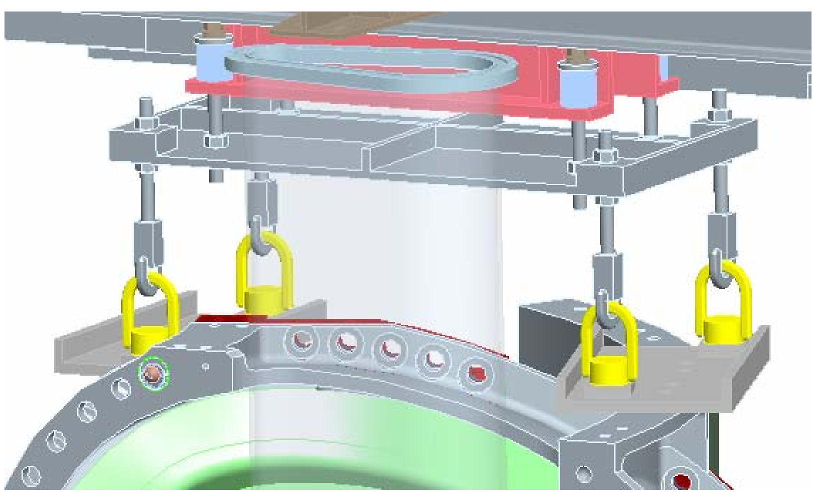


Figure 2.1-1 Gantry Crane / MCHP Interface

effort to aid the seating of the two MCHP's as the gantry crane mechanism moves the right MCHP to its final position, engaging the left side MCHP. Figure 2.0-1 and the local view of Figure 2.1-1 shows the approach used in the Reference design for interfacing the gantry crane with the MCHP. The MCHP is supported off four links that span the CG of the MCHP. Relatively stiff disk springs have been added to provide some additional "float" to the support system to increase the allowable deflection of the system to ~ 0.10". The evaluation of the support method and final specification of the allowable deflection is under internal review.

3.0 Specification

3.1 Seismic Criteria: Section 3.1.19 of the draft MCAF specification document currently states: All systems (MCAF and secondary support structure) must be designed for seismic conditions assuming a static seismic criteria factor of 0.11 and cannot tip over during operations. Also referenced is an NCSX Seismic Requirements document, "NCSX-CRIT-Seis-00". This document references a number of codes and standards that were used in developing the MCAF seismic criteria. The seismic criteria that we have specified relates to a single "g" force factor applied to the center of gravity of the component in question. We do need to make some adjustments in the seismic criteria.. We will alter the seismic criteria specification to state that all rigid components mounted to the floor must be designed for conditions assuming a static seismic criteria factor of 0.108 (a three place number specified in the NCSX seismic Requirements document). This will apply to the gantry crane and to the MCAF when it is located at the end of the guide rail in a "collapsed" position. No seismic criteria will be specified during the time period when the turning fixture is in operation. We will cover this condition under our internal Job Hazard Analysis documentation that will define safety procedures to mitigate risks. We will retain the requirement that the Turning Fixture cannot tip over during operation in another section of the specification document to cover a sudden stop condition.

3.2 Dimensional Accuracy: At the time of the information meeting the specification document only provided a general workmanship statement (3.4.2.1). We will refine this in the final release. The dimensional accuracy of the individual turning components appears to be less critical since the Turning Fixture operates with six degrees of freedom of motion. We feel that the structural members should not be overly constrained in their dimensional accuracy, potentially escalating the overall cost. We had envisioned that the positional accuracy of the system would be developed through the small step requirement of the servo drives needed to position the three spherical seats and the control system that programs the motion of the Turning Fixture (under load).

3.3 Spherical Seat and Machine Position Measurement: PPPL has a Leica laser tracker system that can be used to accurately measure the position of the spherical seats located on the face of the Type-A modular coil to within +/- .002". We will use this device in the assembly of the MCHP over the VV and during the final machine assembly. There will be a number of fiducials located on the vacuum vessel and modular coils that will be used to define best fit orientations of both the vacuum vessel and MCHP's to position them in the MCAF and to determine the proper orientation of a MCHP when positioned at the start of the base guide rail of the Reference Design. It was envisioned that using the Leica laser tracker, measurement of incremental movement of fiducials located on a simulated MCHP object would be used in establishing the operating steps of the servo program. In an effort to keep the cost of the MCAF down it should be possible that PPPL provide the Leica equipment and personnel needed to operate it during the measurement and motion characterization time period of the MCAF contract. Further discussions should be undertaken to develop the details of this arrangement if it is deemed cost beneficial.

3.4 Welding Procedures: Procedures for welding of structural components will be expanded to include ASME Section IX in addition to AWS D1.1. Inspection and testing of welds will still be done to AWS D.1. Criteria for statically loaded structures will be used as the acceptance criteria (from AWS D.1.1 Table 6.1). We do not anticipate that Stainless Steel will be used in the fabrication of the MCAF; however, AWS D1.6 (for Stainless Steel) will be added to the specification to cover situations where it might be used.

3.5 Codes and Standards: The MCAF shall be designed to the latest edition of AISC "Steel Construction Allowable Stress Design".

3.6 Limit Switches: The Limit switch is intended as a safety precaution for stopping an over-travel condition.

3.7 Shear Coupling: The requirement of the shear coupling was to protect the components from excessive torques; however safety conditions must be taken into account so that there is no movement of the MCHP if the coupling is sheared. If the gear ratios within the design is high enough a self-locking condition will exist to hold the load without back-driving. Limit switches can be used to handle an over-travel condition but additional capabilities (such as motor torque feedback) need to be added to the control system to cover any off-normal binding condition.