NCSX FPA Metrology and Dimensional Control Overview

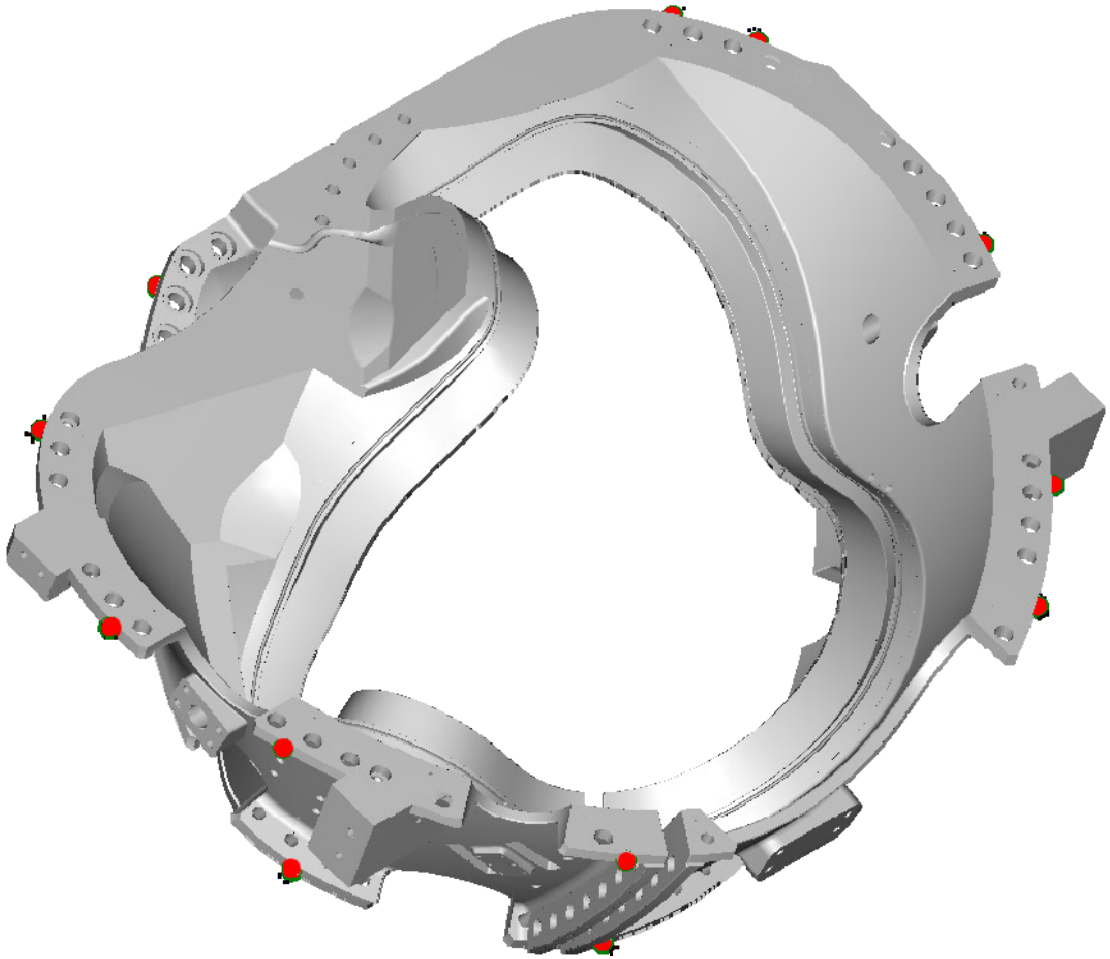
Haange/Klinger visit to PPPL

October 6-7, 2008

Dimensional Control Overview

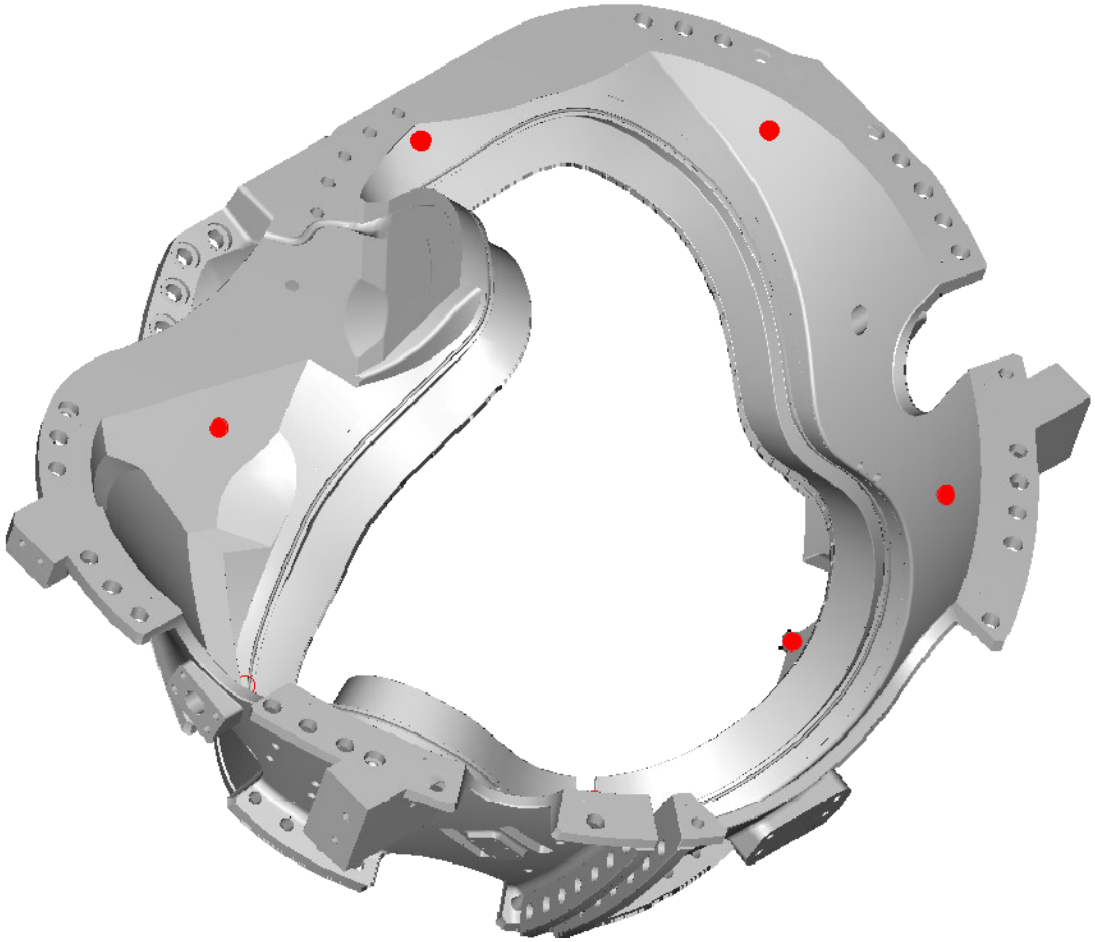
- Goal: Current center of Modular Coil Winding Form (MCWF) positioned within 1.5mm [.06in] of Theoretical Position
- After coil fabrication, Windings cannot be measured directly
- Set of monuments (“conical seats”) relate points on MCWF to HPA global coordinate system
  - Assumptions/Parameters:
    - Measurement accuracy during winding.
    - Deviations during winding.
    - No movement of windings after lacing.
    - No distortion during VPI and curing.

Coil Monument History



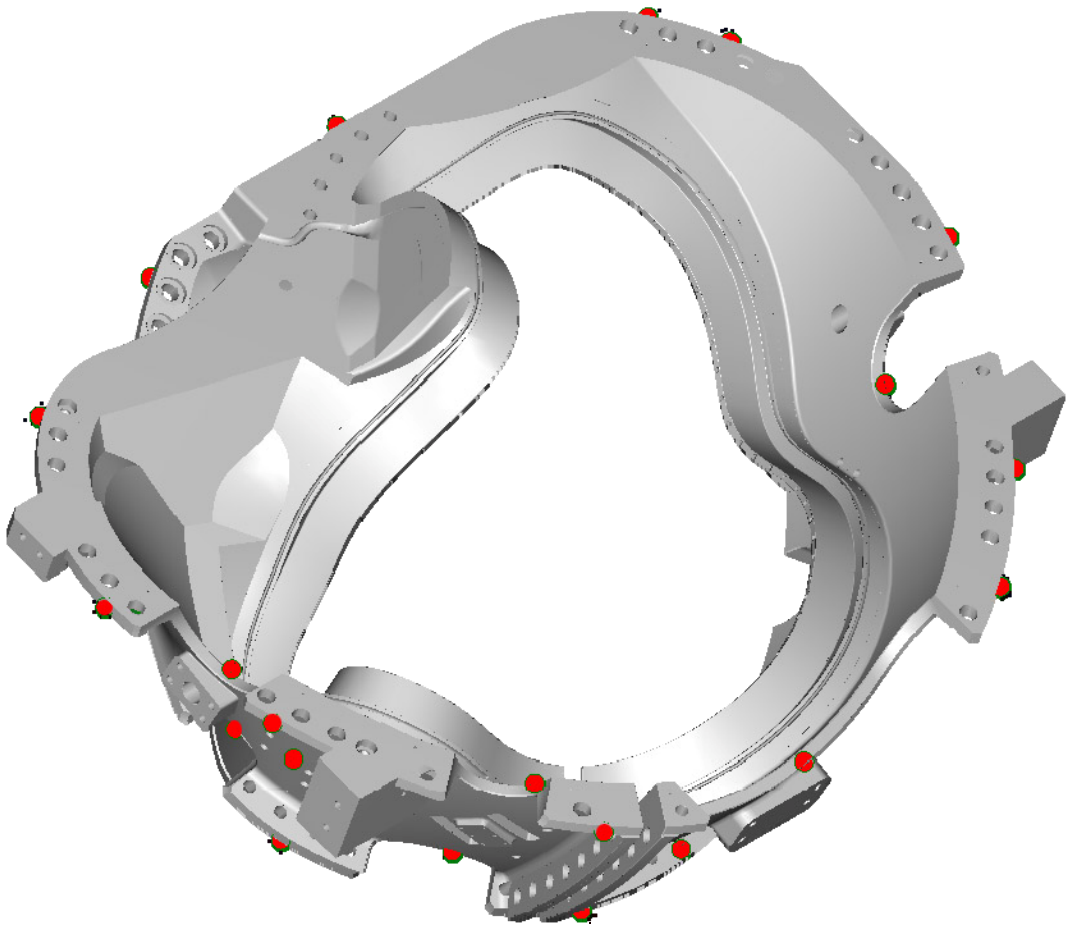
MTM flange tooling balls used for initial inspection and alignment

Coil Monument History



PPPL adds 15mm conical seats for subsequent alignment during winding

Coil Monument History



After winding, metrology transitions back to flange tooling ball locations and adds body tooling balls

Pre-Measurement Process

- Quality of alignment is critical to the success of this step
- Modular coils can deform significantly as a function of their supports
  - Winding fixture (vertical, bolted)
  - HPA assembly position (horizontal)
- Before pre-measurement, modular coils must be twisted, or “racked”, into its as-wound shape as best as possible
  - Adjustments normal to flange
  - Gravity load of one coil
  - 0.005” RMS deviation on alignment to conical seats (ALARA)
- Measure tooling balls

Pre-Measurement of Flanges and Monuments Follows Alignment

- Establish a network of global monuments attached to building
  - Use for relocating laser tracker
  - Use for resuming work after equipment powered down overnight or inadvertently bumped
- Alignment criterion for global monuments is 0.002” RMS deviation
- Measure all monuments
  - Multiple laser positions are necessary.
- Scan the appropriate flange

Sample Alignment Report

Verisurf Alignment Report

Verisurf Alignment Report

Part Name: 072707 B1 COIL ON MTM WEDGE BWARP-AA

Alignment Name: 072707 b1 warp Auto Align 1

Coord System: WORLD

Date: 08/02/07

Fit Results

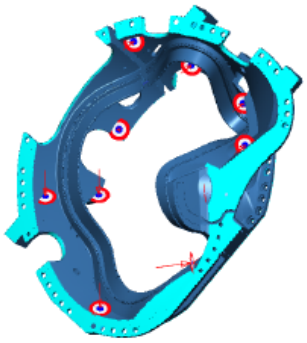
Name	DX	DY	DZ	3D
3D Point 10	-0.002	-0.001	0.003	**0.003**
3D Point 11	0.001	0.002	0.000	**0.002**
3D Point 12	-0.002	0.000	0.001	**0.003**
3D Point 13	-0.003	-0.003	0.001	**0.004**
3D Point 14	0.000	-0.003	-0.002	**0.004**
3D Point 15	0.000	0.000	0.001	**0.001**
3D Point 16	0.001	-0.002	0.001	**0.003**
3D Point 17	0.004	0.006	-0.004	**0.008**
3D Point 18	(0.006)	(0.010)	(-0.012)	**(0.017)**
3D Point 19	0.002	0.002	-0.002	**0.004**

Fit Summary

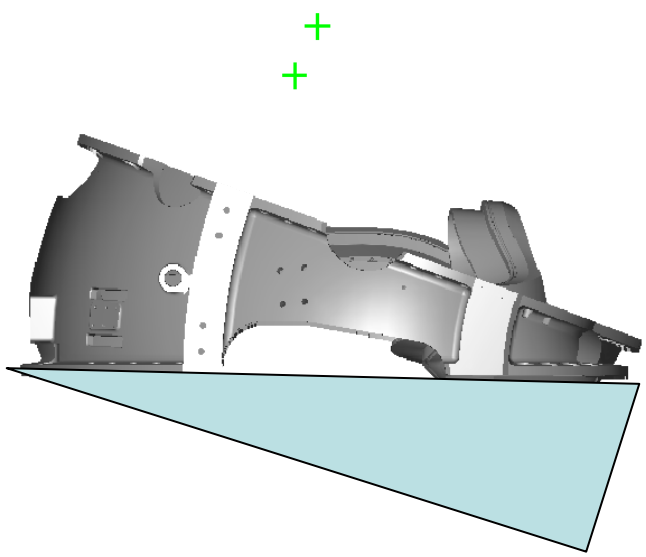
Total Points: 9	DX	DY	DZ	3D
Maximum Deviation:	0.004	0.006	0.003	**0.008**
Minimum Deviation:	-0.003	-0.003	-0.004	**0.000**
Deviation Range:	0.006	0.009	0.007	**0.008**
Average Deviation:	0.000	0.000	0.000	**0.004**
RMS Deviation:	0.002	0.003	0.002	**0.004**
Standard Deviation:	0.002	0.003	0.002	**0.002**

Transformation

	X	Y	Z
Translation:	31.221	103.049	26.283
Matrix I:	0.765	-0.015	-0.644
Matrix J:	0.011	1.000	-0.011
Matrix K:	0.644	0.002	0.765

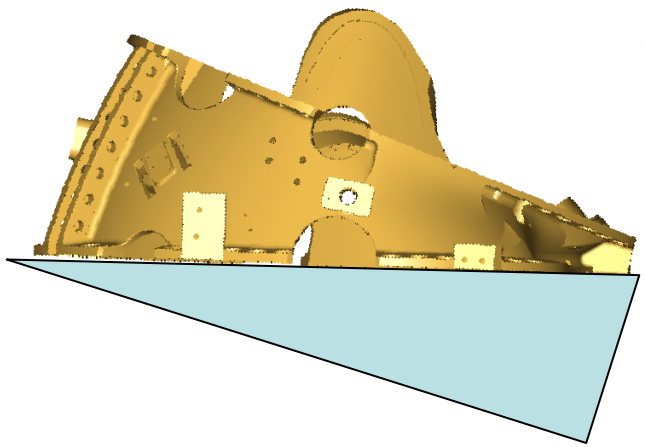


Metrology for Assembly Process



- Wedge 1, Coil A1
  - Rack
  - Clamp
  - Flange scan
  - Measure monuments
    - Send data to Back Office for shim calculation

Metrology for Assembly Process

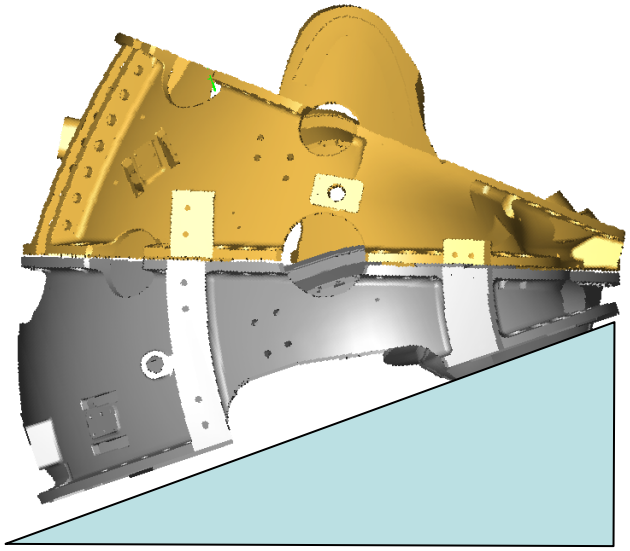


- To expedite our process, we complete steps for B-C interface in parallel
- Wedge 2, Coil B1
  - Rack
  - Flange scan
  - Measure monuments
    - Send data to Back Office for shim calculation

“B” Coil is Added

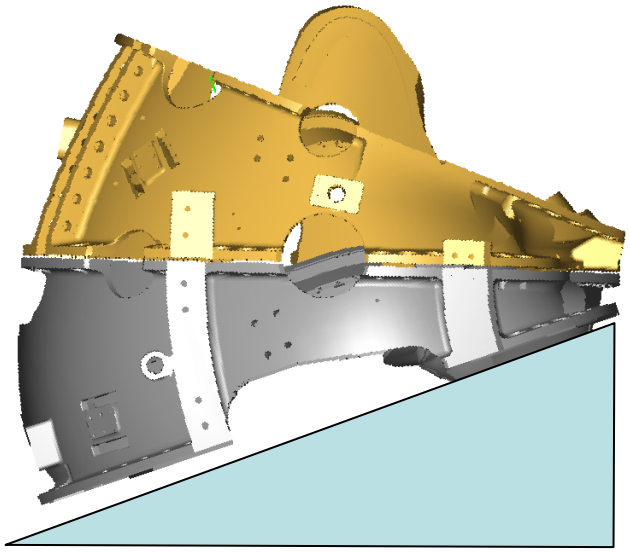
- Shims establish shape of coil and positioning normal to A-B interface
- Measure monuments on coil to verify
  - opportunity to correct shim thicknesses
- Alignment calculator used for positioning “B” coil in plane of A-B interface
- Initial shim weld, position “B” coil, torque bolts, measure, final shim weld, measure
- Accuracy goal is 0.012” deviation of monuments from theoretical position
- **How did we do?**
  - **78 monuments measured, 2 outliers [0.014”, 0.015”]**

Metrology for Assembly Process



- Wedge 1, A-B fitup
  - Align X-Y using spreadsheet
  - Test shims from Back Office
  - Measure nose puck heights using nose shim template

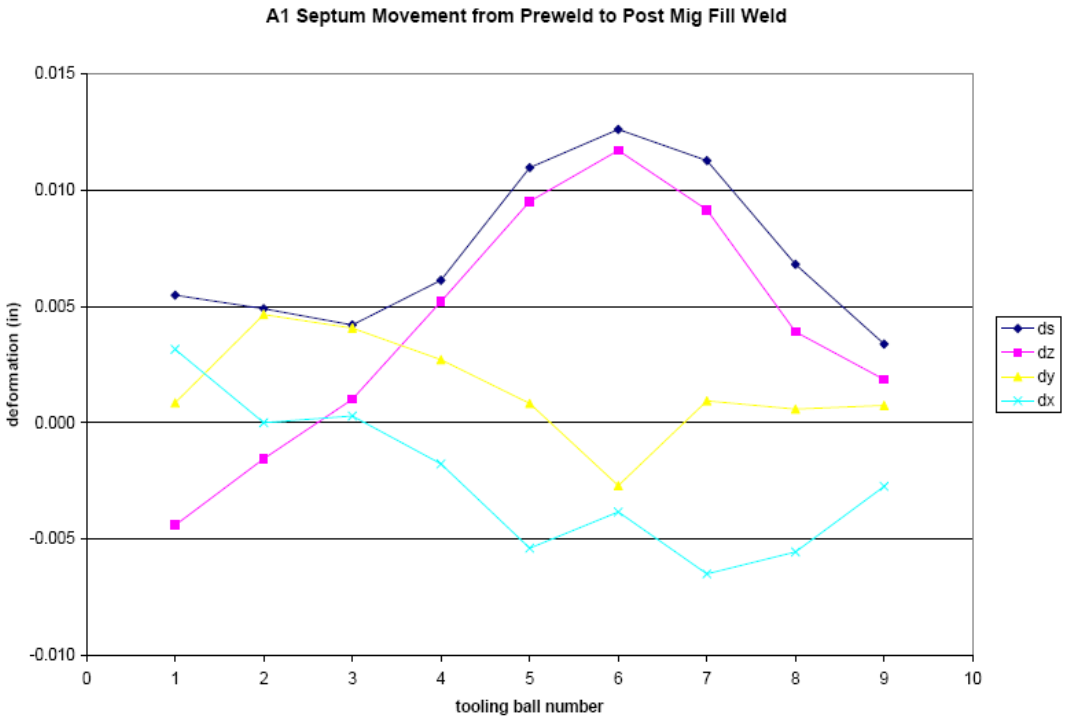
Metrology for Assembly Process



- Realign X-Y
- Weld inboard side of nose shims
- Torque bolts to 100%
  - Re-measure monuments after each step
- Scan B-C flange

- Increase wedge incline to 40 degrees for B-C fitup
  - Repeat previous steps

Welding Process



- Separate coils, weld plasma side of nose shims
  - Monitor septum distortion during weld process

“C” Coil is Added

- Follow same general steps as the A-B assembly
- Accuracy goal is 0.020” maximum deviation of monuments from theoretical positions
  - **HPA1: 100 monuments measured, no deviation greater than 0.015”**
  - **HPA2: 105 monuments measured, one nonconforming at 0.021”. Only three monuments with deviation greater than 0.015”.**

- We have implemented a systematic, repeatable method of achieving the project dimensional goals for half period assembly.

Laser Measuring Tools

- Corner Cube (CCR)
  - 1.5” or 0.5” diameter
  - Sits in magnetic nest
  - 0.5” diameter, with special nest, mimics short shank tooling ball
  - Negligible positioning accuracy relative to nest
  - Global monuments are 1.5” dia. CCR in nest secured to building or HPA fixture
  - When nest placed in tooling ball hole, accuracy issues are same as for tooling balls – tightness of the hole
  - Possible blunders using 0.5” dia. CCR and special nest – does it remain seated in hole after grip is released? [air pressure in hole may act as spring] ~.001” - .002” effect; difficult to recognize
  - Limited viewing angles

Laser Measuring Tools

- Leica Surface Reflector (LSR)
  - Allows laser to measure to the center of tooling ball by creating a virtual center
  - Avoids problem of tooling ball or nest “releasing” during measurement
  - Limited view angles
  - Highly accurate

Laser Measuring Tools

- Measure a sphere around a tooling ball (or 15mm ball bearing in a conical seat) using CCR in a nest on a wand
  - Best view, least accurate
  - Necessary for measuring conical seats
  - Qualification tests performed to assess accuracy of this technique
  - In-field checking of sphericity of measurement helps to eliminate blunders

Photogrammetry Tools

- 90°, 45°, and 0° Tooling Targets
  - Replicate tooling ball shoulder-to-center offset
- Stick-On Codes
- Stick-On Targets (where necessary)
- GSI V-Stars software
- Nikon D2Xs camera (modified)

Photogrammetry Summary

- Surveys using same tooling ball locations agreed with Laser Tracker measurements
- Significant time savings not realized
  - Steep learning curve for Back Office post-processing
- Survey timing
  - Targeting: ~1 hour (initial setup)
  - Photo taking:
    - ~12 min (single coil)
    - ~20 min (2-pack)
    - ~1 hr (3-pack)
  - Post-processing: ~20 min (after Driver File completed)

Conclusions

- The “Right Tool” for the Job
  - Laser Tracker
    - Coil-to-coil alignments
    - Real-time control/driving
    - Discrete point measurement
  - Photogrammetry
    - Multiple point measurement in single survey
    - Deformation/distortion studies
  - CMM Arm
    - Non line-of-sight part feature characterization