Investigation of High Temperature Baking of Jacketed Quarter Wave Resonators

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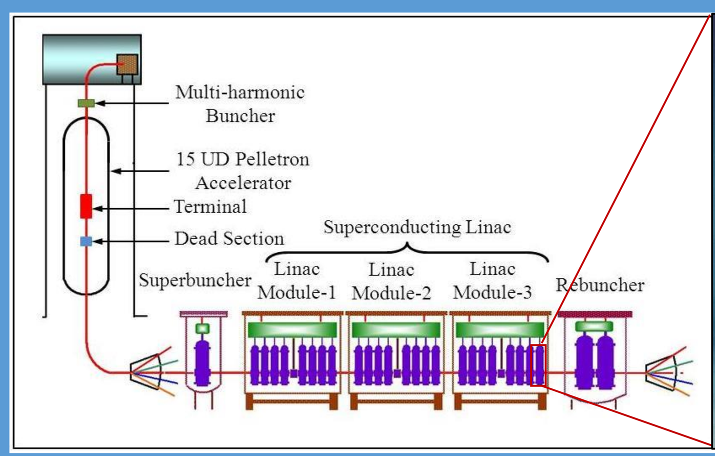
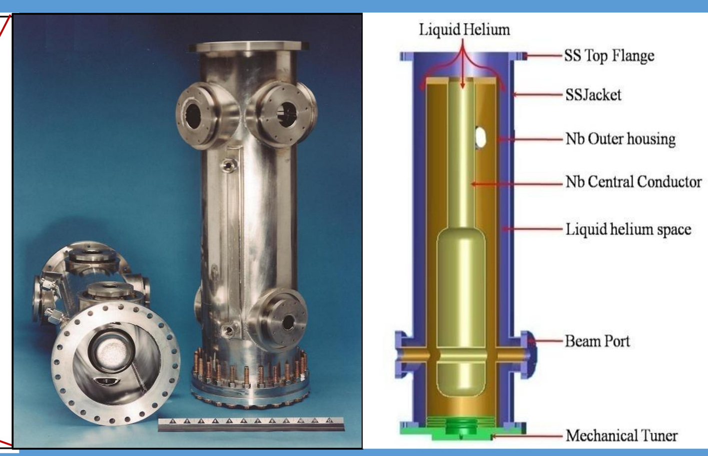
The Superconducting Linac (SC Linac) at IUAC

- Booster to the existing 15 UD Pelletron accelerator.
- Niobium Quarter Wave Resonator (QWR) used as the accelerating element.
- QWRs designed and the first batch of twelve resonators fabricated at Argonne National Lab (ANL).
- Superconducting Resonator Fabrication (SRF) infrastructure was commissioned at IUAC to cater to Linac development.



The Accelerator System



The Quarter Wave Resonator

Parameter	Value
β_0	0.08
f	97 MHz
U_0	110 mJ
B_{peak}	132 G
E_{peak}	3.9 MV/m
R_{sh}/Q	370 Ω
QR_s	17.3
V_{Gain}	0.85 MV
L_{eff}	15.9 cms.

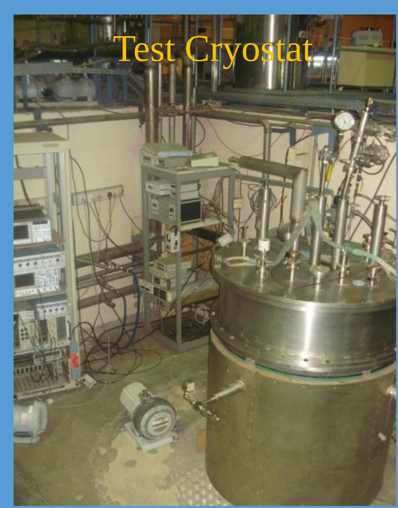
QWR parameters @1 MV/m

SRF Infrastructure at IUAC

- Beam Power: 15 KW
- Voltage: 60 KV
- Current: 150 mA
- Chamber Size: 1 m × 1 m × 2.5 m
- Control: CNC with PC & Touch Screen

- Bottom loading type
- Max Temp.: 1300 °C
- Chamber Vacuum: 5×10^{-6} mbar @ 1300 °C
- Heating Element: Molybdenum
- Chamber Size: Φ0.6 m × 1 m
- Control: SCADA & PC

- Large Fume Hood
- DC Power Supply: 0-20 V, 1000 A
- Large Ultrasonic Cleaners (27 kHz & 68 kHz)
- DI Water Plant: 200 lph
- Chiller, Sink, Fridge, Acid Pump, Acid Containers and Safety Gadgets & Garments.



- Φ1 m × 2.5 m
- Lead and μ metal shields
- Turbo pump based vacuum system
- Low static heat load < 4W

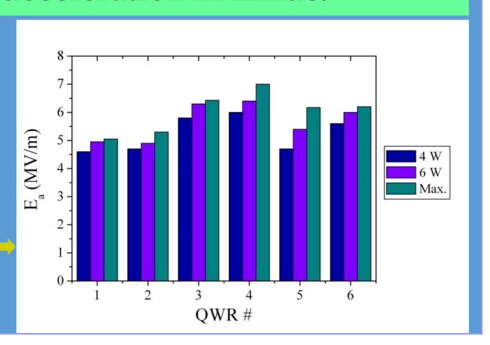
The Indigenous QWRs

- The first indigenous QWR (QWR # I01) was fabricated using the Niobium sub-assemblies left over from the ANL project in the year 2003.
  Achieved 5 MV/m @6 W at 4.2 K (Q =2.8×10^8)
- Installed in the Linac.

- Two more resonators QWR# I02 and I03 were thereafter fabricated to freeze the fabrication algorithm.
  QWR #I02 successfully tested offline and installed in Linac
  QWR #I03 suffered an accident during one of the Electropolishing (EP) procedures. RF surface was spoiled.

- After two successful prototypes, fifteen QWRs were built. All are being used for beam acceleration in Linac.

Indigenous QWRs and their performances



High Temperature (HT) bake of QWR # I03

QWR # I03 History

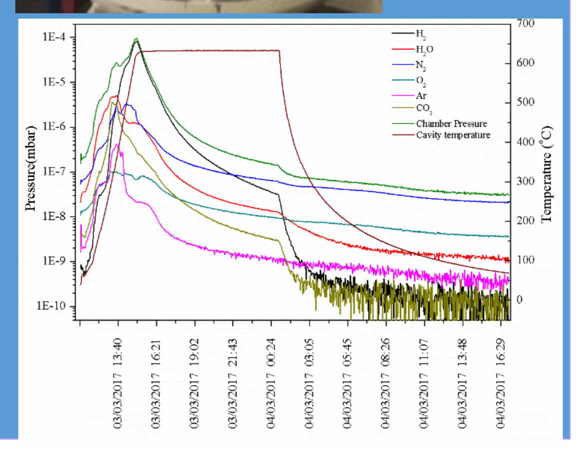
- One of the first QWR to have fully indigenous fabrication
- Tested after 20μm EP post fabrication
  3.1 MV/m @ 3.5 W (Q =1.8×10^8) @ 4.2 K, could not be tested at higher powers due to non-availability of LHe.
- RF surface was unevenly etched resulting in increased roughness (surface closely resembled fish scales) and frequency detuning.
  Cause: A wrong composition of the electrolyte used for EP
  Usual composition: 98% H_2SO_4 and 40% HF in volume ratio 85:15
- Chemical analysis showed presence of Nitric acid ~1.3 % by weight in the acid mixture.

RF surface of QWR # I03 after EP accident

- Cavity tested after 50μm of EP with fresh electrolyte.
  1.2 MV/m @ 16W (Q =5.9×10^6).
- Q measurements could not be done as the cavity was unstable at higher powers.

HT Bake

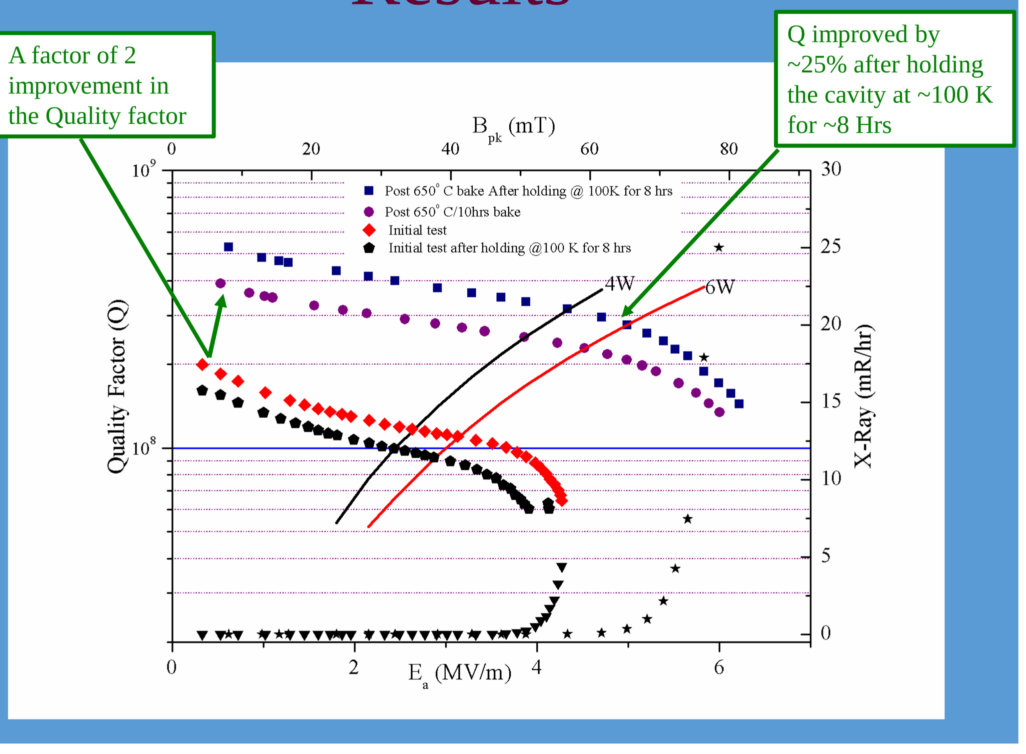
- A pre-bake test was done to establish a baseline performance. Prior to the test the cavity was cleaned in a high frequency (68kHz) ultrasonic bath (at~55°C) followed by a rinse with low pressure ultrapure water.
  2.6 MV/m @ 4 W (Q =1.1×10^8) @ 4.2 K,
  Surprisingly good result !! (Ultrasonic rinse)
- Resonator was held at ~100K for 8hrs followed by another fast cooldown to 4.2 K (identical to the first case at >150 K/hr) and Q measurements.
  ~15-20% deterioration in Q
  $1.1\times10^8 \longrightarrow 8.8\times10^7$
- Resonator was baked at ~650°C for 10 hrs. It was cleaned in an identical manner as in the baseline test. Q measurements were done after a fast cooldown (>150K/hr) to 4.2K. Measurements repeated after holding the cavity at ~100K for ~ 8hrs



Resonator ready for bake (left)

RGA spectrum during bake cycle (bottom)

Results



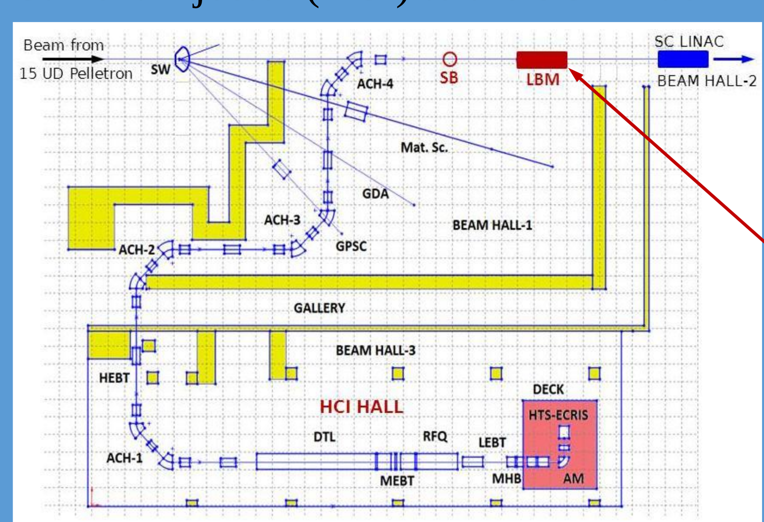
Conclusions

- A high temperature bake at 650 °C for ~ 10 hrs. improves the cavity performance significantly and also makes it immune to Q disease.
- At low RF frequencies the reduction in the RF surface resistance is predominantly that in the residual resistance as the BCS component is small.
- Hydrogen degassing alone cannot account for the improvement in the Quality factor as it is significantly more than the deterioration due to hydride precipitation.
- Cleanliness of the Furnace and cavity surfaces is very essential to achieve positive results.
- Studies have been planned on niobium samples to have a better understanding of the phenomenon.

HT bake of β=0.05 Cavity

History and initial test results

- The β=0.05 QWR was developed for use as a velocity matching structure with the High Current Injector (HCI) to the SC Linac.

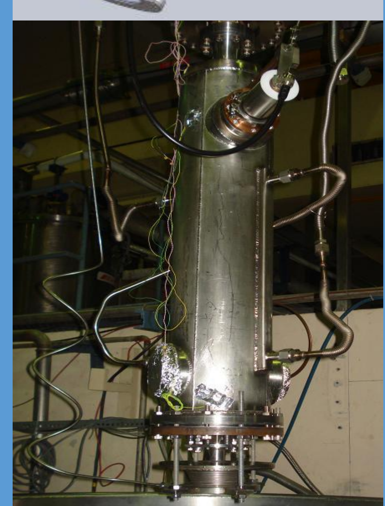


Layout showing the High Current Injector along with the proposed location of the β=0.05 module with eight cavities.

- The cavity was electropolished to remove ~100 μm of material. It was cleaned in a high frequency (68kHz) ultrasonic bath (at~55°C) followed by a rinse with low pressure ultrapure water. Subsequently, it was tested after a fast cooldown to 4.2 K
  Design goal of 6 MV/m @ 1.8 W (Q =3.1×10^8)
  9.5 MV/m @ 6 W (Q =2.4×10^8)

QWR parameters @1 MV/m

Parameter	Value
β_0	0.051
f	97 MHz
U_0	26 mJ
B_{peak}	64.2 G
E_{peak}	3.45 MV/m
R_{sh}/Q	650 Ω
QR_s	16.1
V_{Gain}	0.63 MV
L_{eff}	10.5 cms.



Resonator made ready for test at 4.2K.

HT bake

- After establishing a baseline performance the resonator was baked at ~650°C for 10 hrs. It was thereafter cleaned in an identical manner as the baseline test. Q measurements were repeated.

Results