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(On behalf of IIFC collaboration)

Collaborators & Team members
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G Wu, ANL

“Single Cell SC Cavity Development in INDIA”
Outline

1.3 GHz

- **Single cell cavity** *(1st prototype)*
  - Aluminum and Copper prototype *(With Industry)*
  - Niobium Single cell *(IUAC Collaboration)*
  - Processing & testing at ANL & FNAL.

- **Single cell cavity** *(2nd prototype)*

- **Multicell Cavity**

650 MHz *(β=0.9)*

- Single Cell cavity
RRCAT has initiated R&D work on development of SCRF technology and associated infrastructure to support their future LINAC program.

RRCAT is also a member of TTC and IIFC (Indian Institution Fermilab Collaboration).

Under IIFC, we are working on design and development of different aspects of SCRF technology viz SCRF Cavity, Cryomodule, RF powering, Processing & Testing infrastructure etc.

This presentation will report cavity development work.

Initial focus of the work jointly with Fermilab was on ILC type $\beta=1; 1.3 \text{ GHz}$ SCRF cavities.

650 MHz ($\beta=0.9$) is the recent addition.
Single cell cavity development

- Single cell cavity is made based on TESLA shape design
- At RRCAT
  - Design & development Forming die & half cell forming
  - Design for manufacturing
    - 3-D Modeling – UGNX, Detail dimensions with tolerances to suit manufacturability
    - Design & development of various machining & welding fixture
    - Machining all the parts in-house
    - Development of manufacturing process and QA plan.
- Design & development of RF measurement set up
- Estimation of Frequency with temperature and $K_{eq}$
- Regular WebEx meeting for progress review & technical discussions
Single cell cavity design activities

3-D design model of 1.3 GHz single cell Cavity (UGNX)

Fabrication drawing of 1.3 GHz single cell

<table>
<thead>
<tr>
<th>Material</th>
<th>RT Frequency</th>
<th>2K Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niobium</td>
<td>1297.8 MHz</td>
<td>1300.00 MHz</td>
</tr>
<tr>
<td>Copper</td>
<td>1303.81 MHz</td>
<td>1306.42 MHz</td>
</tr>
<tr>
<td>Aluminium</td>
<td>1306.42 MHz</td>
<td></td>
</tr>
</tbody>
</table>

Estimation of equator sensitivity coefficient ($K_{eq} - 5.2$ MHz/mm)

Estimation of change in frequency with temperature

Fundamental frequency in GHz

Extra length at equator of half cell in mm

15th International Conference on RF Superconductivity, Chicago 28 July 2011
1.3 GHz Forming tool development and half cells forming

- Two sets of forming tools were developed.
  - One set of forming tooling was delivered to Fermilab.
  - This was used for vendor development.
- The second set was used for making cavities in India.
1.3 GHz Prototype Single cell
Aluminum and Copper cavity with industry

- Technology development efforts started with Aluminum prototype cavities (No EBW, No Nb qualified vendor)

This has helped us to

- Develop cavity manufacturing process
- Test & qualify the welding fixtures
- Understand various mechanical & RF qualification procedure

- Copper cavity was made as per request from FNAL for thin film R&D.

- Later on these cavities were useful in pre-commissioning of various cavity processing facility at RRCAT

A lot can be learned making Non Niobium Cavities in a cheaper way

We have been able to generate interest in Industrial units to participate in R&D projects.

EBW Machine: 6 KW, 60 kV, 450 x 450 x 500 mm chamber size, Vacuum < 5 x 10^-05 m-bar
M/s Laxmi Technology & Engineering Industry Coimbtour

Aluminum and copper Prototype single cell cavities
1.3 GHz Prototype Single cell Aluminum cavity activities

Beam pipe - Flange welding

Inside Iris welding

Outer IRIS welding

Final equator welding
1.3 GHz Prototype Single cell Copper cavity activities

Beam Pipe Welding

Beam pipe - Flange welding

Inside Iris welding

Copper Half cell assembly

Copper prototype
IUAC EBW Machine:
15 KW, 60 kV-250 mA, chamber size, 2.5 x 1 x 1 m
Vacuum < 5 x 10e-05 m-bar
Prototype Niobium single cell SC cavity progress with IUAC

- Beam pipe rolling
- Beam pipe seam welding
- Pipe Flange welding
- Iris welding
- Equator welding
### Qualification & testing at RRCAT

#### Mechanical inspection

#### RF measurements

#### Leak testing

<table>
<thead>
<tr>
<th>Cavity ID</th>
<th>Vacuum leak rate (mbar l/s)</th>
<th>RF Frequency (MHz)</th>
<th>Total length (392 1)</th>
<th>Shrinkage equator</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE1CAT001</td>
<td>&lt; 1 X 10^{-12}</td>
<td>1297.2666</td>
<td>393.52</td>
<td>0.47</td>
</tr>
<tr>
<td>TE1CAT002</td>
<td>&lt; 1 X 10^{-12}</td>
<td>1296.73333</td>
<td>392.97</td>
<td>0.42</td>
</tr>
</tbody>
</table>
After all pre-dash dispatch qualification these cavities were shipped to Fermilab for processing & qualification testing.

- **Incoming inspection at FNAL**
  - *Internal optical inspection*
  - *RF testing*

<table>
<thead>
<tr>
<th>Frequency</th>
<th>TE1CAT001</th>
<th>TE1CAT002</th>
</tr>
</thead>
<tbody>
<tr>
<td>FNAL (23 C)</td>
<td>1297.031</td>
<td>1296.793</td>
</tr>
<tr>
<td>RRCAT (27 C)</td>
<td>1296.926</td>
<td>1296.675</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>'Q' factor</th>
<th>FNAL (23 C)</th>
<th>RRCAT (27 C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FNAL (23 C)</td>
<td>9960.53</td>
<td>9917.766</td>
</tr>
<tr>
<td>RRCAT (27 C)</td>
<td>9076</td>
<td>9328</td>
</tr>
</tbody>
</table>
Processing steps

- 1\textsuperscript{st} set of processing (TE1CAT002)
  - Bulk EP ~ 120 µm
  - HPR 85 bar for 6 hrs followed by clean room assembly
  - Low temperature backing 120 °C - 48 hrs
Cavity was quench-limited to 21 MV/m. Cavity was FE-free. Q was > 1.0 E10 with no significant “Q” drop.
Processing & Qualification testing at FNAL

- Processing steps
  - **1\textsuperscript{st} set of processing (for TE1CAT002)**
    - Bulk EP \(\sim 120\ \mu m\)
    - HPR 85 bar for 6 hrs
    - Clean room assembly
    - Low temperature backing 120 C - 48 hrs
  
  - **2\textsuperscript{nd} set of processing (for TE1CAT001)**
    - CBP \(\sim 140\ \mu m\)
    - HT \(\sim 800\ \text{oC}\) for 6 Hrs
    - Light EP \(\sim 20\ \mu m\)
    - HPR 85 bar for 6 hrs
    - Clean room assembly
    - Low temperature backing 120 C - 48 hrs

To polish the special weld feature near equator
Centrifugal Barrel Polishing

CBP process summary

Single cell TE1CAT001 mounted on CBP machine

TE1CAT001_equator_000.00

as received

After 1st CBP_50um

After 2nd CBP_100um

15th International Conference on RF Superconductivity, Chicago 28 July 2011
2 K Test results

Cavity was quench-limited to 19 MV/m. Cavity was FE-free. Q was > 1.5 E10 with no significant “Q” drop
T-mapping & Internal inspection post 2 K testing

• For the diagnostic purpose, total 16 temperature sensors (cernox) were mounted near each side of the equator. (8 x 2 bands)
• Strongest quench (temp) signal was on sensor #2, band 1.
• Next strongest was on sensor #4 of band 2,
• Then sensor #3 of band 2.

Optical inspection was performed again on TE1CAT002 to see the quench spots and inner surface after EP.

EP could not polish the weld undulations features

It was decided to do molding to investigate it further near the quench spots
Molding and Profilometry

Silicone mold making compound used
TRV 630 A & B (10:1 by weight)

Profilometer inspection
KLA-Tencor P-16

These results are in line with visual inspection.
Profilometry quantified the weld undulations, (274 µm, peak to valley)

Tumbling was carried out on TE1CAT002 also following the results discussions

2010-3-15 Equator 202

2010-3-15 Equator 204
The cavity’s gradient improved up to 23MV/m.

There was no FE observed at any time, but some minor radiation levels were briefly observed accompanying the multipacting.

Both low field and high field $Q_0$’s were reasonably good – $2.5 \times 10^{10}$ and $1.7 \times 10^{10}$, respectively.
1.3 GHz Single Cell cavity (2\textsuperscript{nd} prototype)

Based on the feedback from the inspection and test results for initial prototype cavities, we worked to make two nos (2\textsuperscript{nd} prototype) single cell cavities.

- Key improvements
  
  A. Careful handling of Niobium components during all manufacturing Process.
  
  B. 20 μm Bulk BCP etch
  
  C. Further optimisation, including beam oscillation, of weld parameter for critical equator weld.
Two more single cell cavity (2nd prototype) have also been fabricated.

- **TE1CAT003** has been tested for Pre-dispatch qualification at RRCAT and sent to FNAL (May 2011)
- This has also undergone optical inspection, RF measurement at FNAL in June 11
- **TE1CAT003** and also been EP’ed at ANL last week & is in Queue at 2 K test facilities at FNAL

**RF measurement data**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>TE1CAT003</th>
<th>TE1CAT004</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRCAT</td>
<td>1299.871229</td>
<td>1299.91538</td>
</tr>
<tr>
<td>FNAL</td>
<td>1299.91538</td>
<td>to be measured</td>
</tr>
</tbody>
</table>

- 'Q' factor
  | RRCAT | 9463.7265 | 9237.3484 |
  | FNAL  | 10014.8086 | to be measured |

- **TE1CAT004** has also been fabricated (May 2011) and is getting ready for shipment to FNAL (August 2011)

We hope to have test results for these cavities in coming months
Towards multicell cavity

- Plans to develop the dumbbells and simple 5 cell cavity.
- End group development in parallel
Progress on multicell cavity activity

1.3 GHz

Development of prototype Dumbbell and their qualification.

After dumbbell qualification we plan to move to make 5 cells cavity with simple end group
Long & Short End Group in Aluminum

Stages of End group fabrication

Long and short End Group prototype

Parts machining & fixtures developed. Niobium End group next
Initial activities on 650 MHz, $\beta = 0.9$ SRF cavity

- Design for manufacturing
- Design & development of various tooling & fixture
- Design and development of forming tooling

Awaiting arrival of Niobium Sheets

We aim for the 1st prototype in 2011.
Dr. P D Gupta (RRCAT), Dr. Amit Roy (IUAC),

Dr. Robert Kephart, Dr. Shekhar Mishra & Mr. Mark Champian (FNAL)

Mr. Michael Kelley (ANL)

for their continuous motivation & support.

And all the team members & collaborators at RRCAT, IUAC, FNAL & ANL for their efforts and excellent collaboration 😊
An interesting historical connections to Chicago City

Swami Vevekanand delivered the historical address at the “Parliament of the World's Religions” at Chicago in 1893 (More than 100 Years Ago!!)

http://www.youtube.com/watch?v=N8MRaevfUU&feature=related
Thank You for your kind attention