ITER CS Inlet Fatigue Test

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ICMC

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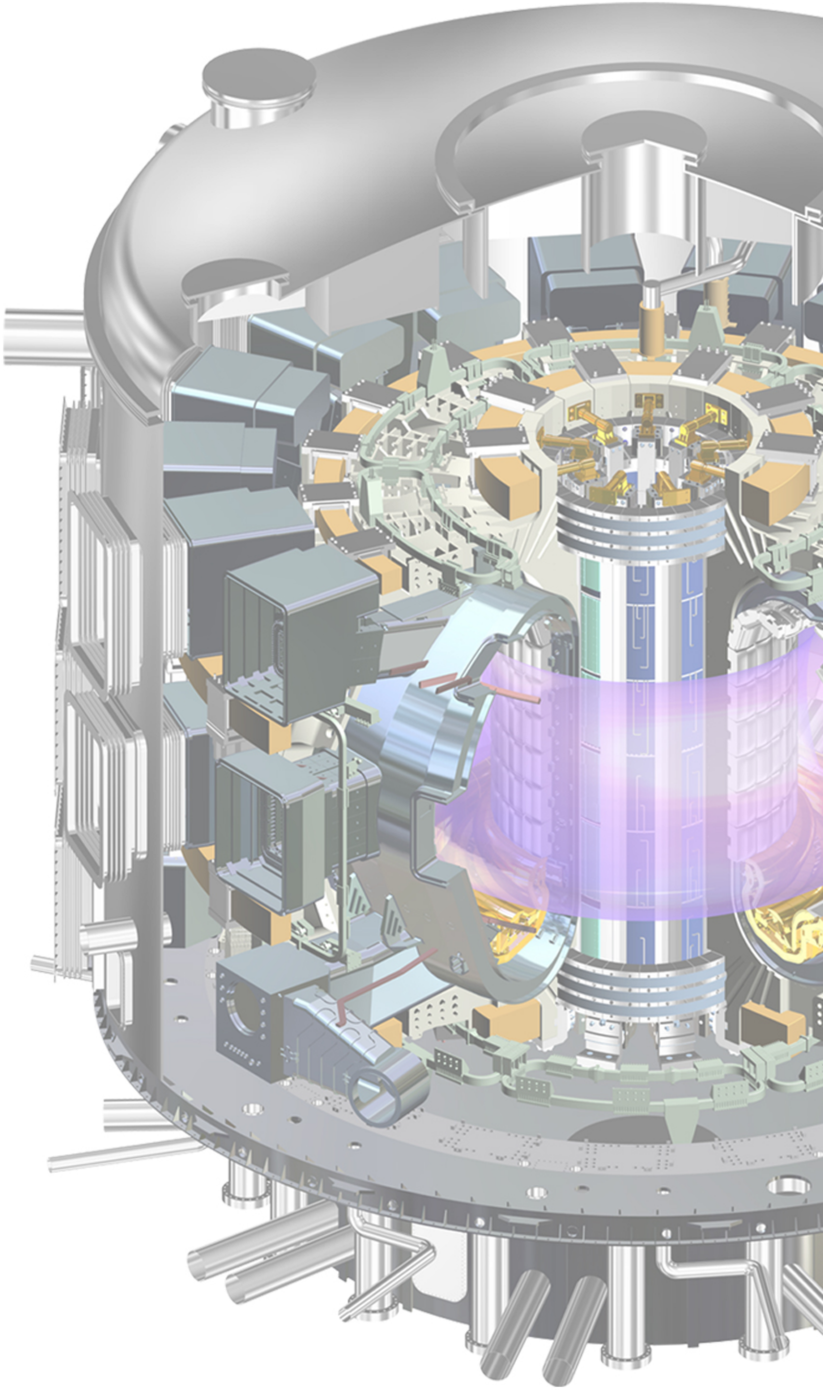
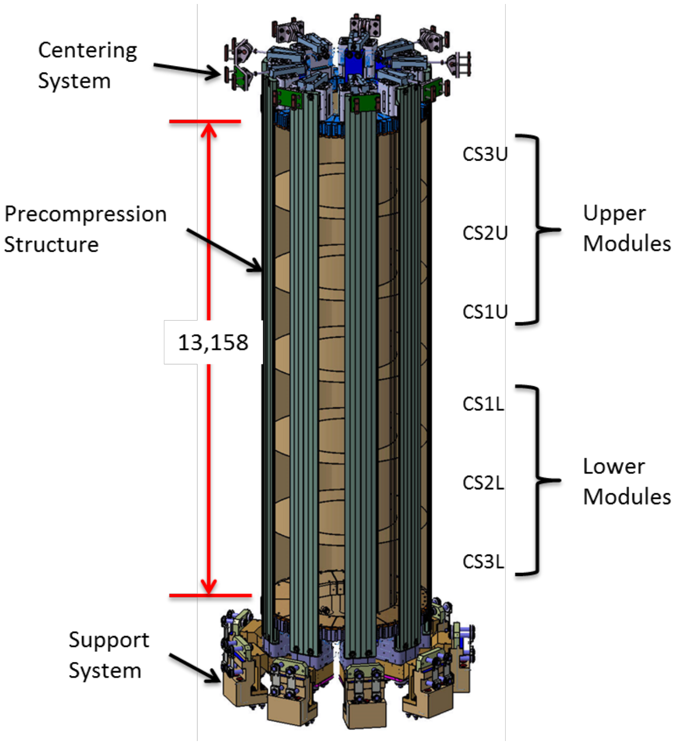
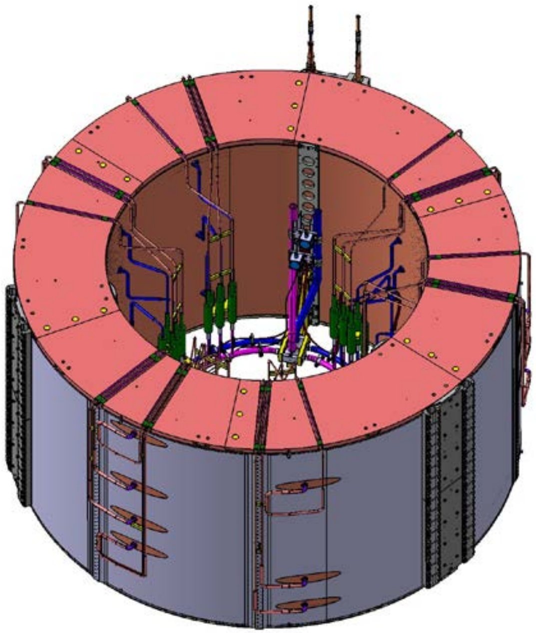


ITER CS

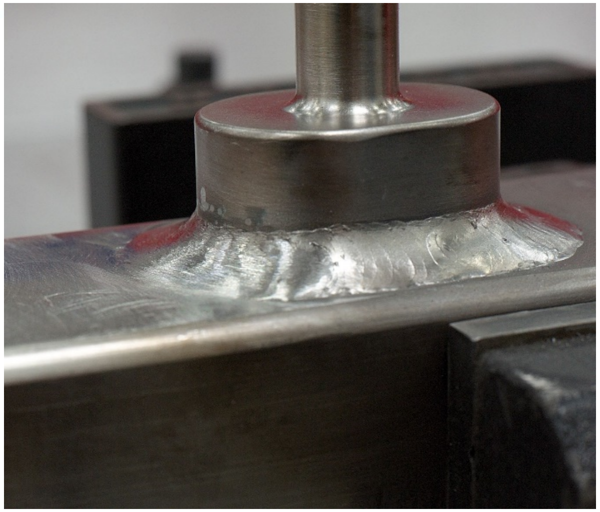
ITER CS Stack





CS Module

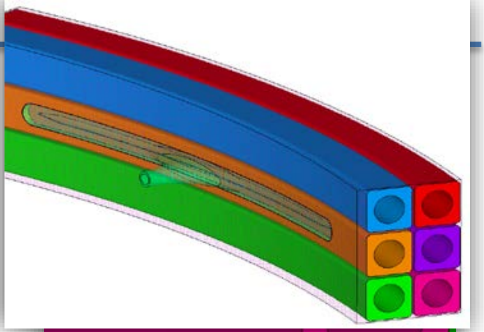
Helium is injected at the ID

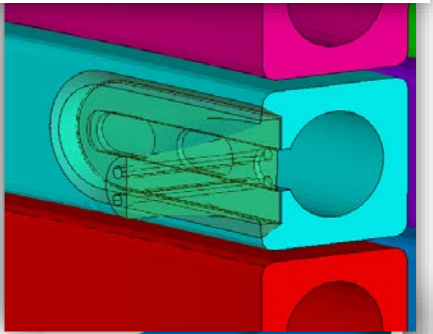


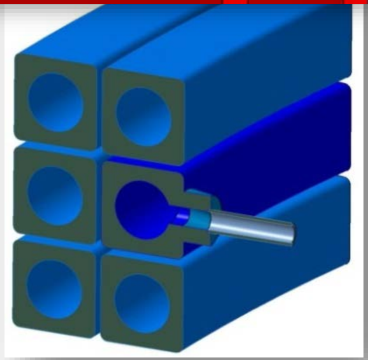
CS Helium Inlet

Introduction

- Since CS CDR (2009), numerous variations of He inlet design have been explored
- Motivation (as listed here, but ultimately based on reliability & cost):
  - Minimize structural impact on highly stressed WP region
  - Simplify manufacturing processes
    - Conduit machining
    - Weldment shape & size
    - Length of closure weld and proximity to conductor
- One design has emerged as simple, robust and meeting design requirements:
  - "Heavy-wall boss" similar to traditional fitting used in ASME Class I nuclear power industry
- Advantages of this particular design:
  - Circumferentially much shorter than the reference design
    - Reduces structural impact on the ID turn
    - Reduces risk of damaging conductor during machining and welding operations
    - Allows toroidal location to float enough to avoid compounding stress fields with conduit butt-welds
  - Simplifies manufacturing issues
    - Easier tooling
    - Faster machining operations
    - Smaller machined region
  - Weld surfaces are accessible for inspection, cleanup/grinding (improved fatigue)
- Structural and hydraulic performance were evaluated



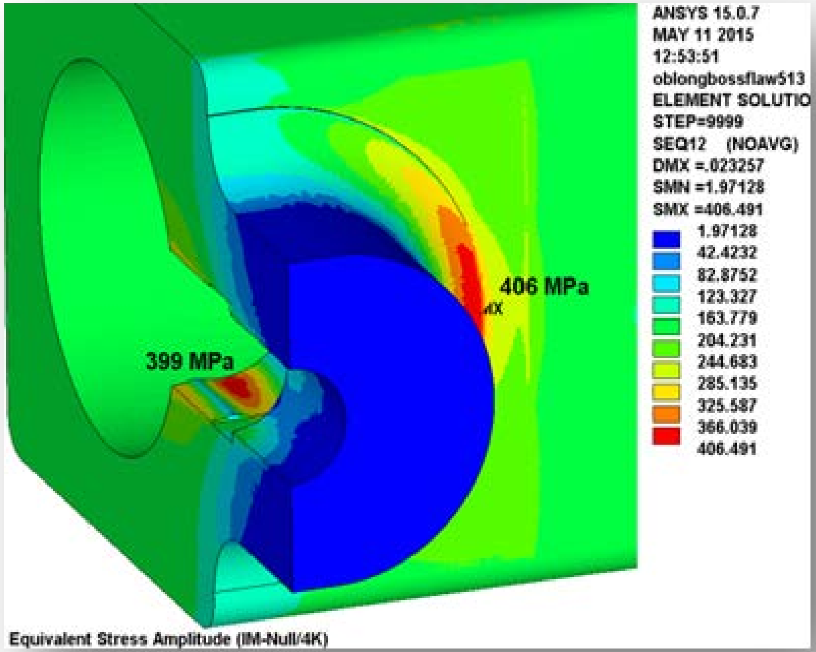




Inlet features

The oblong hole is made by three overlapping round holes

The highest stress and highest B – lowest Tcs
60 kcycles in operation



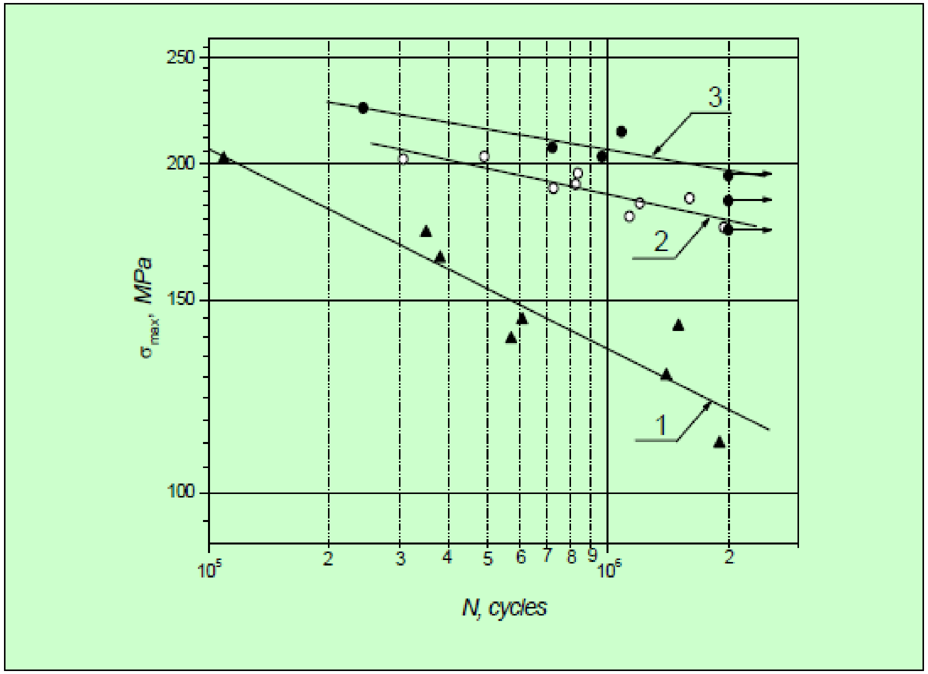
Two peaks of the equivalent stress amplitude – pretty high: Cumulative Usage Factor is close to 1.0

Qualification

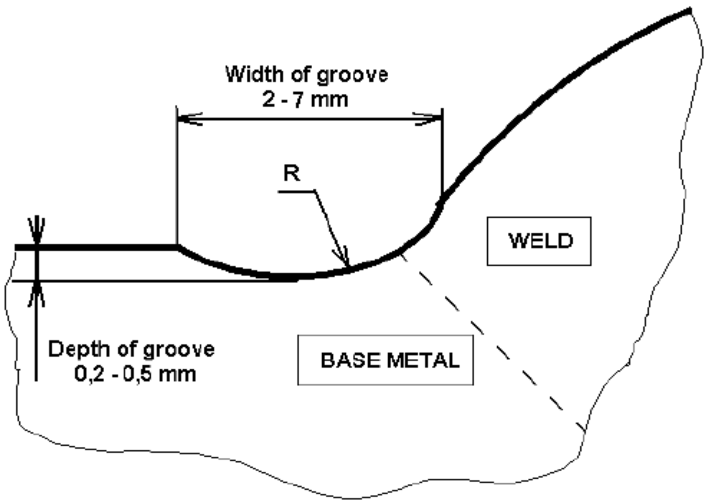
- Qualification by analysis: too close to allowable
- Recommended Ultrasound Peening to increase fatigue endurance

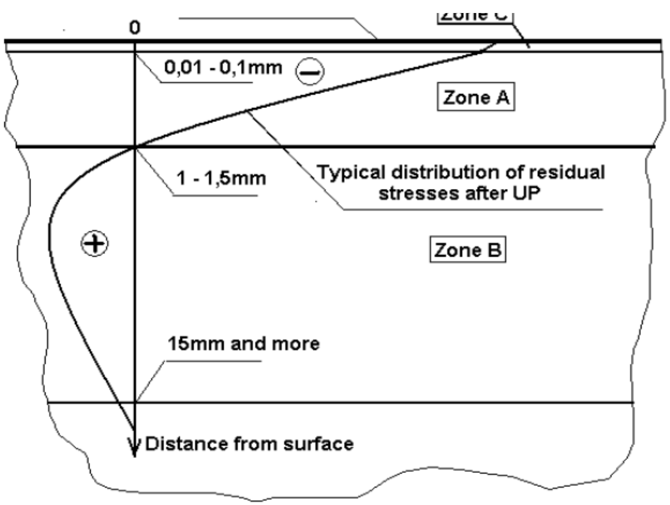
Basic UP system for fatigue life improvement of parts and welded elements

Ultrasound peening extends life of welded joints



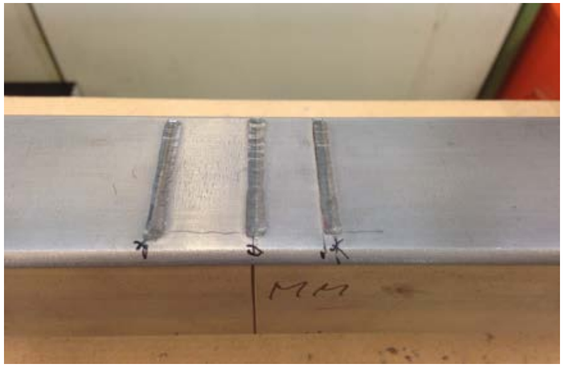
Fatigue curves of large-scale welded samples (transverse non-load-carrying attachment, R=0):
1 – in as-welded condition, 2 – UP was applied before fatigue testing,
3 – UP was applied after fatigue loading with the number of cycles corresponding to 50% of expected fatigue life of samples in as-welded condition

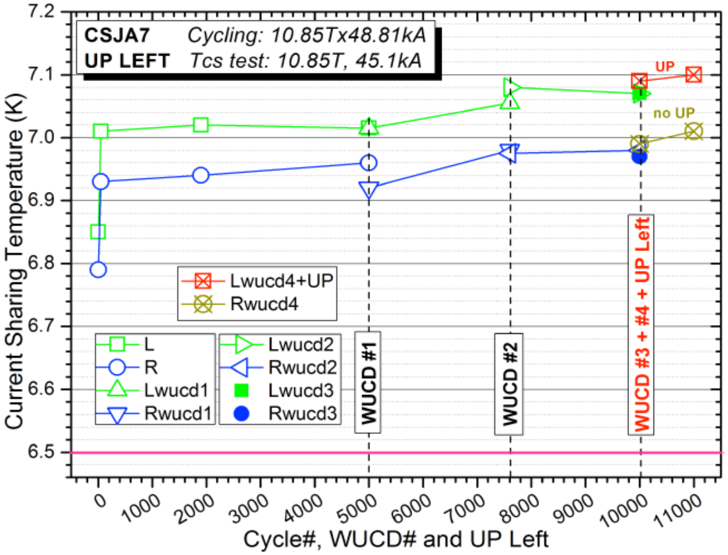




UP – before or after HT?

Concern will UP damage the superconductor?



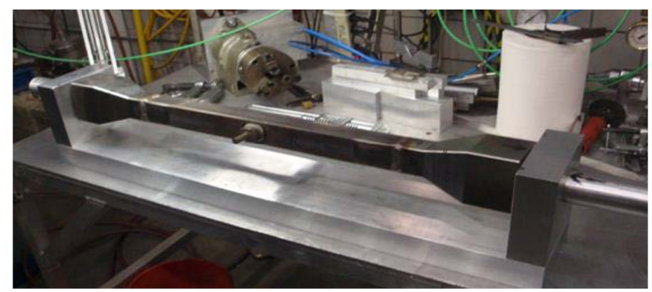


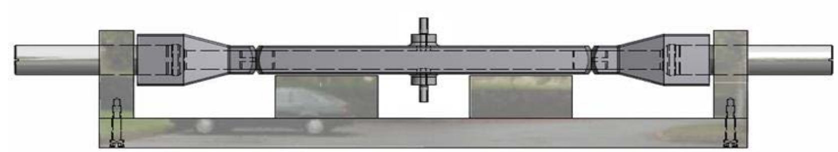
Study showed – UP does not damage the superconducting properties

Qualification by testing

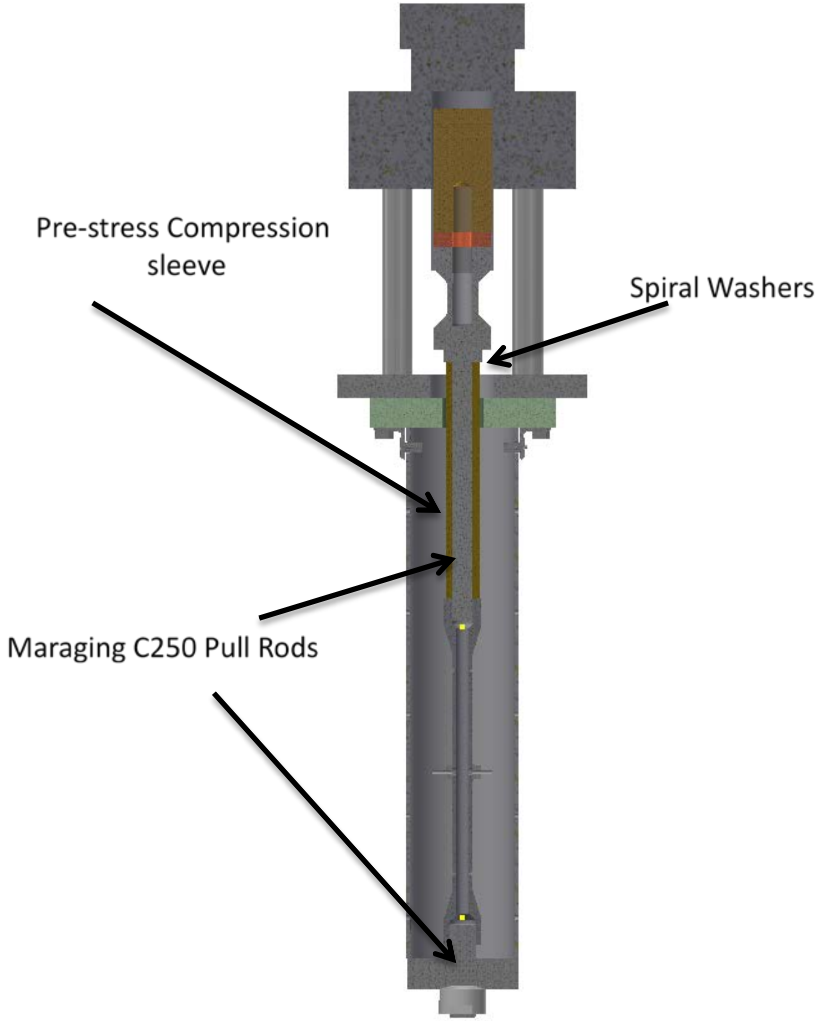
Total number of specimens	6
Number of UP treated specimens	5 (10 with two inlets per sample)
Stress	As in operation
Cycles in operation	60 000
Minimum number of test cycles required*	540 000

*code EN 13445 – geometrically mean





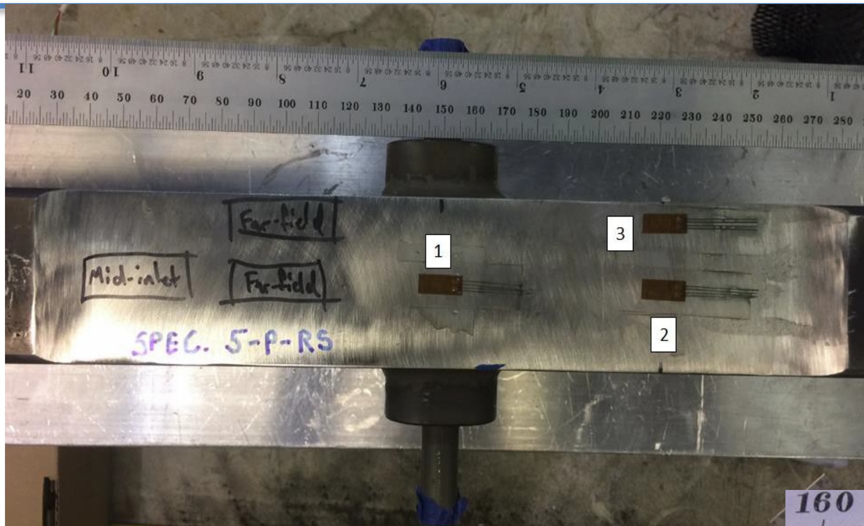
Inlet testing

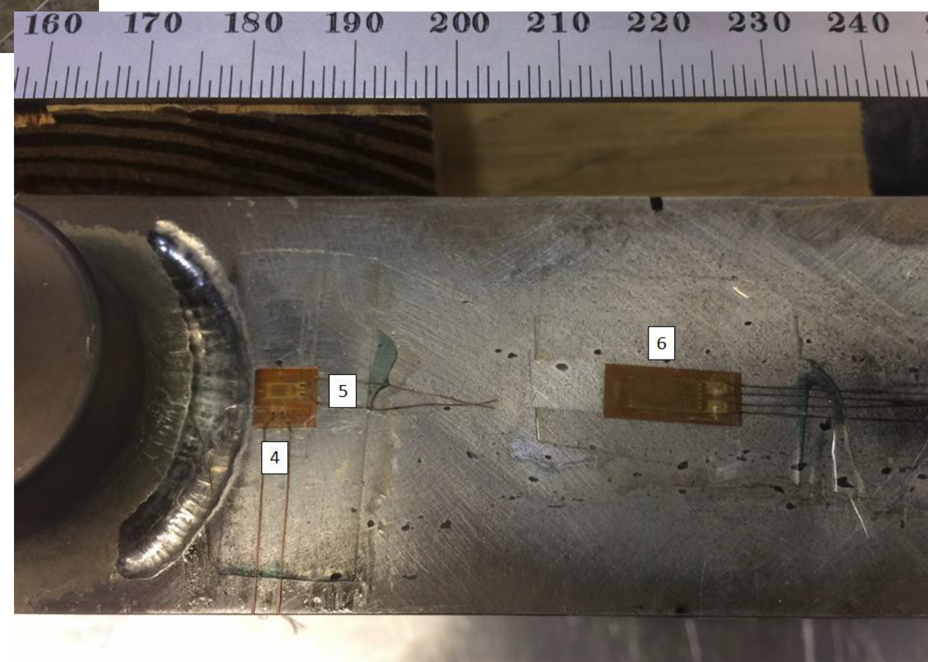


Schematic of test specimen and fixture, liquid nitrogen bucket dewar is not shown.

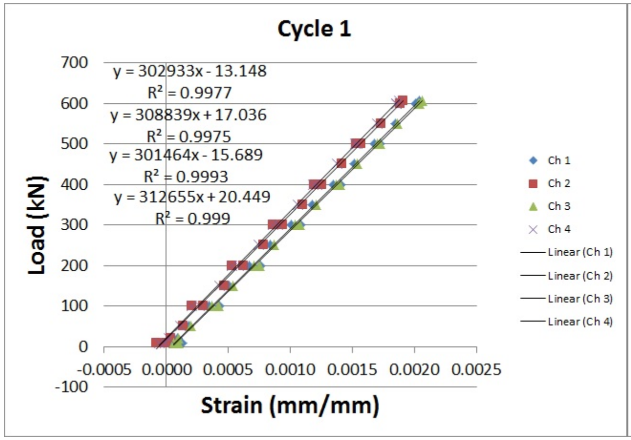
Testing arrangement

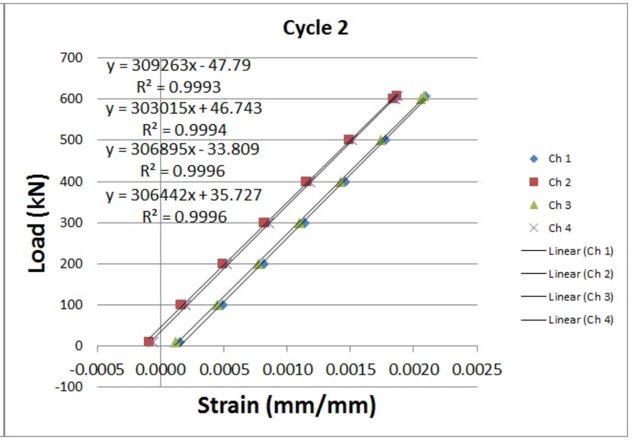
Strain gauge instrumentation

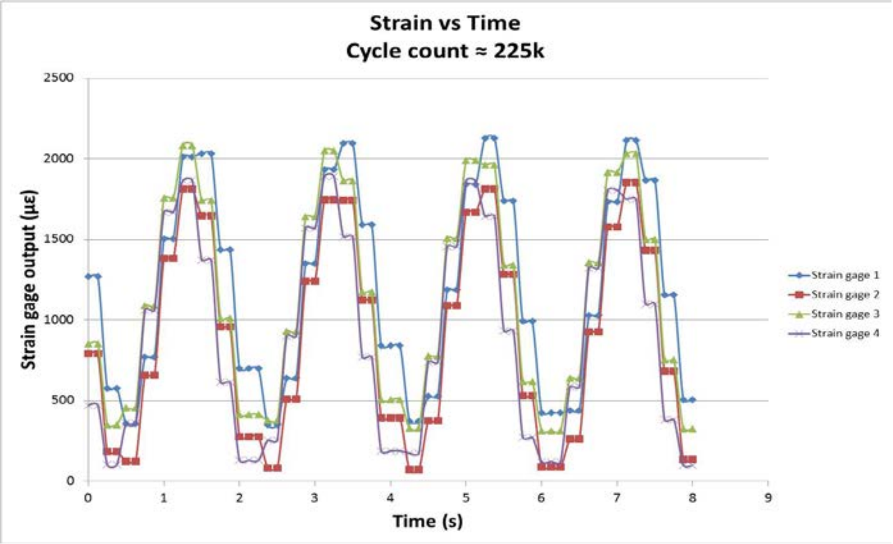




Typical stress-strain curve



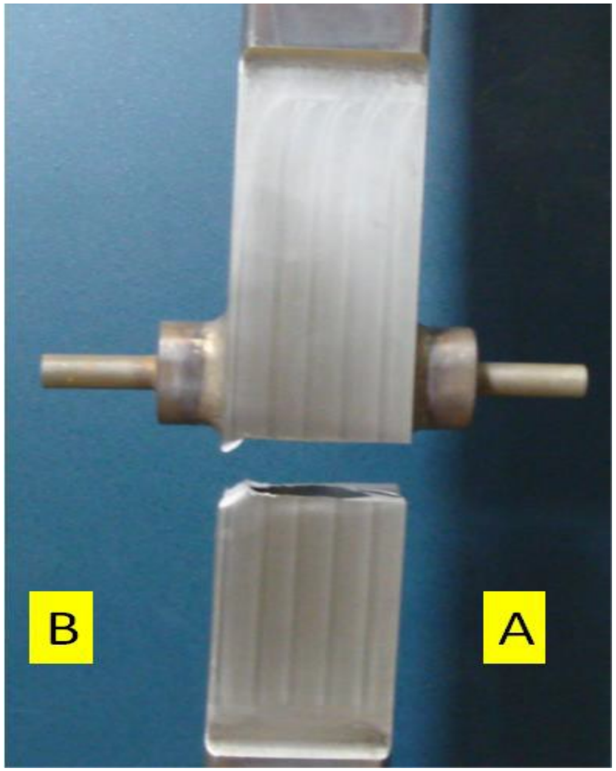




CS inlets testing summary

Condition	Sample ID	Max force, kN	Max fatigue stress, MPa	Nominal fatigue stress range, MPa	Cycles to failure	Comments
As welded + HT	1-AW-RS	434	336	303	158,451	Crack originated at the weld toe
As welded + HT + UP	1-P-RS	434	336	303	337,491	Crack originated at the hole in the jacket
	2-P	607	387	348	> 540,000	Did not fail and reached designed number of cycles
	3-P-RS	434	336	303	> 850,660	The inlet did not fail, but the grip failed
	4-P-RS	434	336	303	723,317	Crack originated at the hole in the jacket
	5-P-RS	434	336	303	534,518	Crack originated at the hole in the jacket

Fractures in UP and not UP treated specimens



As welded – not UP treated failed after 158.5 kcycles at the weld toe

UP treated failed after 534.5 kcycles at the drilled hole

Conclusions

- The ITER CS inlets meet requirements for fatigue testing presented in national and international structural codes
- Ultrasonic peening is a necessary condition for fabrication of the inlets with sufficiently long life for ITER CS. Ultrasonic peening extends life of the inlets by a factor of 3.5–5 or higher.
- All failures in the peened specimens were initiated in the second-highest stress location—the area where the cable space meets the drilled hole of the inlet. This agrees with the FEA and fracture mechanics predictions.