

SRF 2013

# Demonstration of RF Stabilities in STF 9-cell Cavities Aiming for the Near Quench Limit Operation

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- Introduction
- Nominal Operation
- High Q<sub>L</sub> Operation
- Fully Automated PkQL Control
- Summary



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# Superconducting RF Test Facility (STF)

STF

 Development and demonstration of high gradient superconducting accelerator technology aimed for ILC Normal conducting photocathode RF gun\* (5 MW Klystron on ground level)











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### **Nominal Operation**



<i>RF Parameter</i> V <sub>Cav1</sub> = 16 MV/m	Beam Parameter Pulse Length = 615 $\mu$ s Current = 6.6 mA ILC Stability Requirements $\Delta A/A = 0.07\%$ Act = 0.24°	Beam	6.6mA* (60 mins)	Off (20 mins)
$V_{Cav2} = 24 \text{ MV/m}$ $Q_{L1} = 3e6$ $Q_{L2} = 3e6$ Filling time = 540 µs *Beam compensation		ΔΑ/Α (cav1)	-	0.042%
		ΔΑ/Α (cav2)	-	0.045%
		ΔΑ/Α (vector sum)	0.009%	0.008%
active Δφ = 0.24	Δφ – 0.24	Δφ (cav1)	-	0.027°
	$am transient$ 800 900 1000 1100 1200 Time [ $\mu$ s] 1500 2000 2500 3000	Δφ (cav2)	-	0.021°
		Δφ (vector sum)	0.009°	0.008°
			All stabilities are estimated the beam transient time.	
Ti	me $[\mu s]$			



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ILC requirements

- Operation intended at Q<sub>L</sub> values in a range of 3e6 to 10e6
- Bandwidth becomes very narrow (e.g. 32Hz at QL=2e7), detune becomes severe
- Microphonics maybe problematic to deal with
- Demonstration only possible at KEK STF due to wide QL range (2e6~5e7)

#### High Q∟ operation at STF

- QL adjustment with waveguide reflectors
- Automated detune compensation via piezo tuners

## High QL Operation

Gradient [MV/m]

5

0

0

19.995

19.990

500

1000

1000

Time [µs]

1300

Time [µs]

1500

1500 1600

2000



RF Parameter		High QL		Nominal		
$V_{Cav1} = 20 \text{ MV/m}$ $V_{Cav2} = 20 \text{ MV/m}$	Beam	6.1 mA* (60 mins)	Off (20 mins)	6.6 mA* (60 mins)	Off (20 mins)	
$Q_{11} = 2e7$ $Q_{12} = 2e7$	ΔA/A (cav1)	0.121%	0.030%	-	0.042%	
Filling time = 800 µs *Beam compensation	ΔA/A (cav2)	0.160%	0.032%	-	0.045%	
active Beam Parameter	ΔΑ/Α (vector sum)	0.011%	0.008%	0.009%	0.008%	
Pulse Length = 615 μs Current = 6.1 mA	Δφ (cav1)	0.033°	0.027°	-	0.027°	
20	Δφ (cav2)	0.028°	0.027°	-	0.017°	
15 20.025 20.020 Beam transient	Δφ (vector sum)	0.015°	0.014°	0.009°	0.008°	
	All stabilities are estimated for the beam transient time.					

- Detuning stayed constant during 1h operation
   → Microphonics are not severe
  - Fulfills ILC stability requirements ( $\Delta A/A = 0.07\%$ ,  $\Delta \varphi = 0.24$ )

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## PkQL Control



Target: Operation with flat flattops

- Stable beam acceleration (Cavity tilts and RF fluctuations induce transverse beam orbit changes)
- High gradient operation near quench limit during whole flattop for all cavities

Operation of multiple cavities driven by a single klystron combined with beam loading leads to gradient tilts  $\rightarrow P_kQ_L$  Control





#### ILC requirements

- Fully automated PkQL operation (~16000 cavities)
- Cavity gradient spread ±20% (e.g. 16 MV/m and 24 MV/m)
- Cavity gradients 5% below of respective quench limits
- Cavity gradients must never exceed quench limits
- Cavity vector sum stabilities  $\Delta A/A = 0.07\%$  and  $\Delta \varphi = 0.24^{\circ}$

#### Steps to engage in *PkQL* operation

- Determination of working point for adjustment of cavity RF input powers (Pk) and QL values respective to the beam current
- Fully automated PkQL setting procedure



### PkQL Operation Stabilities

Gradients [MV/m]



RF Parameter		PkQL	Nominal		
$V_{Cav1} = 16 MV/m$ $V_{Cav2} = 24 MV/m$	Beam	6.4 mA* (60 mins)	6.6 mA* (60 mins)	Off (20 mins)	
$Q_{L1} = 966$ $Q_{L2} = 366$	ΔA/A (cav1)	0.041%	-	0.042%	
*Beam compensation active	ΔA/A (cav2)	0.031%	-	0.045%	
<i>Beam Parameter</i> Pulse Length = 615 μs	ΔΑ/Α (vector sum)	0.009%	0.009%	0.008%	
Average current = 6.4 mA	Δφ (cav1)	0.042°	-	0.027°	
• Cavity 1 • Cavity 2	Δφ (cav2)	0.031°	-	0.021°	
15 Vector Sum	Δφ (vector sum)	0.009°	0.009°	0.008°	
$10 \begin{bmatrix} 10 \\ 10 \\ 10 \\ 10 \\ 10 \\ 10 \\ 10 \\ $	All stabili the bean First actual PkQL operation Vector sum stabilities comparable with			ies are estimated for transient time.	
0 500 1000 1500 2000 Time [μs]	• Fulfills ILC s	tability requirem	ents (ΔA/A = 0.0	7%, Δφ = 0.24)	



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- Stabilities for long time nominal operation were evaluated with and without beam
- Even under high Q<sub>L</sub> (2e7) operation the stabilities were comparable to nominal operation, microphonics were not severe
- First full automated ILC-like PkQL operation was demonstrated with stabilities comparable to nominal operation with flat flattop 5% below the respective virtual quench limits





# Thank you very much for your attention! Merci pour votre attention!