# NCSX A-B Flange Weld Test Post-Weld Debriefing and A6/B6 Casting Weld Planning

July 27, 2008

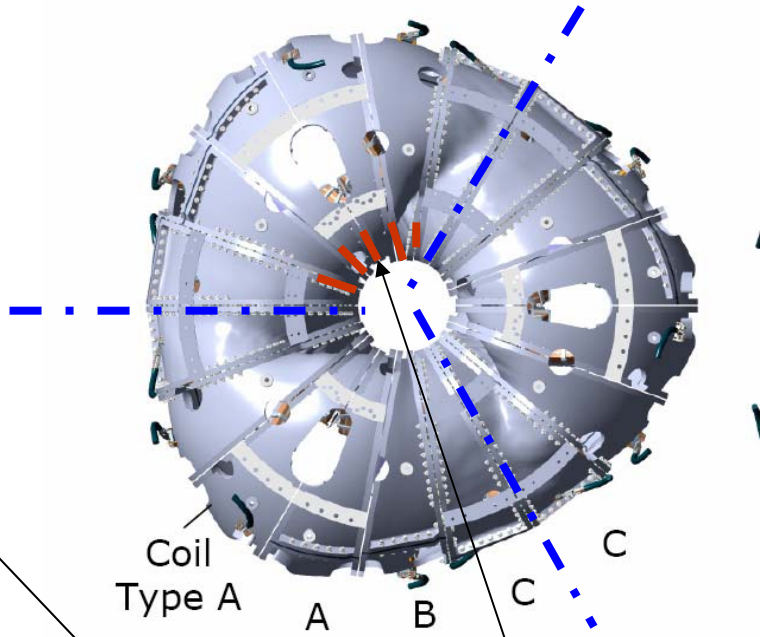
# Agenda

- Background info & Overall Plan
- Distortion measurements
- Test flange weld experience results
- Permeability results
- Discussion of A6/B6 test plan
  - Metrology plans
  - Dial indicators
  - Shim configuration
  - Weld procedures
  - Test plan

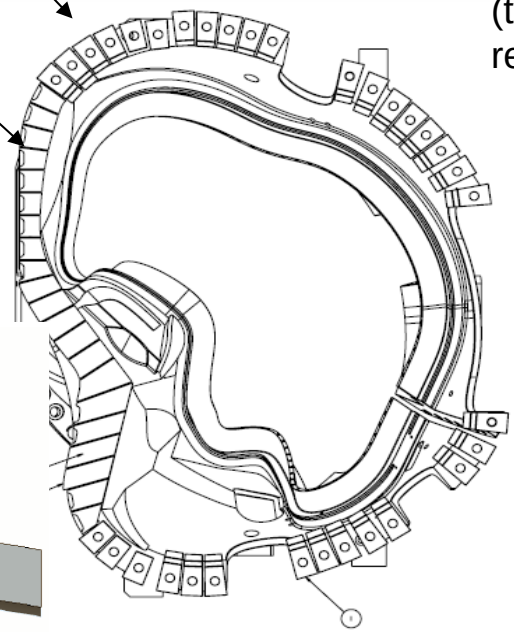
# Robust Coil-Coil Interfaces Have Been Developed for NCSX's Modular Coils

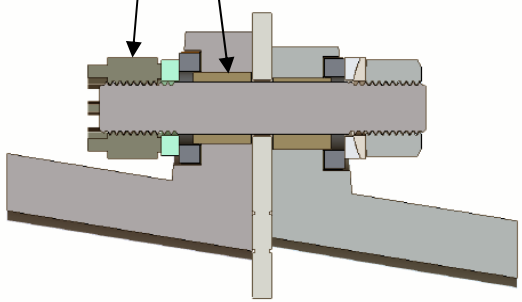
- High friction alumina coated shims under all bolts.
- Welded coil-coil inner legs on intra-field period coils.
- Tight fitting bushings around studs as backup.
- "Supernuts" and ultrasonic monitoring of stud tensioning.

***It won't move now!***




5 welds/period (typ.) in central region.

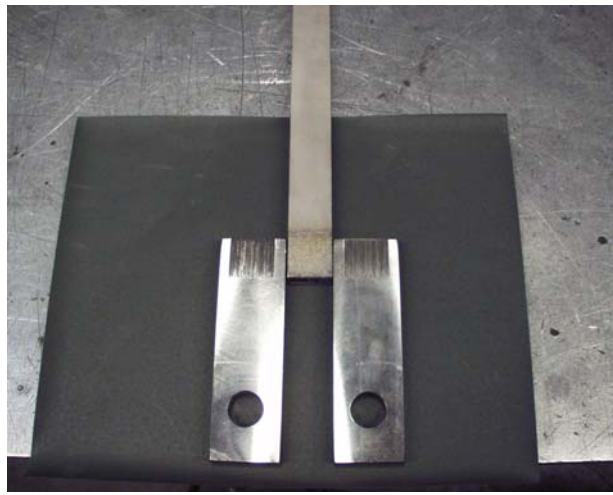




# Alumina coated shim friction characteristics have been verified by testing

*Side rams apply normal pressure to test specimens simulating bolt pressure; tensile tester applies shear load*

*The test setup is cooled to 80 K for testing.*

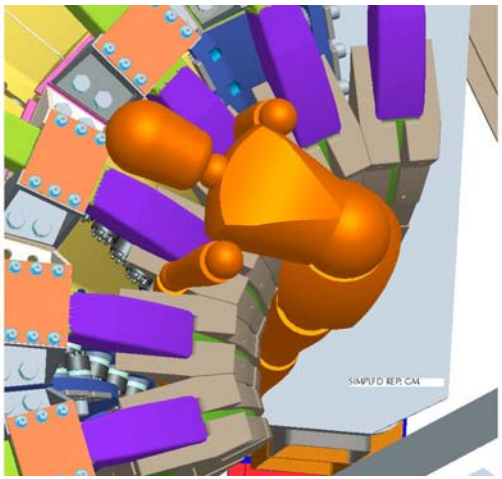


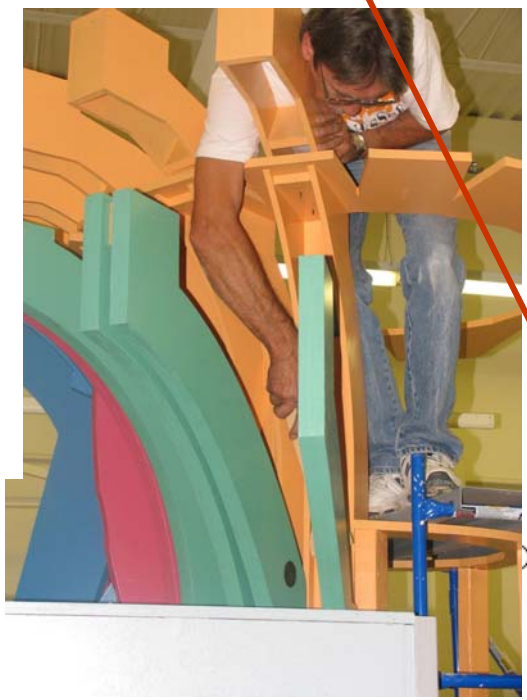
*Test specimen – two alumina coated SS sideplates sandwich SS center bar.*

- The coefficient of friction, $\mu$, required is 0.4 for the C-C interface and ~0.16 elsewhere.
- A stable $\mu$ of 0.4 has been demonstrated for a life of 130,0000 cycles (full machine life), 0.5 for 130,000 cycles and 0.6 for 48,000 cycles (when the test was stopped due to hydraulic system problems) .

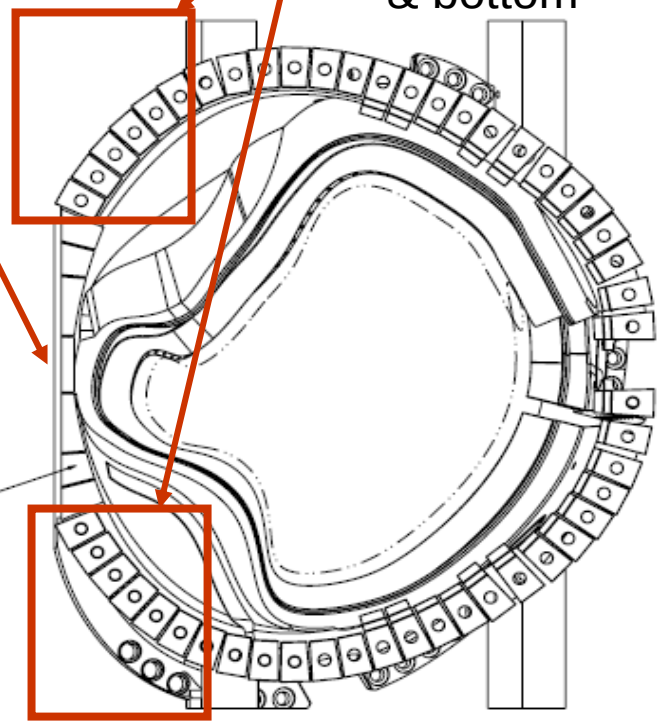
# C-C (period-period) connections are bolted

Sliding shims will react centering forces in mid-region.





(6) Additional bolts & shims top & bottom



***Bolt access was demonstrated first by a Pro-E model and then by a mock-up.***

# NCSX Modular Coil Weld Development

Completed June 15

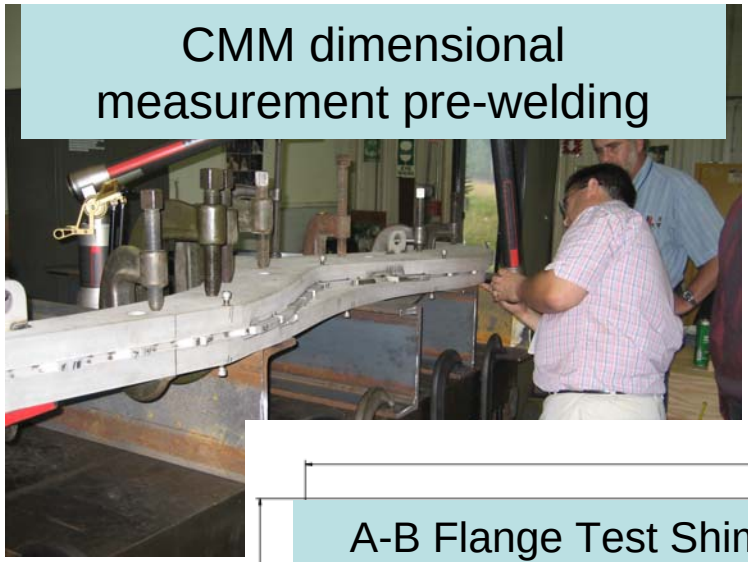
Welding completed July 23; EWI evaluation of results pending.

Scheduled for August 15-23

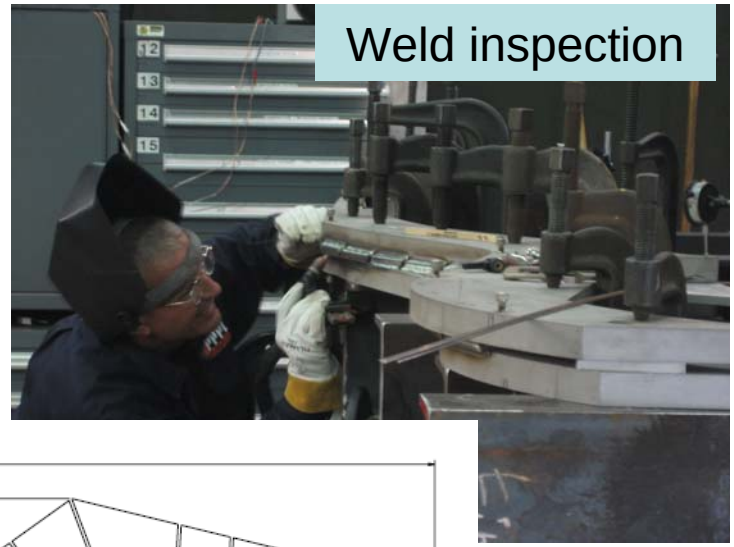
3 phase program:

- **Phase I: On-site Assessment** of NCSX's plans by Edison Welding Institute.
- **Phase II: Mock-up welding tests** of a Type A-B winding form flange. Primary goal: to determine likely **weld quality & likely flaw size distribution** in welds (for fatigue life assessment & to determine if NDT is required).
- **Phase III: A6/B6 casting to casting weld tests**. Primary goal: to demonstrate **distortion control** and overall assembly and weld procedure.

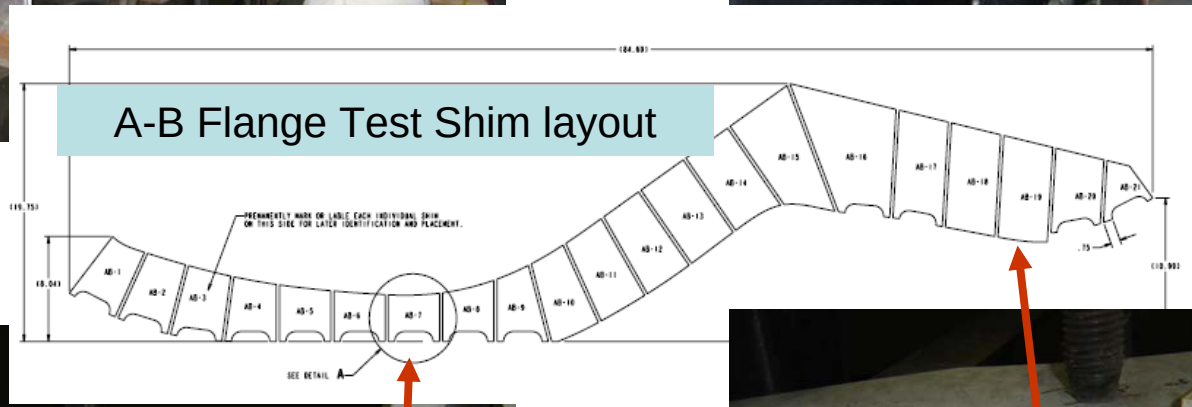
CMM dimensional measurement pre-welding

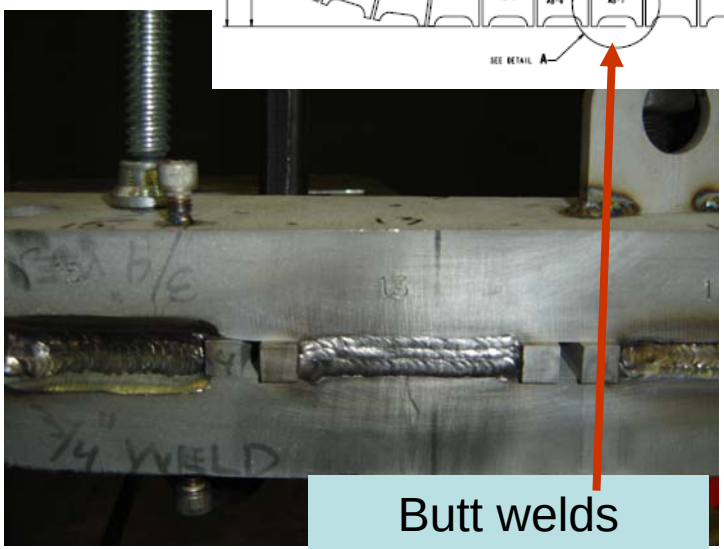


Weld inspection

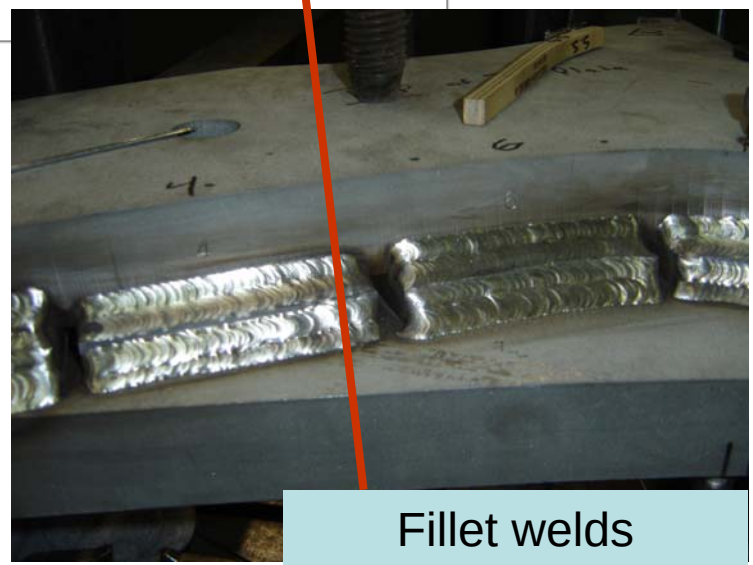


A-B Flange Test Shim layout




Butt welds



Fillet welds

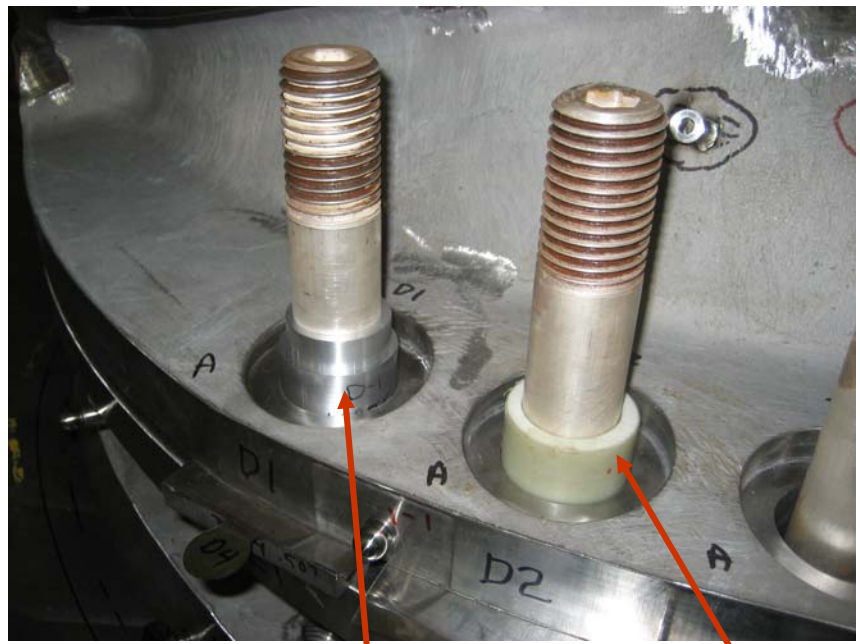
# Weld Permeability Is Controlled

- Shims are made from 316 SS which, after all machining and grinding is completed, are solution annealed at 1150 C followed by rapid air cool to reduce magnetic permeability.

- Specified mu is 1.02;  localized areas slightly higher can be accepted.
- Results from the weld tests are excellent:
  - 1.5" plate before welding: all below 1.02 Mu.
  - 1.5" plate after welding:all below 1.02 Mu.
  - 1/2" shims before welding:  average of >1.02 Mu but <1.03 Mu with isolated readings of >1.03 Mu but <1.04 Mu.
  - 1/2" shims after welding:  shims 2 & 3 rose slightly from >1.02 but <1.03 Mu to >1.03 but <1.04 Mu, shims 11 & 20 rose slightly from isolated spots of >1.03 but <1.04 Mu to isolated spots of >1.04 but <1.05 Mu, shim 18 rose from isolated spots of >1.03 but <1.04 to an isolated spot of >1.06 but <1.08 Mu.
  - Weld metal:  all below 1.02 Mu.

# Bushings

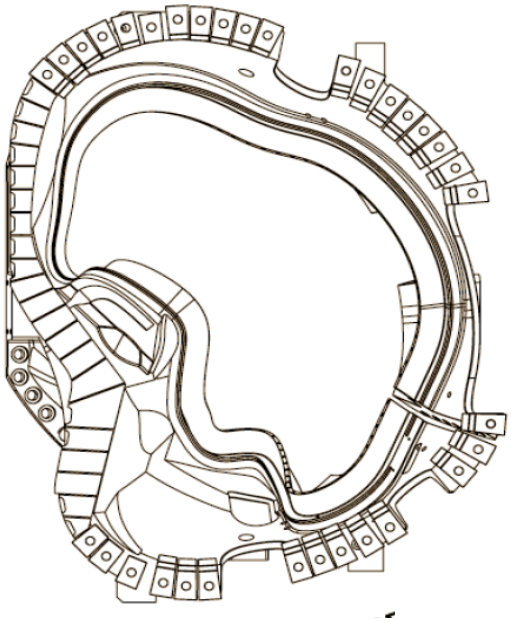
- Tight fitting insulating bushings are installed around each after the coils are aligned. Each bushing needs to be custom fitted to accommodate stud positions and flange hole dimensions.
- These insure against movement between the castings as the nuts are tightened and serve as insurance against movement between the castings if preload is lost due to cool-down lags, nuts loosening, etc.
- This photo shows the stock G-11 fiberglass bushing and an aluminum double eccentric mock-up being evaluated to determine if time can be saved using these. (if used, one of the bushing parts would be made of G-11 to insulate the stud).
- Both are being evaluated during the A6/B6 casting alignment to determine how to minimize bushing fit-up time.

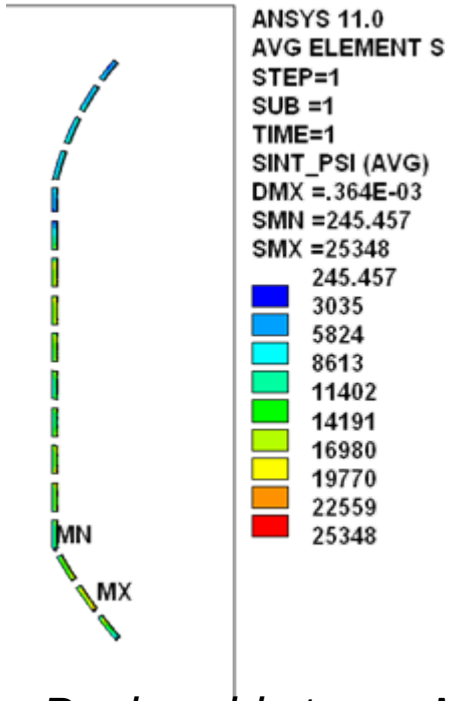


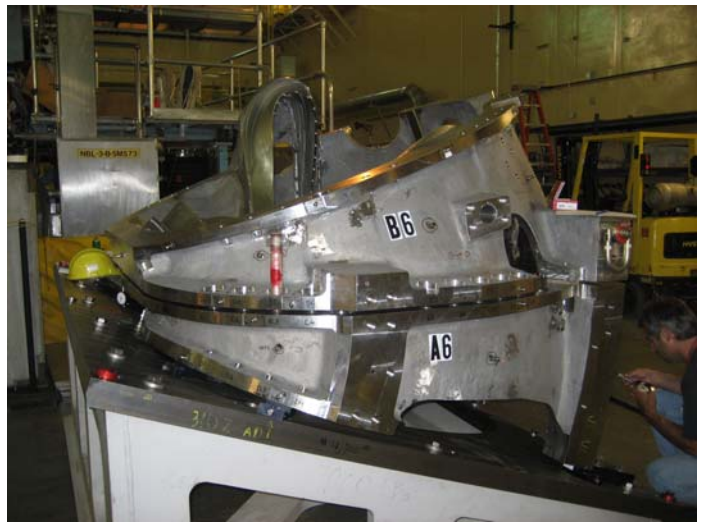

*Double eccentric bushing prototype*

*G-11 bushing*

# Coming next: A6-B6 Weld Tests





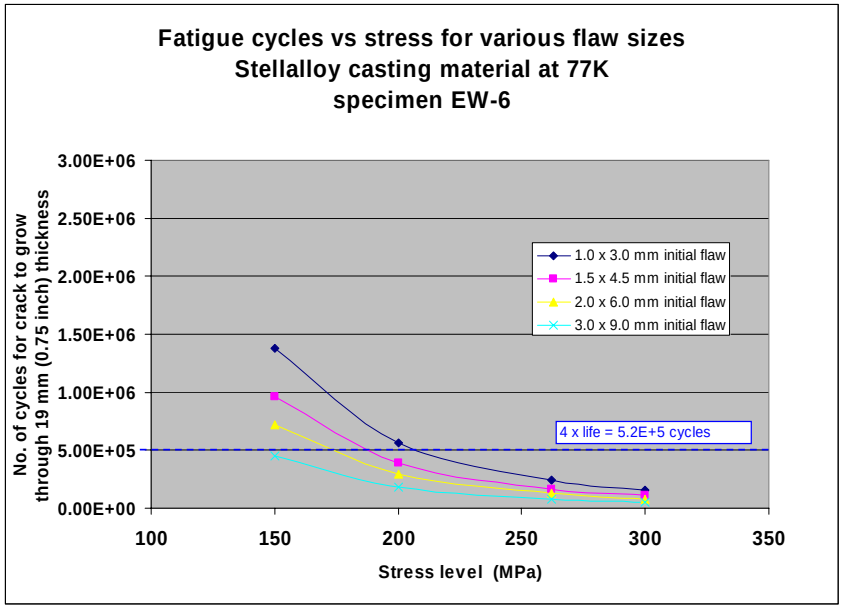



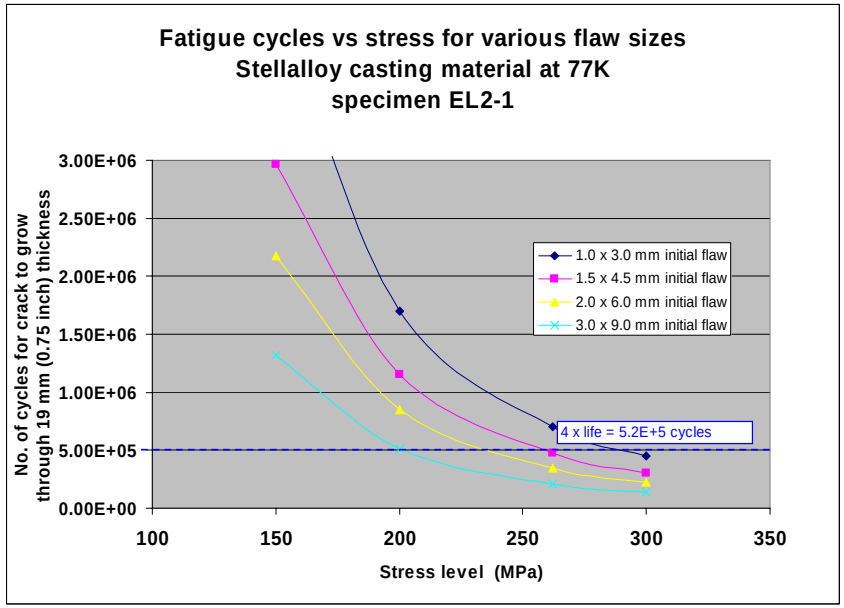

*Shim Layout –welded shims along inboard edge can be identified by absence of bolt holes.*

*Peak weld stress, Mx, is 25.3 ksi vs. 31.5 ksi allowable. We plan to increase weld size for <20 ksi everywhere.*

*A6 & B6 being aligned for weld test*

# Weld fatigue is satisfactory




*Fatigue data for welds in Stellalloy*

*Fatigue data for Stelalloy*

- As can be seen in the curve above, crack growth is faster in the welds (but OK!).
- Welds are being sized for 20 ksi, max. (138.4 MPa).
- Calculations indicate that an initial flaw size of 5 mm can be tolerated for 4 x life (520 K cycles) at this stress level.
- We expect to be able to avoid flaws of this size in these welds by using qualified welders and procedures.
    - We will determine the reasonableness of of expectation through NDT and macro photographs of welds from the flange mock-up weld tests.

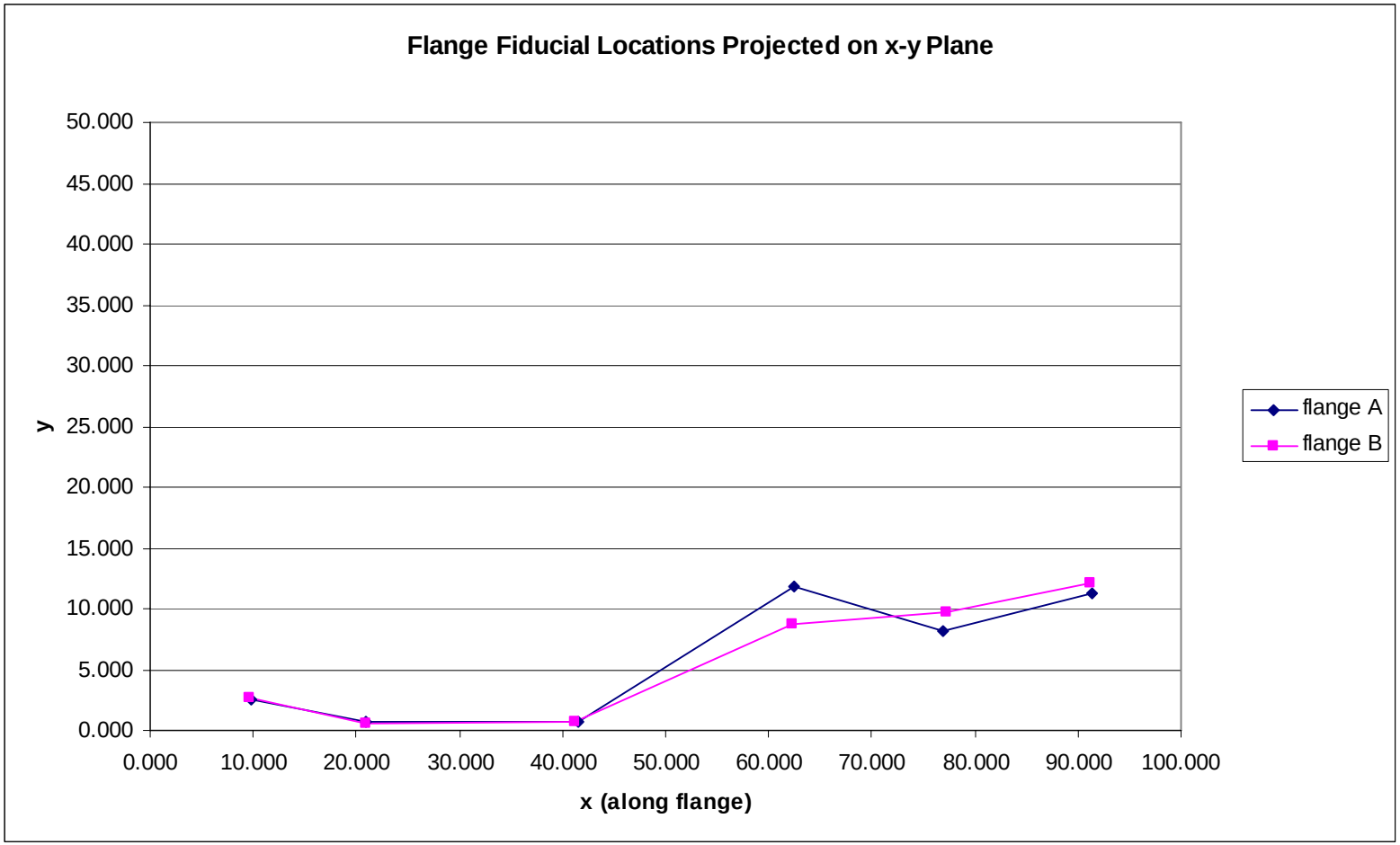
# Summary of Weld Test Mockup Distortion Measurements

S. Raftopoulos

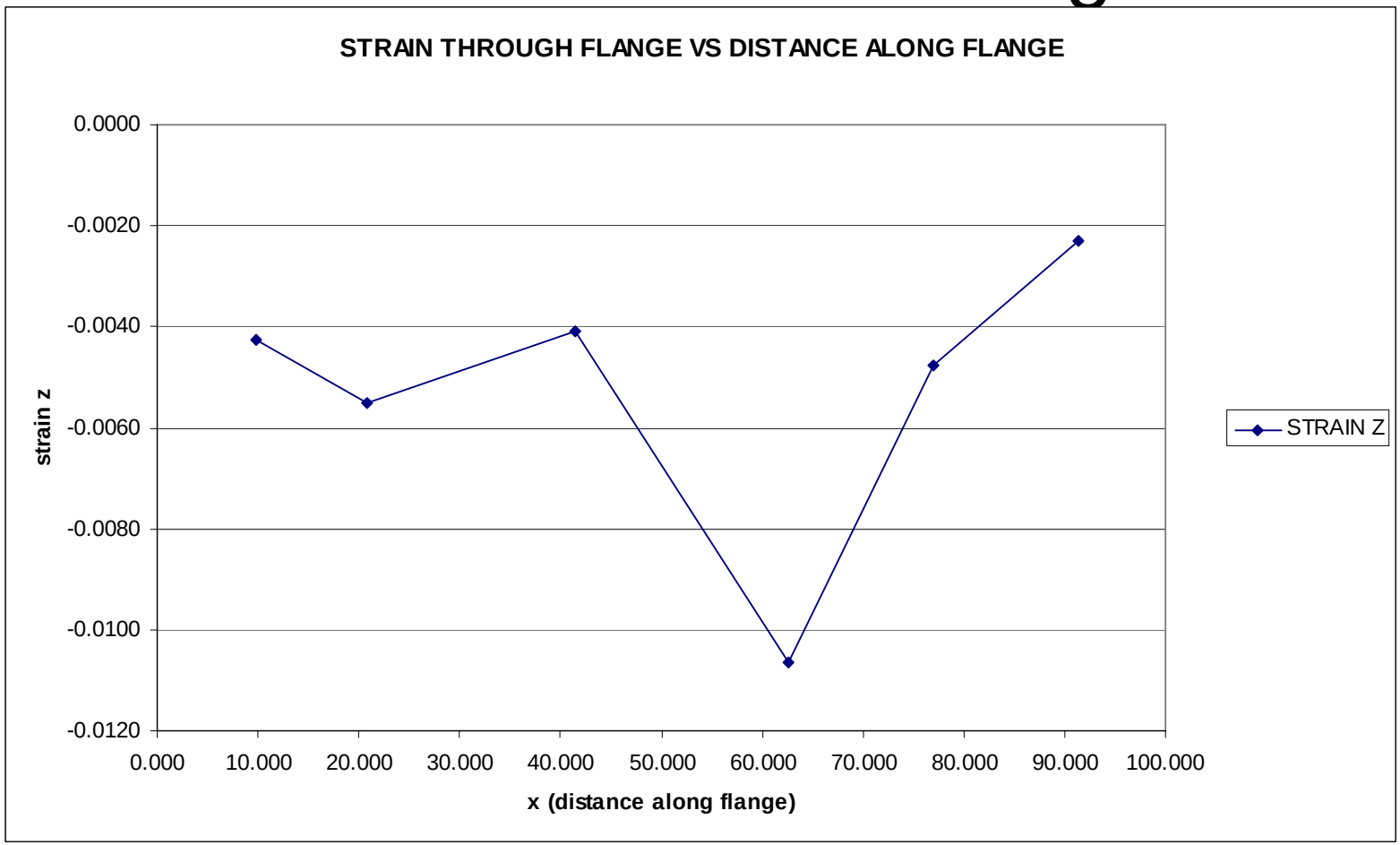
R. Ellis

July 26, 2007

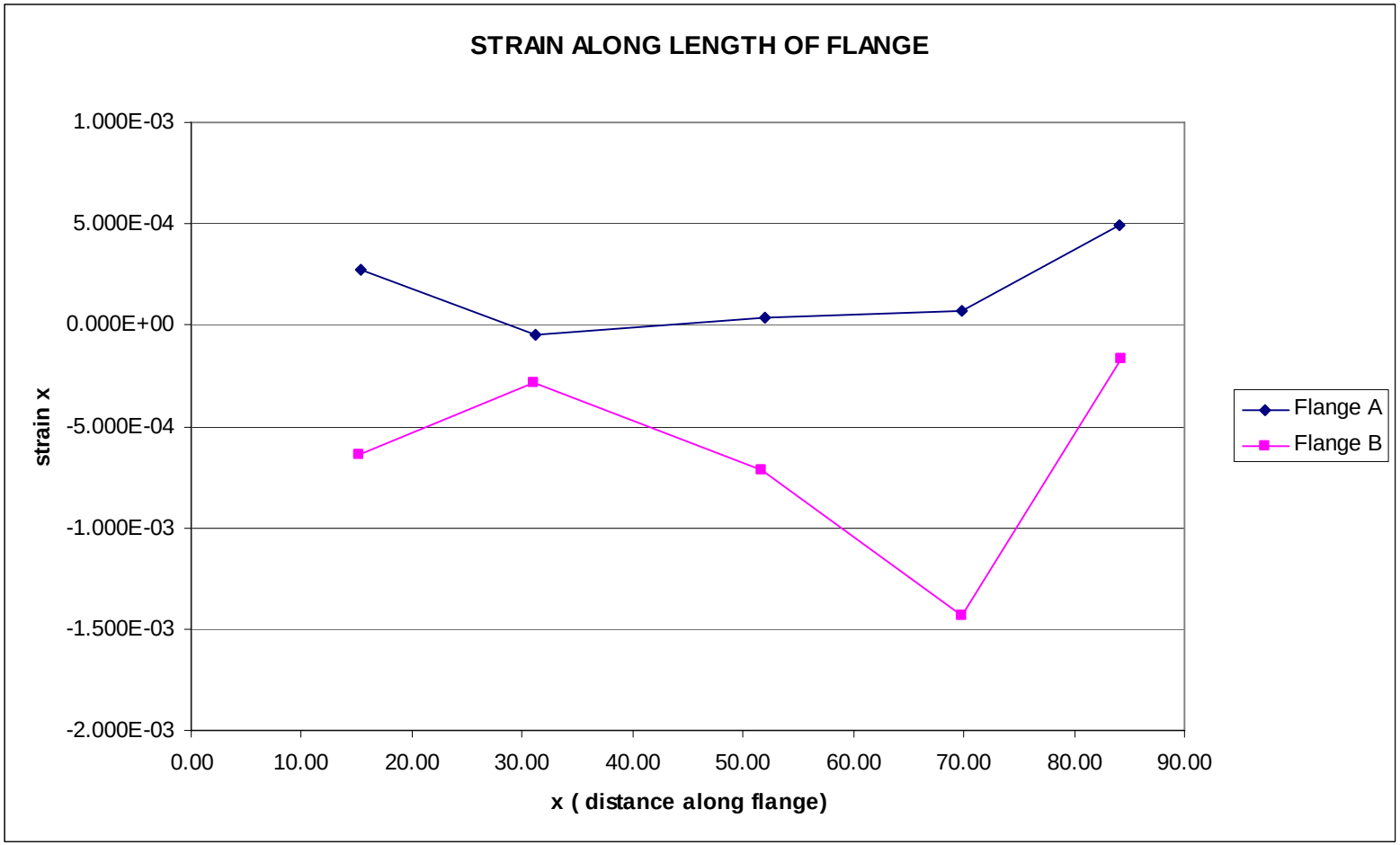
# Tooling Balls on Flanges A and B are Located Above Each Other



# Strains in z-direction (perpendicular to flanges) can be Calculated from Distances between Tooling Balls



# A Similar Calculation Gives Strains Along the Edges of the Flanges



# Permeability Results are Good!

Below are the results of the magnetic permeability results for the coil to coil 1.5" plate weld test.

1.5" plate before welding = all below 1.02 Mu.

1.5" plate after welding = all below 1.02 Mu.

1/2" shims before welding = average of >1.02 Mu but <1.03 Mu with isolated readings of >1.03 Mu but <1.04 Mu.

1/2" shims after welding = shims 2 & 3 rose slightly from >1.02 but <1.03 Mu to >1.03 but <1.04 Mu, shims 11 & 20 rose slightly from isolated spots of >1.03 but <1.04 Mu to isolated spots of >1.04 but <1.05 Mu, shim 18 rose from isolated spots of >1.03 but <1.04 to an isolated spot of >1.06 but <1.08 Mu.

Weld metal = all below 1.02 Mu.

Let me know if you have any questions.

Colin

# Weld Experience

- Shims:  re-configured 4 of them to get ½” legs on the welds.
  - Shim update is underway at ORNL.
  - Basically, no concerns – welding was straightforward.
  - Casting welds will all be horizontal except the A-A, which will be vertical.
  - Metal flow was good;  like welding standard 308 or 316.
  - Should make a water jet cut aluminum template to simplify shim layout.
  - Chamfer grinding worked out well – will do it the same way in the future.

# Deflection monitoring during test

- Criteria:  deformation should be <0.010” anywhere on winding surfaces.
- Deformations will be most pronounced on wing areas, so the “inboard” area wings will be monitored during the test. How:
  - Dial indicators for real time.
    - Will capture as many directions as possible.  (Bob Parsells, lead)
    - Will get digital type so welders can see them.
    - Welders will “skip” around based on indications.
  - IF POSSIBLE monitor with laser tracker in survey mode, real time.
  - Initial:  full CMM characterization of 1 side of the T on both castings.
  - Septum tooling ball measurements along inner legs, ~ 9 locations on each casting using laser tracker.
    - ~ 1-2 hrs. for a set of measurements.
    - Perform each morning before welding begins.
    - Will decide to peen or not based on distortion results. (we’re hopeful it will not be necessary).
- No formal interpass weld inspection.
- Visual inspection at the end.
- Welder and procedure qualifications have been made for Stellalloy-316-Stellalloy.

# Schedule (TENTATIVE)

- Casting fit-up: as of 7/27
  - 75% of al bushings complete.
  - All outboard shims complete.
  - inboard shims being ground – expect completion by ~Wed.
  - Start placing shims on Friday Aug. 3.
  - Final shim adjustments, torque and UT measurements on Saturday Aug. 4.
  - Final pre-weld scan on Monday, Aug. 6. Set up dial indicators.
  - Begin welding Tuesday Aug. 6 am.