Successful development of new fabrication technique , based on laser welding, for SCRF cavities

– Results and path ahead

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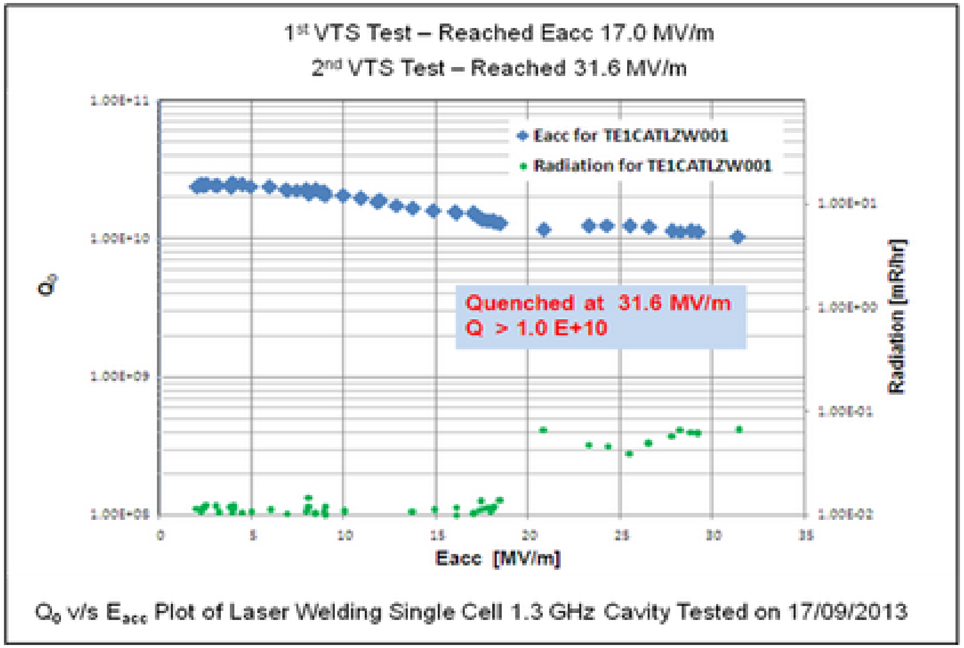
Results of First Laser welded SCRF cavity

- **Conceptualized & fabricated at RRCAT**
- **Processed & tested at FNAL**

Cavity being lowered inside VTS at FNAL



Q_0 v/s E_{acc} Plot of Laser Welding Single Cell 1.3 GHz Cavity Tested on 17/09/2013

Novelty

Use of Laser welding instead of Electron Beam welding
Use of inert gas environment instead of high vacuum

The very first 1.3 GHz SCRF cavity developed at RRCAT with this technique showed

(E_{acc}) of 31.6 MV/m with a quality factor (Q_0) of 1.0 x 10^{10} at 2 Kelvin.

Developmental path traversed so far

More than 150 experiments carried out till date

Optimized parameters for full penetration welding

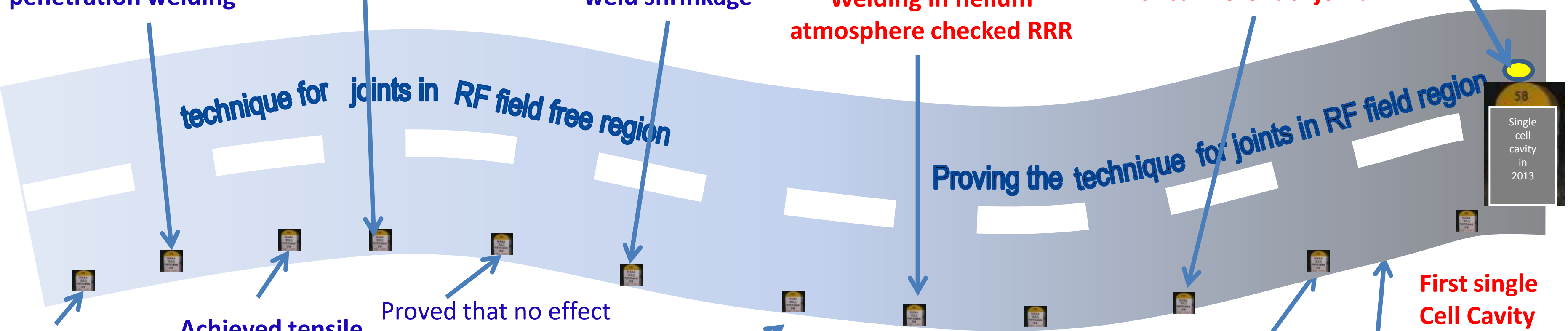
Demonstrated Vacuum tight joint

Optimized parameters for low distortion & weld shrinkage

Welding in helium atmosphere checked RRR

Circumferential joint

2013 achieved Mile stone



Demonstrated Weldability of Nb to Nb, Nb to NbTi with laser

Achieved tensile strength reqd.

Proved that no effect on SC properties of neighboring area

Welding in vacuum also

Smoothened bead parameters

Single cell weld rig fabrication

First single Cell Cavity welded & tested successfully

Welding a prototype3.9GHz SCRF cavity

Inner bead surface without polishing

Next Target → SB **Multi-cell cavity By 2014**

Main Infrastructure Created

- Established an experimental welding rig (instruments to monitor welding environment and welding process).
- Development of target maneuvering system (capable of weld tacking, giving precise movement, displaying length welded etc).
- Development of a tailor made laser System for SCRF cavity.

Specially Developed Nd:YAG Laser

Laser Welding rig

Optimization was the key to developing this technique

Parameters Optimized

- Achieve full depth of penetration with minimum energy.
- Parameter optimization for smoothening of bead.
- Parameter Optimization for HAZ and shrinkage reduction.
- Gas Flow optimization so that debris is dislodged, cooling is good & weld pool is un-disturbed

Result With Optimized Parameters

A. Tensile test

Original Substrate	UTS 180 MPa	YS 100 MPa
Welded sample	UTS 170 MPa	YS 100 MPa

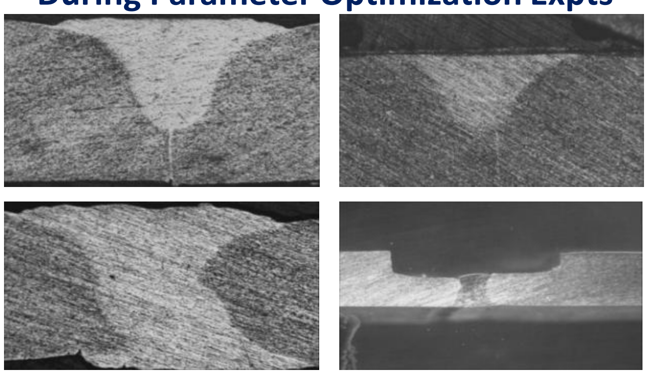
B. Vacuum test

Leak rate was of the order of 1 X 10^{-10} mbar l/s

C. RRR measurement

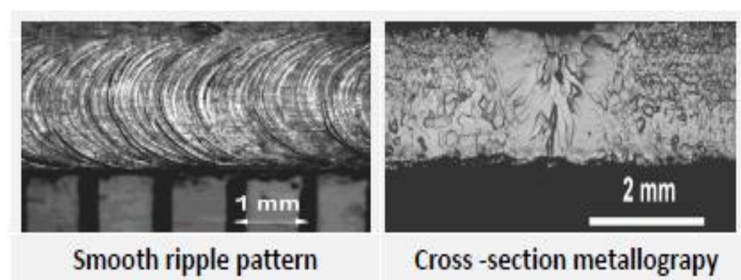
Welded in Argon Environment (99.9999 %) RRR value reduced from 314 to 296 (~6%)

During Parameter Optimization Expts



Metallographic Images of Niobium samples during parameter optimization

Metallographic Images with final parameters



- 2.5 mm weld bead, smooth ripple pattern
- No defect seen in cross sectional examination
- Very narrow HAZ ~ 500 µm

Advantages of this technique

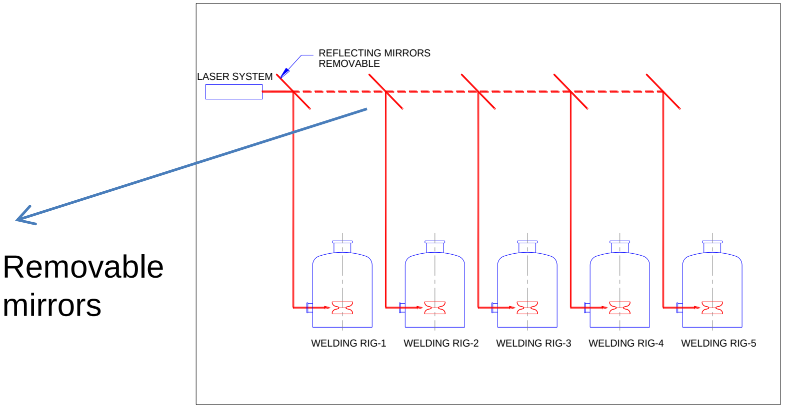
ECONOMICS

- **A. Lower capital cost** 25 times less (Including the cost of fixtures and welding rig)
- **B. Operating Cost** is less (laser welding is $39 per hour, EBW is ~ $250/hr).

  Just 10 KW of electric power + flash lamp lasts 1 mn shots+2 operators
- **C. Manufacturing time** will be very less as

  1. Laser travels through optical fiber so many joints can be made in a single setting.

  2. One LASER System can drive operations in 4-5 chambers (Weld preparation in second chamber by the time welding is over in the first one (see Fig below).



4-5 chambers can work with a single laser. Cost of chamber and fixtures is very less so it is a significant advantage.

Advantages of this technique

Factors effecting performance

- A. Lower HAZ . With rigorous parameter optimization we could bring it to 0.5mm
- B. Energy deposition rate is 5-6 times less hence very less shrinkage and distortion.
- C. Predictability of shrinkage . These are very predictable with a variation of less than 10%.

  Maybe a right amount of allowance would mitigate the requirement of intermittent machining.
- D. Inert gas jet can drive away metal vapors, spatter etc, thus protecting the inner cavity surface
- E. As laser can also weld / repair /smoothen from inside a very smooth surface can be obtained. Not necessary to form a hump on the underside of the bead as in EBW
- F. Similarly while welding stiffening ring there is no “swelling” on the inside surface.

Intangible Benefits

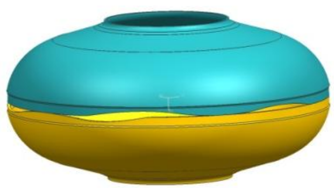
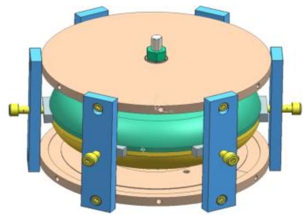
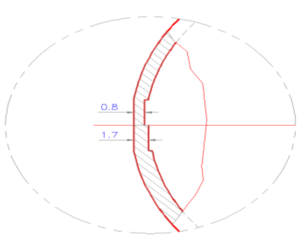
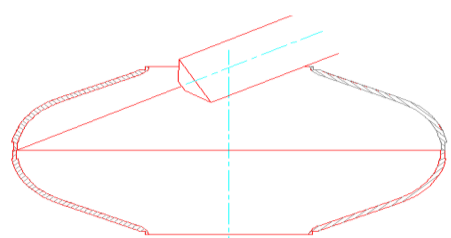
- **A.** May provide flexibility to designers . Possible to join components along complicated seam.
- B. May be helpful in reducing contamination and thereby reduce chemical processing.
- **C. Specially useful for low beta cavities with complicated shapes.**

Seek Valued Opinion of TTC on Path Ahead

What we plan to do

1. Fabricate a single cell Large grain cavity - Completed
2. First develop 3 cell 1.3GHz SCRF cavity - half cells under machining
3. As a next step fabricate a nine cell 1.3 GHz SCRF cavity.- To start

1. Work on Large Grain Cavity

	
Inaccuracy in Flatness (1.22 mm)	**Solution Developed**
	
Step inside equator joint	**Laser Smoothening to remove inside step**

1st single cell cavity completed

Our Experience and Conclusion

Our Experience

- LBW process is quite versatile and forgiving . This latter aspect is specially helpful when we are dealing with components made from a costly material like niobium.
- There is high repeatability in this process. The amount of shrinkage , penetration depth, spread of HAZ etc are identical with similar parameters. Will benefit SCRF cavity fabrication.
- The new technique using laser welding process has many variables ex pulse energy, pulse duration ,repetition rate, focal spot size and location, pulse shaping, scan speed of the job , gas jet velocity , nozzle shape, flow rate etc.
- Careful selection of the parameters can give us required properties in the weld joint.

Conclusion

- **A**. This technique has shown technical feasibility and financial viability can be easily assessed.
- **B**. The new technique may simplify the fabrication process and open up some new avenues too.
- **C. RRCAT has a long tradition in Laser technology and we are putting in considerable efforts in developing this technology for future projects.**

Thanks

For Details Please see:

Prashant Khare et al , "New Technique and Result of Laser Welded SCRF Cavity Developed at RRCAT",16th International Conference on RF Superconductivity,SRF2013 ,Sept2013.

Cavity Processing Steps before 1st Test-At FNAL

- Optical Inspection of Cavity
- 120 micron BCP for bulk removal of damaged layer during fabrication
- 800 deg C baking for 2 hrs at 10^{-6} mbar for hydrogen degassing
- 40 micron Light EP for 2 hrs (to smoothen enhanced grain boundary from BCP)
- High Pressure Rinsing & Cavity Assembly in Class 10 Clean room

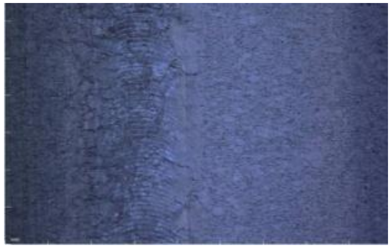
Cavity Assembled for Testing

Cavity Inserted in VTS for Testing

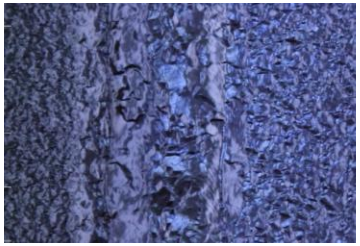
(E_{acc}) of 17 MV/m with a quality factor (Q_0) of 1.0×10^{10} at 2 Kelvin.

Cavity Processing Steps after 1st Test

- Centrifugal Barrel Polishing (CBP) to remove ~ 120 micron in equator
  - **1st step**: (material removal 80 µm @ 10 µm/h)
  - **2nd step:** (material removal 36 µm @ 3 µm/h)
  - **3th Step**: 800 mesh alumina powder + wood blocks + water for 30 hrs
  - **4th Step**: 0.04 micron colloidal silica gel + wood block for 70 hrs



cavity Surface after Welding



cavity Surface before 1st Test

Cavity Surface after CBP

- 13 micron Light EP for eliminating any polishing media inclusion
- Ultrasonic Cleaning and then HPR
- 800 deg C baking for 3 hrs with Nb end caps to remove hydrogen
- Final HPR and Cavity Assembly at Class 10 Clean Room
- 120° C Baking for 48 hrs for reducing surface oxides

Target Maneuvering System

Development of target maneuvering system (TMS)

Objectives of System

- Movement in both directions in continuous & fixed distance mode.
- Programmable speeds and distances for jobs of different diameters
- Sudden stopping during operation & precise display of distance moved.
- Tack welding facility for proper welding of circular jobs.

Description of the System

- The system drives the stepper motors connected to linear and rotary translation stages of Laser Welding Rig.
- TMS is based on Philips 89C51VRD2 microcontroller.
- LMD18245 full-bridge power amplifier is used to drive and control current in a stepper motor.
- The system uses 20X4 LCD and 4X4 keyboard for user interface.
- The Software is developed to facilitate all application specific functions.