Electropolishing of Niobium SRF Cavities in Low Viscosity Aqueous Electrolytes without Hydrofluoric Acid

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Objective

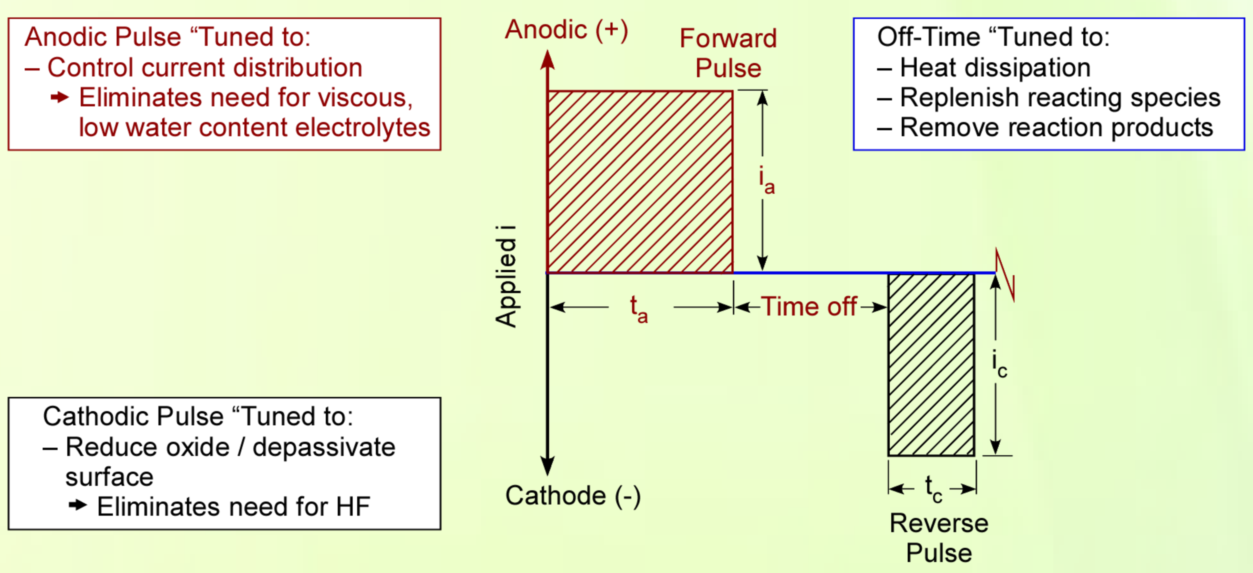
- Develop eco-friendly electropolishing process for SRF cavities
- Reduce personnel and environmental risks

Conventional EP

- **Nine parts sulfuric acid (95-98%) to one part hydrofluoric acid (49%)**
- **Jacquet "viscous salt film theory"**
  - Thick viscous boundary layer focuses current on asperities under mass transport control
  - Hydrofluoric acid added to remove the surface oxide layer
  - Diffusion limited access of fluoride to the surface

Approach

- **Pulse reverse waveform → Bipolar EP**



Transition From Coupons to Single-cell Cavities

Waveform	V_{anodic} (V)	t_{anodic} (ms)	t_{off} (ms)	$V_{cathodic}$ (V)	$t_{cathodic}$ (ms)	H_2SO_4 in Water (wt %)
Coupons:						
High Frequency - High Power	30	0.06	5.0	35	0.20	30
High Frequency - High Power	3	2.50	1.0	9	2.50	30
Cavities:						
Ultra Low Frequency - Low Power	4	200	300	10	200	5
Very Low Frequency - Low Power	4	100	150	10	100	10

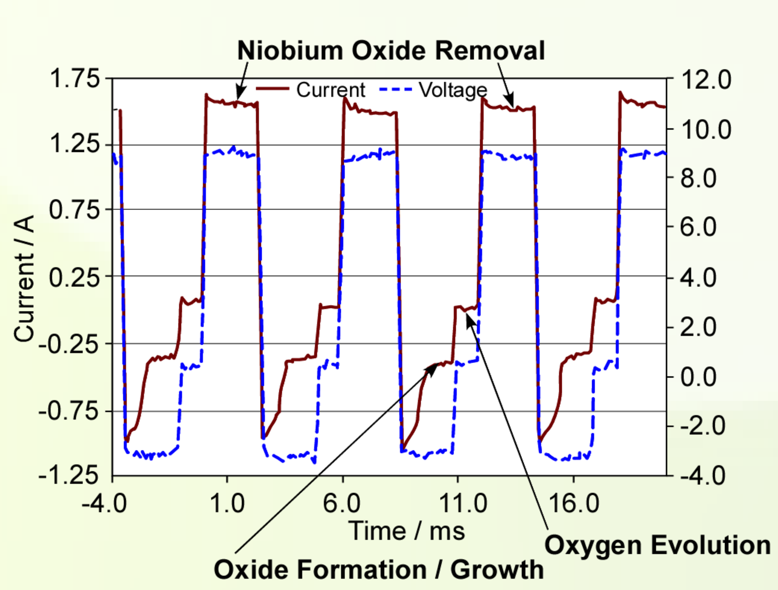
Coupon Study:

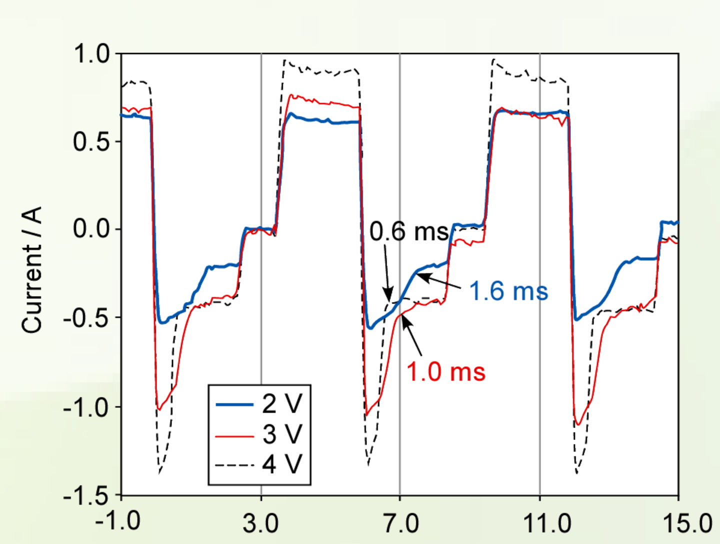
Amelioration of Heat Build-up
(High Frequency / High Power Waveform)

t_{off} (ms)	Total Time (min)	Initial Temp. (°C)	Final Temp. (°C)
0.3	40	15	33
0.6	120	14	35
1.0	120	14	28
5.0	560	16	19

- **3"x 3" Coupons**
- **30 wt% H_2SO_4 in water**
- **15 L bath volume**

Anodic Current Transition → "Cathodic Polishing"
(Low Frequency/Low Power Waveform)

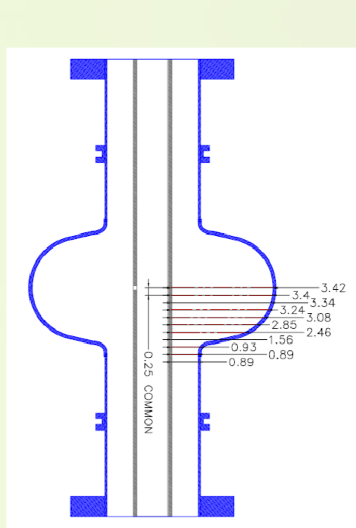


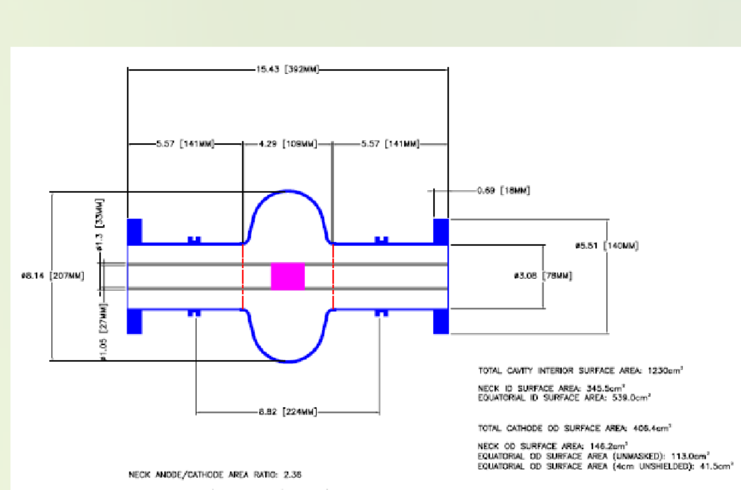


Anodic pulse: Niobium oxide film growth followed by oxygen evolution
Cathodic pulse: Niobium oxide removal
→ The anodic current transition correlates with niobium polishing

Simulation of Electrode to Cavity and Area Ratio

Variable gap; cathode to cavity surface (~1 to 3.5")
Variable area ratio; cavity to cathode surface area ratio (~2:1 to 5:1)
In order to maintain the anodic current transition:
→ As coupon gap increases; waveform frequency decreases
→ As coupon surface area ratio decreases; waveform frequency decreases





Developmental Cavity (TE1NR001)

- **Initial processing similar to conventional cavity EP**
  - Horizontal orientation
    - Rotation
    - 60% volume fill
  - *→ Based on visual inspection, no polishing*
- **Horizontal cavity orientation developed for viscous electrolyte**
  - Avoid streaking due to bubbles
  - Rotation rate optimized to form "electrolyte film"
  - *→ Conditions not appropriate for low viscosity electrolyte*
- **Subsequent processing**
  - Vertical orientation
    - No rotation
    - 100% volume fill
  - *→ Based on visual inspection, polishing; confirmed at Fermilab*

Performance Cavity Experiment 1 (TE1DESYB5)

- **Vertical orientation**
- **No rotation**
- **100% volume fill**
  - 5 wt% H_2SO_4 in water; 4 V anodic for 200 ms: off for 300 ms: 10 V cathodic for 200 ms
  - Average ~30 μm removed
  - *→ Cavity performed with a quench field about 31 MV/m with a low-field Q_0 of 2.0E+10 which is within the normal performance band of a cavity receiving standard EP .*

Performance Cavity Experiment 2 (TE1AES007)

- **Vertical orientation**
- **No rotation**
- **100% volume fill**
  - 5 wt% H_2SO_4 in water; 4 V anodic for 200 ms: off for 300 ms: 10 V cathodic for 200 ms
  - Average ~30 μm removed, followed by
  - 10 wt% H_2SO_4 in water; 4 V anodic for 100 ms: off for 150 ms: 10 V cathodic for 100 ms
  - Average ~70 μm removed
  - *→ The cavity exhibited "average" performance as well as Q-disease, which was eliminated after bake.*

Performance Cavity Experiment 3 (TE1AES007)

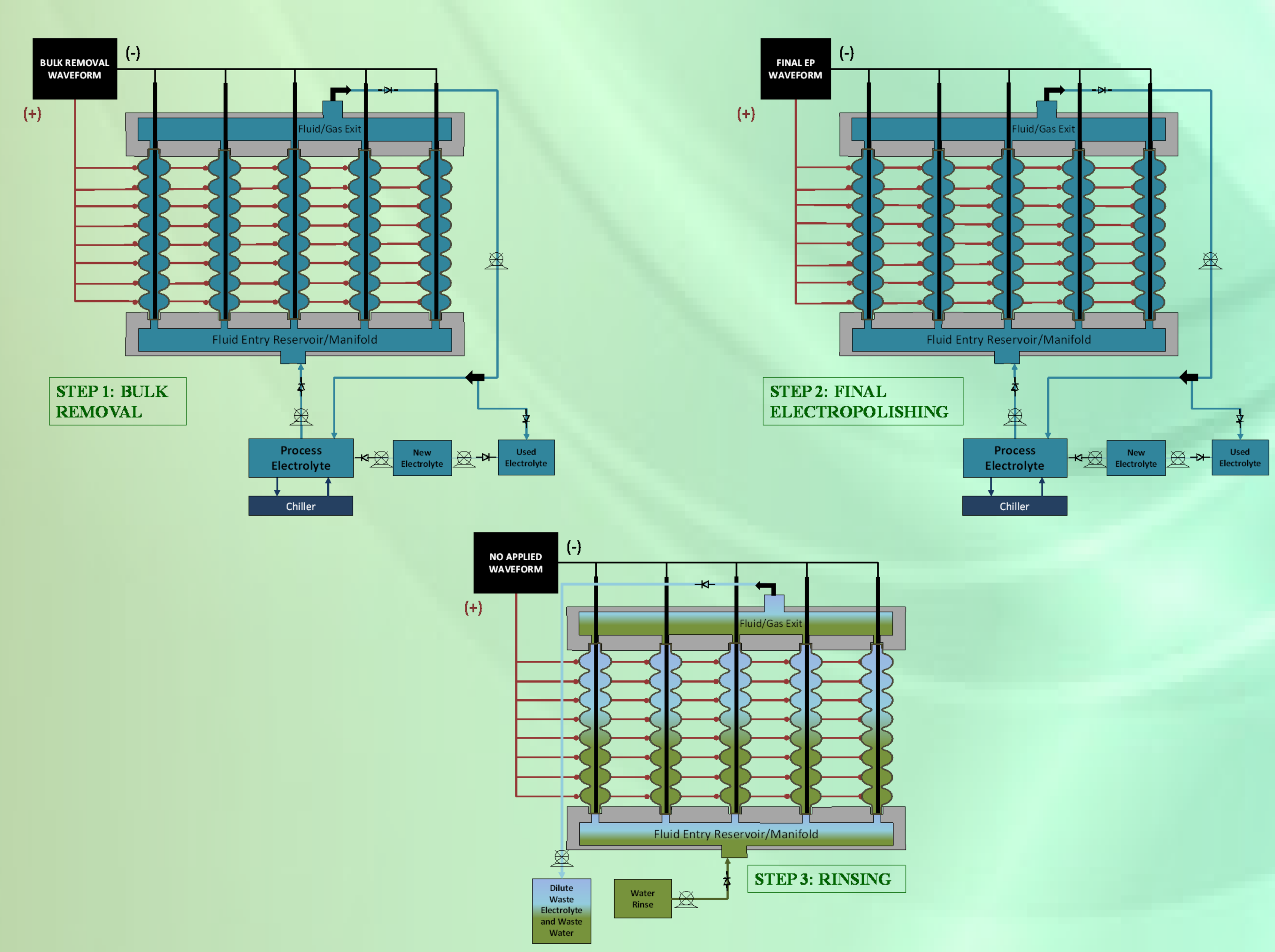
- **Vertical orientation**
- **No rotation**
- **100% volume fill**
  - 10 wt% H_2SO_4 in water; 4 V anodic for 100 ms: off for 150 ms: 10 V cathodic for 100 ms
  - Average ~20 μm removed
  - *→ The cavity did not exhibit Q-disease.*

Performance Cavity Experiment 4 (TE1AES012)

- **Vertical orientation**
- **No rotation**
- **100% volume fill**
  - 10 wt% H_2SO_4 in water; 4 V anodic for 100 ms: off for 150 ms: 10 V cathodic for 100 ms
  - Average ~25 μm removed
  - *→ The cavity achieved a maximum gradient of ~44MV/m with a Q of 1x1010, the highest gradient and Q value at this gradient observed at Fermilab in any cavity regardless of processing technique.*

Summary

- **Bipolar EP successfully transitioned from coupons to single cell SRF cavities**
- **Pulse reverse waveforms enable sulfuric acid-water electrolytes WITHOUT HF**
- **Vertical orientation cavity enables without rotation**
  - Lower cost industrial implementation
  - Simultaneous multiple cavity processing
- **Potential for sequentially applied waveforms tuned for bulk removal followed by final EP in the same electrolyte**



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