Overview of RF SYSTEM

Kazunori AKAI

8 Jun. 1995

Outline

1. Requirements
2. Normal-conducting cavity (ARES) ---- Kageyama will give detailed talk.
3. Superconducting cavity ---- Mitsunobu will give detailed talk.
4. High power system
5. Low level control system ---- Ezura will give detailed talk on RF feedback system.
6. Response to a bunch gap
7. Crab cavity ---- Hosoyama will give detailed talk.

Layout of RF Stations

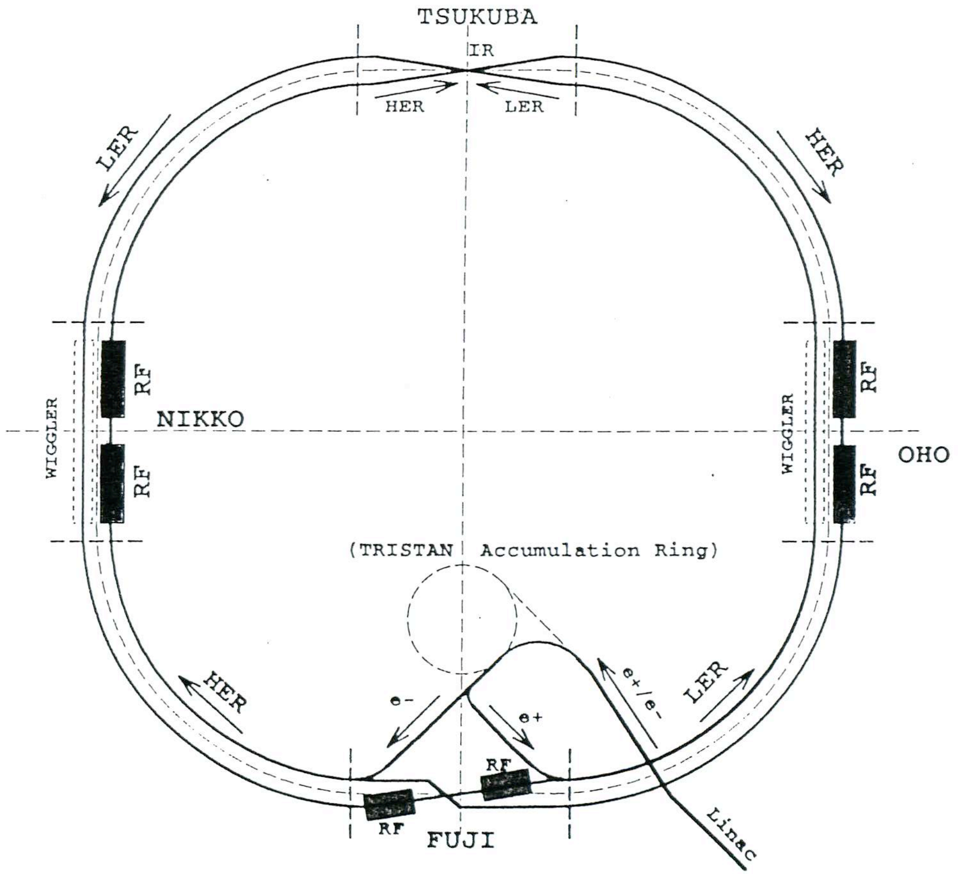
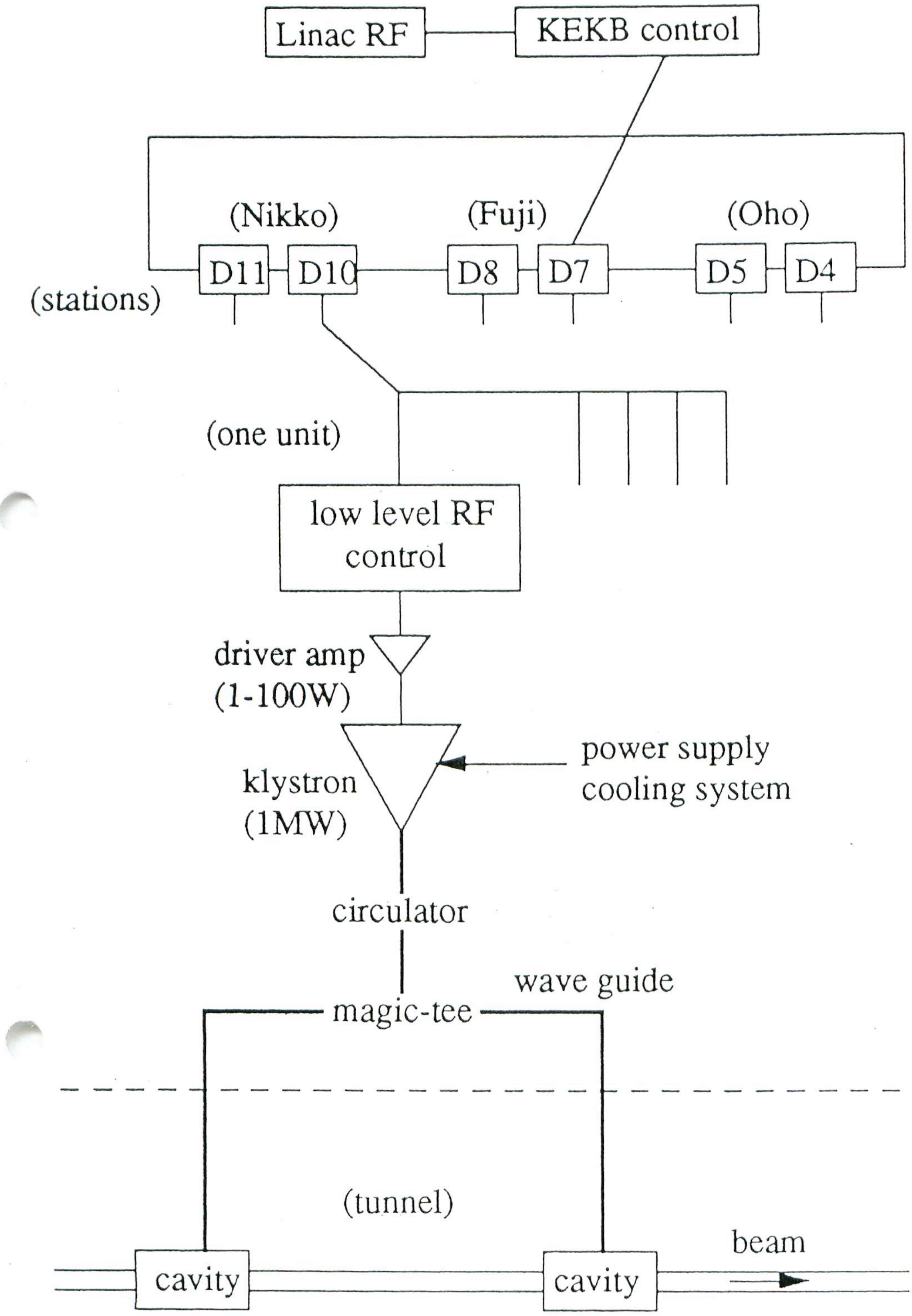


Figure 0.1: A schematic plan view layout of KEKB.


Linac RF
KEKB control
(Nikko)
(Fuji)
(Oho)
(stations)
D11
D10
D8
D7
D5
D4
(one unit)
low level RF control
driver amp (1-100W)
klystron (1MW)
power supply
cooling system
circulator
wave guide
magic-tee
(tunnel)
beam
cavity
cavity

RF-related Machine Parameters

	LER	HER	
Beam energy	3.5	8.0	GeV
Beam current	2.6	1.1	A
Bunch length	4	4	mm
Synchrotron tune	0.01 - 0.02	0.01 - 0.02	
RF voltage	4.9 - 9.4	8.7 - 16.2	MV
RF frequency	508.887		MHz
Damping time	43 / 23	23	msec
Radiation power	2.1 / 4.0*	3.8	MW
HOM loss	0.57	0.14	MW
Total beam power	2.7 / 4.5*	4.0	MW

*with wigglers for LER

- It is desired that the synchrotron tune should be variable.

-----> RF voltage needs to be able to be varied, correspondingly.

Heavy Beam Loading and R&D Issues

- Coupled-Bunch Instability arising from
  the accelerating mode -----> ARES, SCC (+RF feedback)
- Coupled-Bunch Instability arising from
  higher-order modes (HOMs) -----> HOM-damped cavity (Q<~100)
- HOM power (~10 kW / cavity) -----> HOM absorber
- RF input power (300-500 kW / cavity) -----> Input coupler
- Phase stability,
  Responce to a Bunch Gap -----> Low level control

Coupled-Bunch Instability arising from the Accelerating Mode

Cavity detuning required to minimize the input power:

$$\Delta f = \frac{I \sin\phi}{2V_c}\left(\frac{R}{Q}\right) \times f = \frac{P_b \tan\phi}{4\pi U}$$

Heavy beam loading

-----> Δ f > revolution frequency.

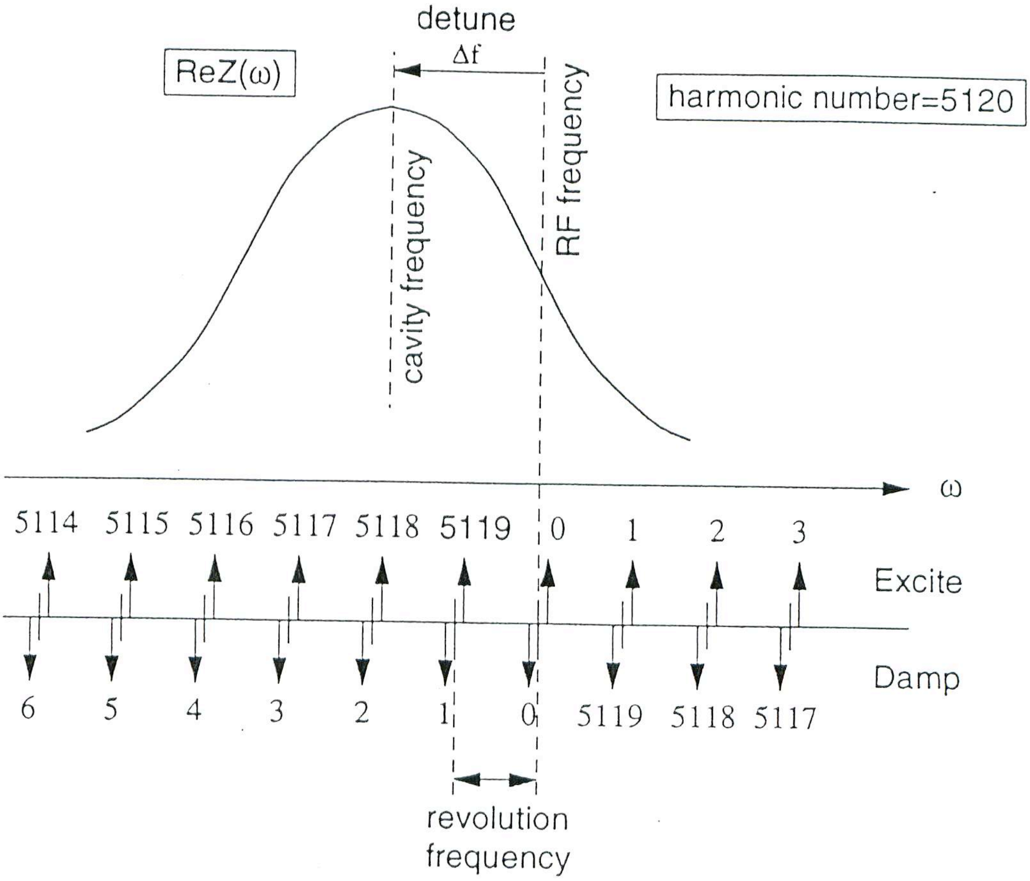
-----> Instability occurs at μ=-1, -2, --- modes.

The growth rate is extremely high. (τ^{-1}~0.1msec^{-1})

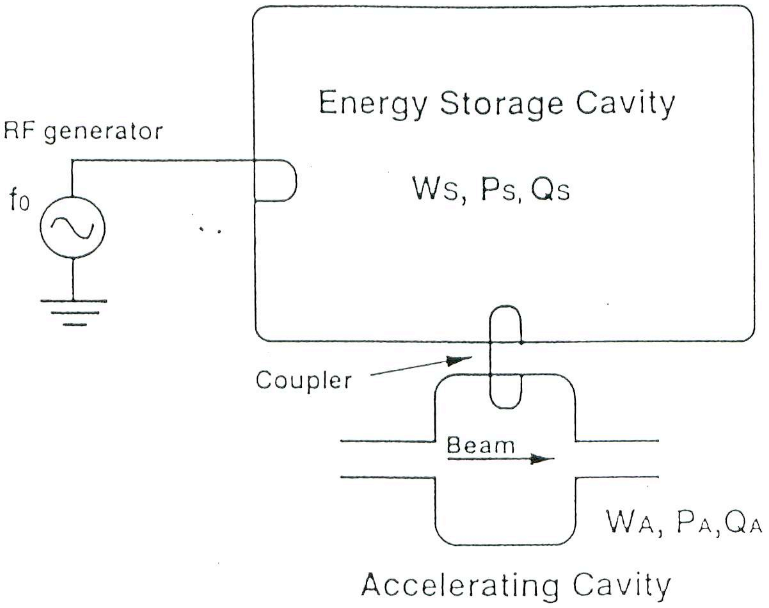
Our solutions: (increase the stored energy (U))

- ARES (normal-conducting) cavity
- Superconducting cavity

(+ additional damping by RF feedback, when necessary)



Coupled-bunch instability caused by the accelerating mode



instability
↑
{ 0 mode
π mode

Fig. 2 Accelerating cavity coupled to an energy storage cavity.

T. Shintake, Part. Acc. 44. 131 (1994)

ARES
=
Accelerator Resonantly Coupled
with Energy Storage

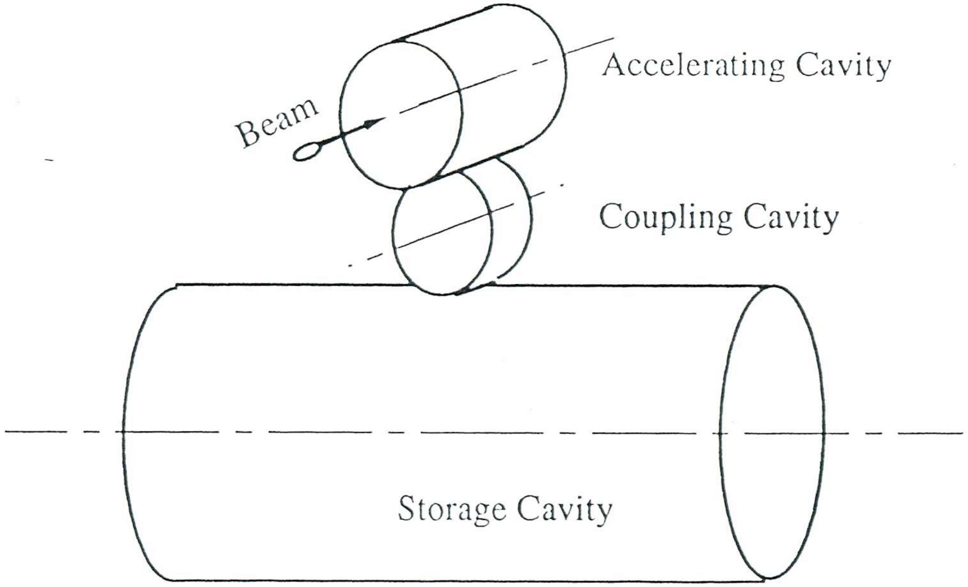


Figure 4.1: A schematic view of the ARES normal-conducting cavity system.

Y. Yamazaki and T. Kageyama, Part. Acc. 44. 107 (1994).

R&D status of ARES

- The principle of ARES has been confirmed.
  (MAFIA calculation, model measurement)
- The basic design of ARES has been carried out.
- A full scale ARES is currently fabricated for a beam test.
- A HOM-damped cavity for ARES has been fabricated and tested in high power operation successfully.
- High power test of SiC absorbers showed high power handling capability and low outgassing rate.
- Input couplers have been designed. High power test is scheduled for this summer.

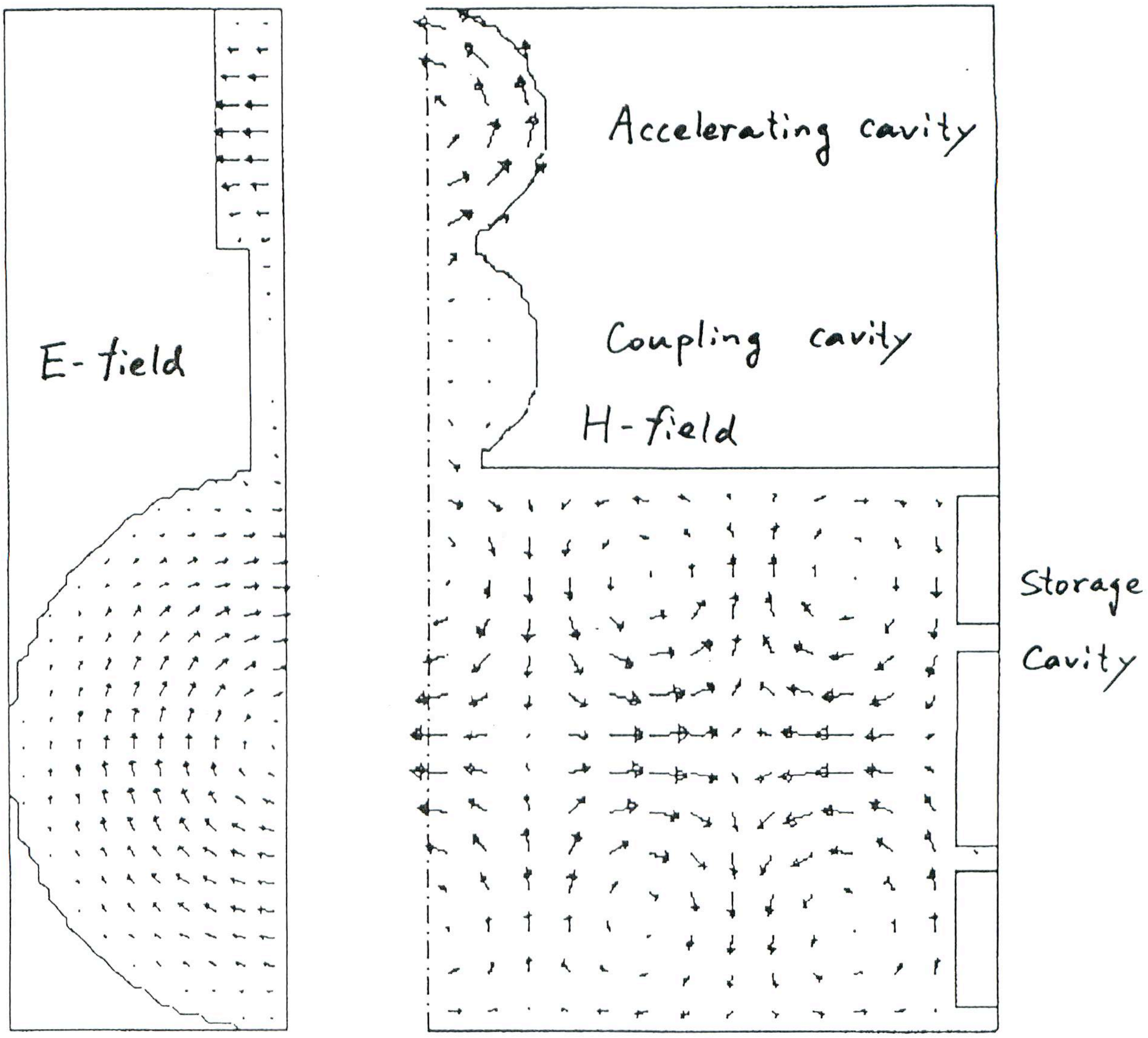
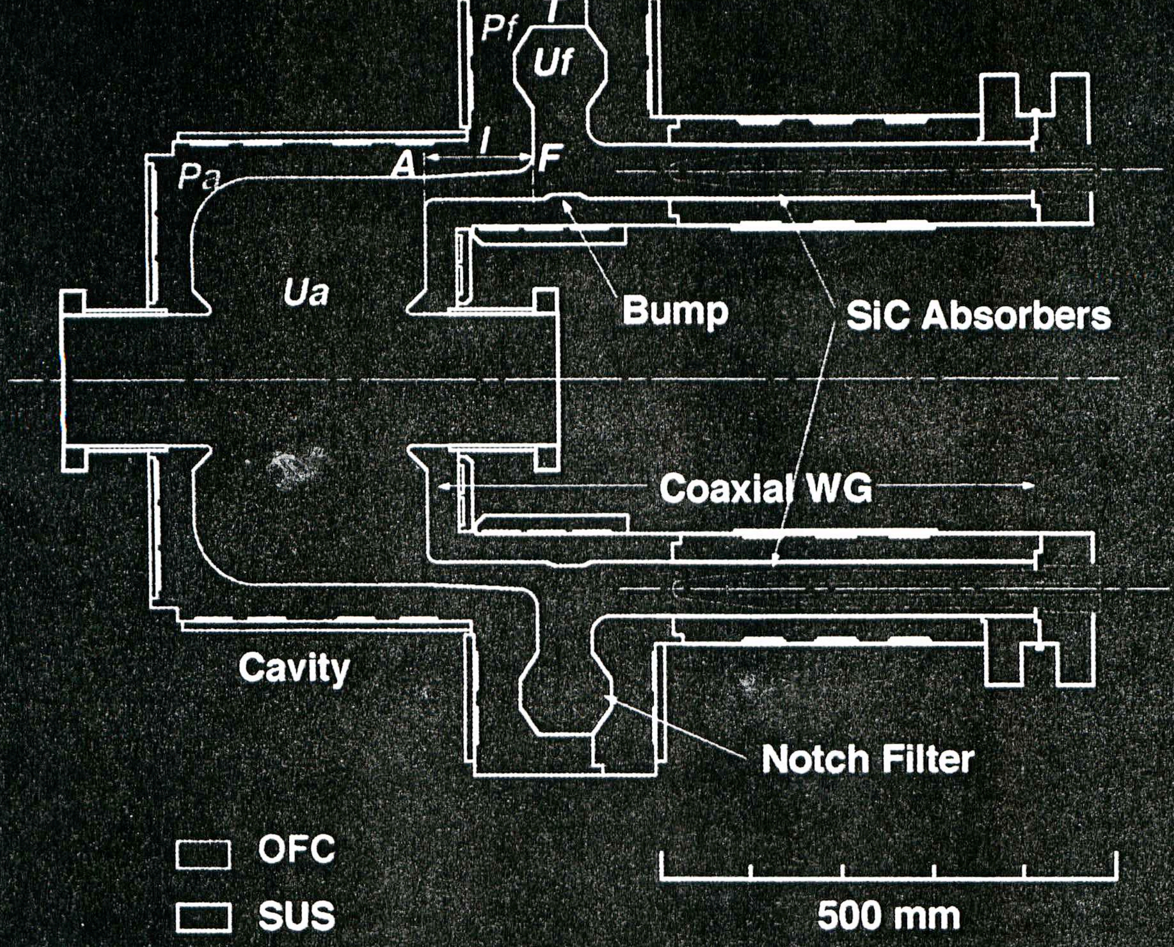


Figure 7.5: Field pattern of the $\pi/2$ mode calculated by the MAFIA code. (left) electric field, and (right) magnetic field.

K. Akai and Y. Yamazaki, Part. Accel.
46 197 (1994)

STRUCTURE



RF parameters of the accelerating mode

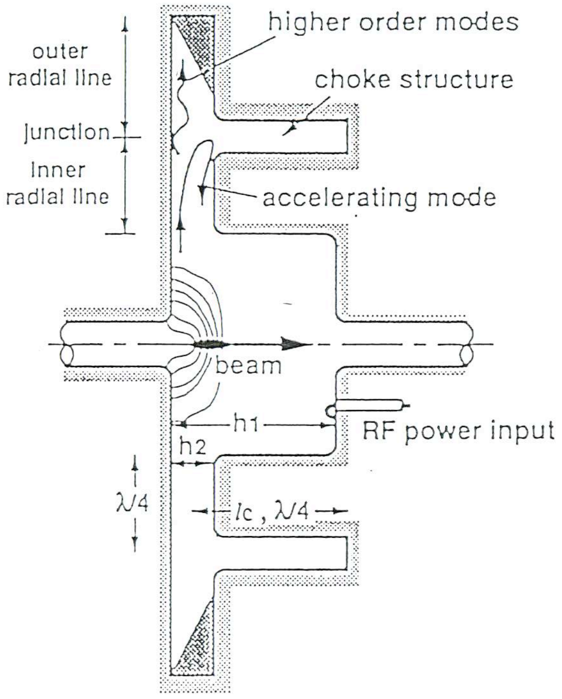
f = 508.6 MHz V_c = 0.6 MV P_c=75 kW *

R/Q = 150 Ω $Q = 3.2\times10^4$ * R = 4.8 MΩ *

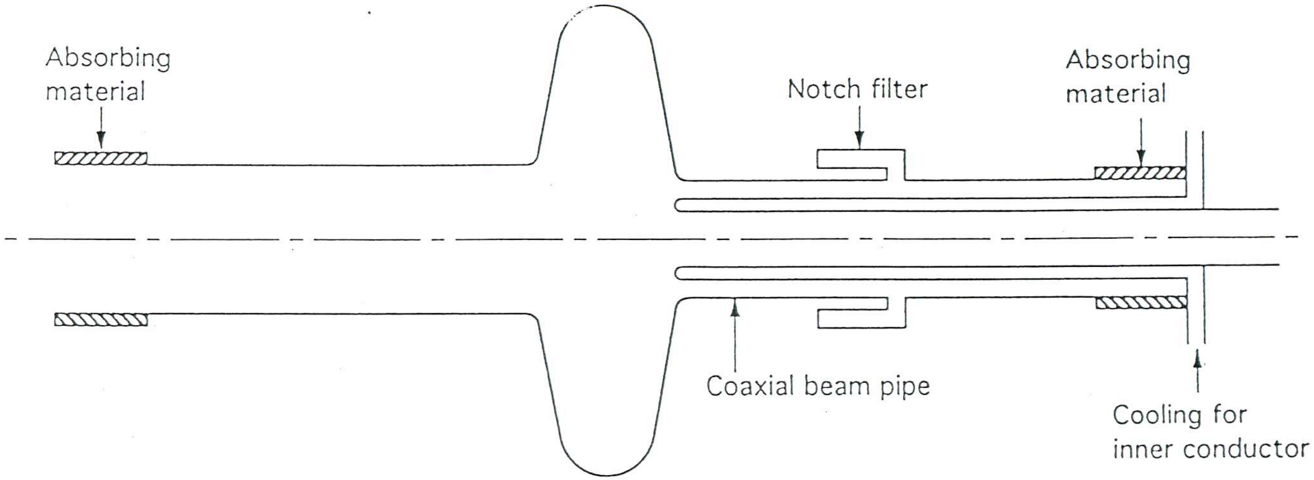
* A degradation of ~10% due to copper surface imperfection and the input coupler and tuner ports is taken into account.

T. Kageyama et.al.,

Coaxial Beam Pipe with a Notch Filter



Choke Mode Cavity



Crab cavity for the B-factories

T. Shintake, Jpn. J. Appl. Phys.
31 L1567 (1992)

K. Akai, et. al., Proc. B Factories
SLAC-400, 181, Apr. SLAC
(1992)

Superconducting Cavity

SCC is fairly immune against the C.B.Instability due to the accelerating mode.

- In the HER, the growth time is slower than the damping time.

  (while the growth time is still fast in the LER)

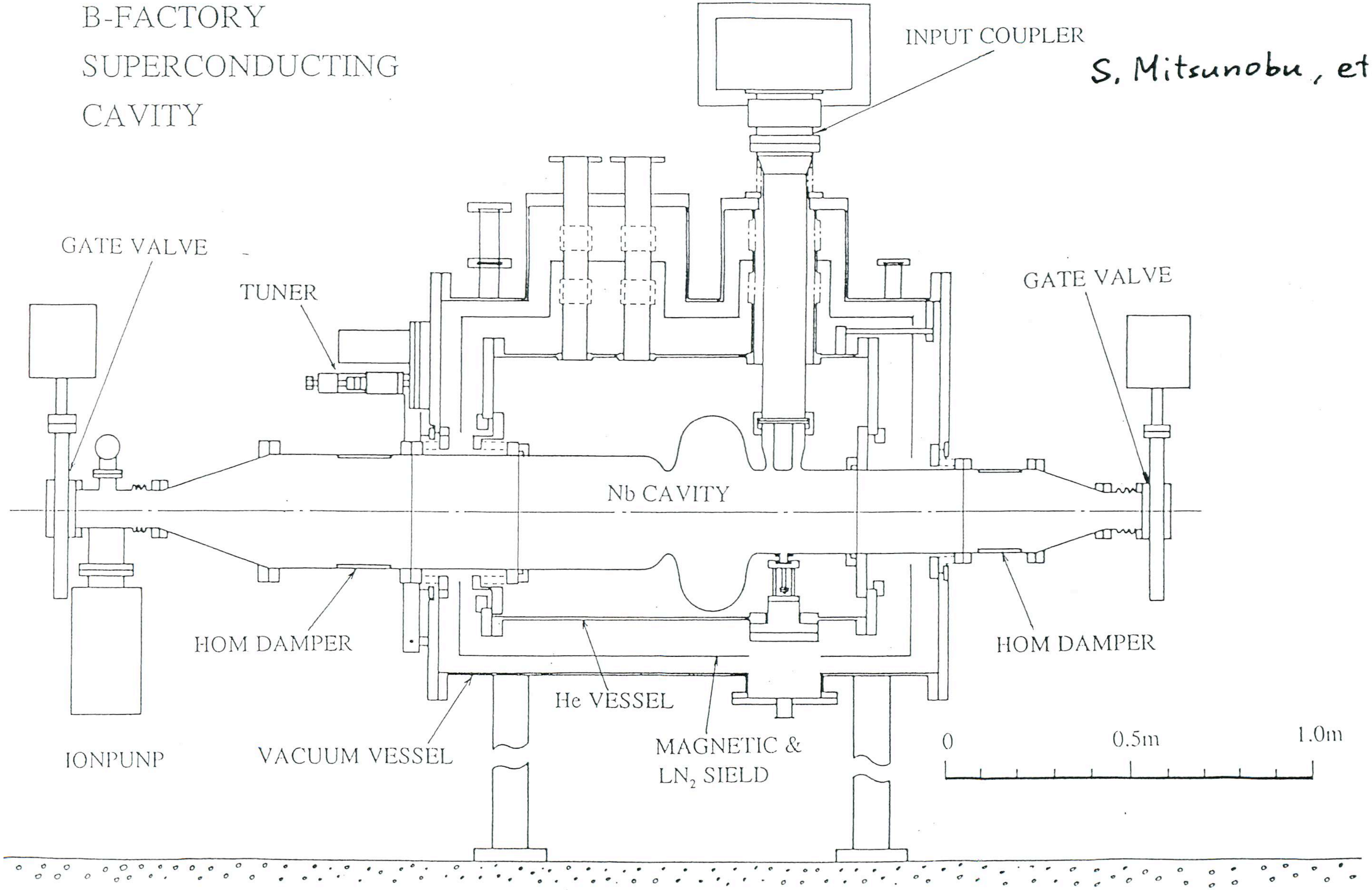
Other encouraging facts to use SCC for the HER of KEKB:

- 32 SC cavities have been successfully operated in TRISTAN (~8 years).
- We already have a 6.5 kW refrigerator at Nikko.

SCC is considered as another good candidate for the accelerating cavities in the HER.

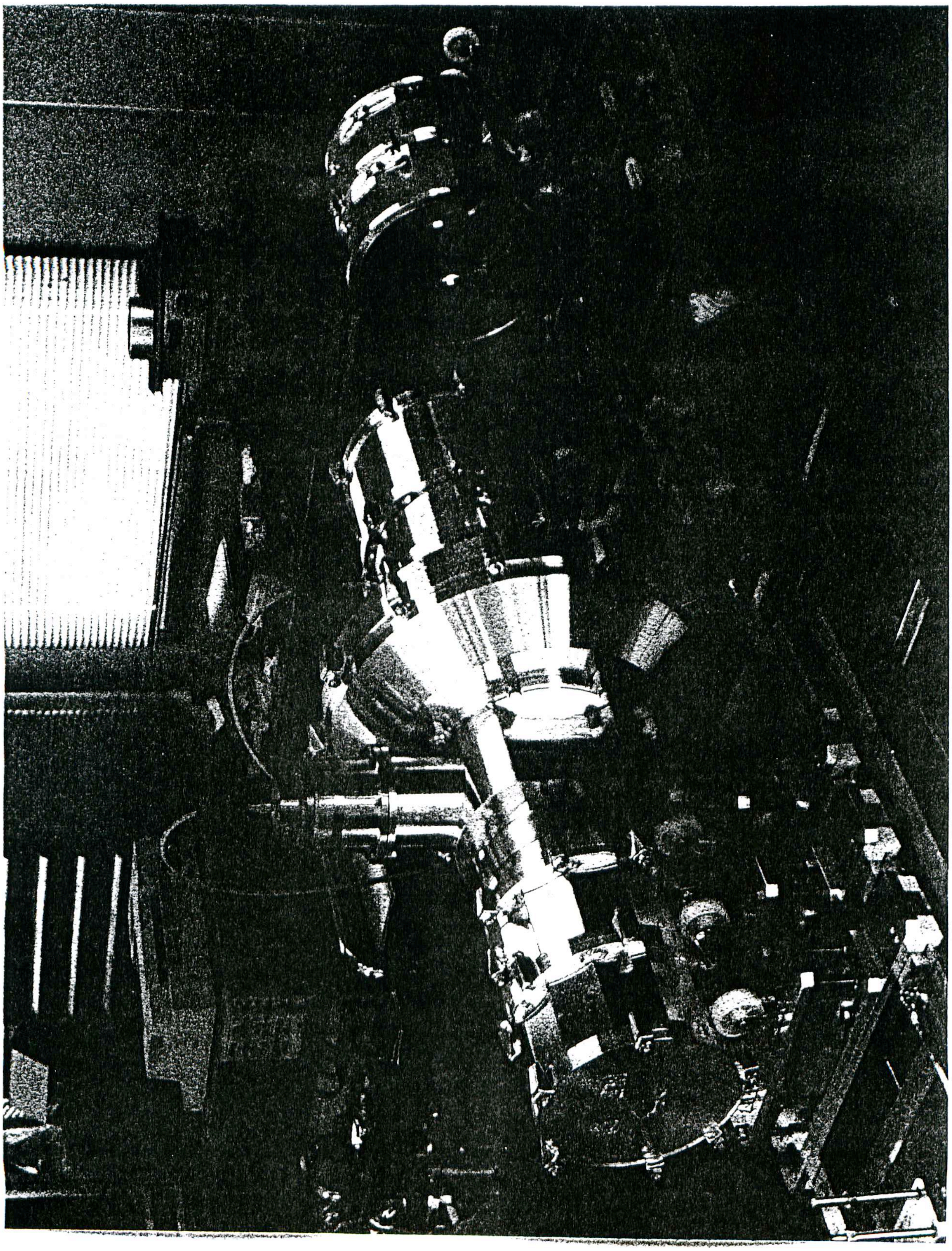
B-FACTORY
SUPERCONDUCTING
CAVITY

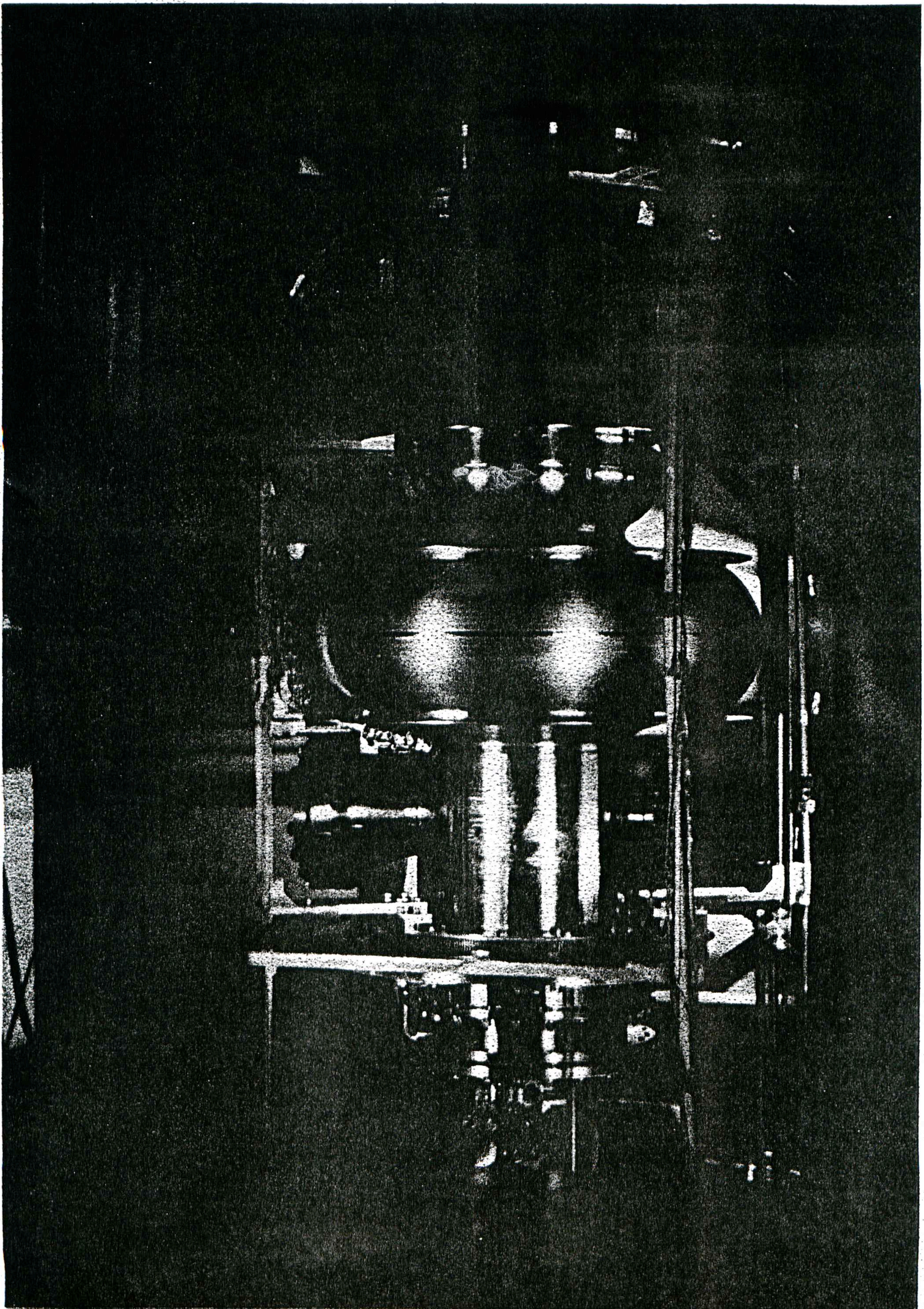
S. Mitsunobu, et. al.,

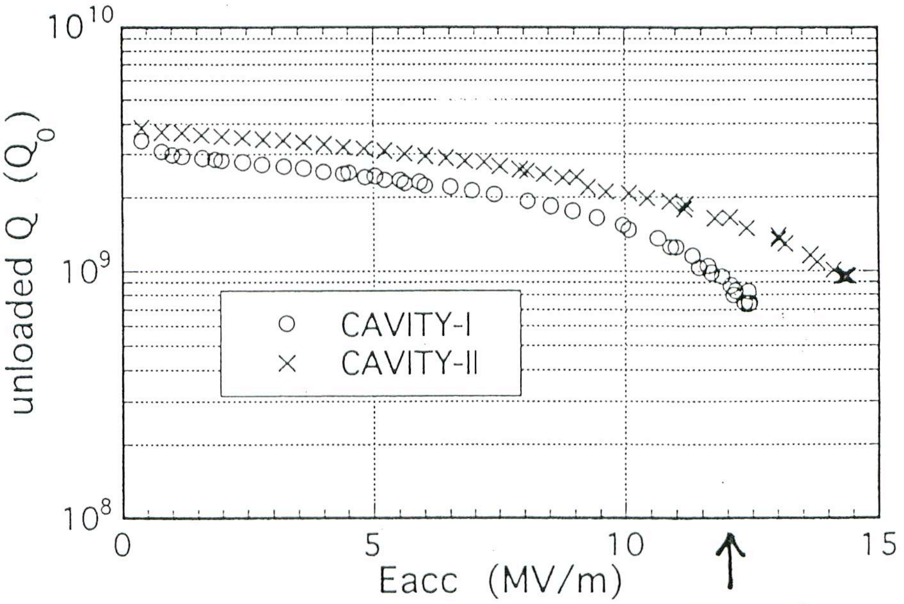


R&D status of Superconducting Cavity

- A preliminary design of the cavity has been carried out.
- A model measurement showed sufficient damping of HOM's.
- Prototype cavities achieved the gap voltage of 3 MV/cavity.
- Ferrite absorbers bonded by the HIP is promising.
  A beam test of an absorber has been done in TRISTAN-MR.
- Input couplers have been operated up to 850 kW in a bench test.
- Beam test in TRISTAN-AR is scheduled in 1996.





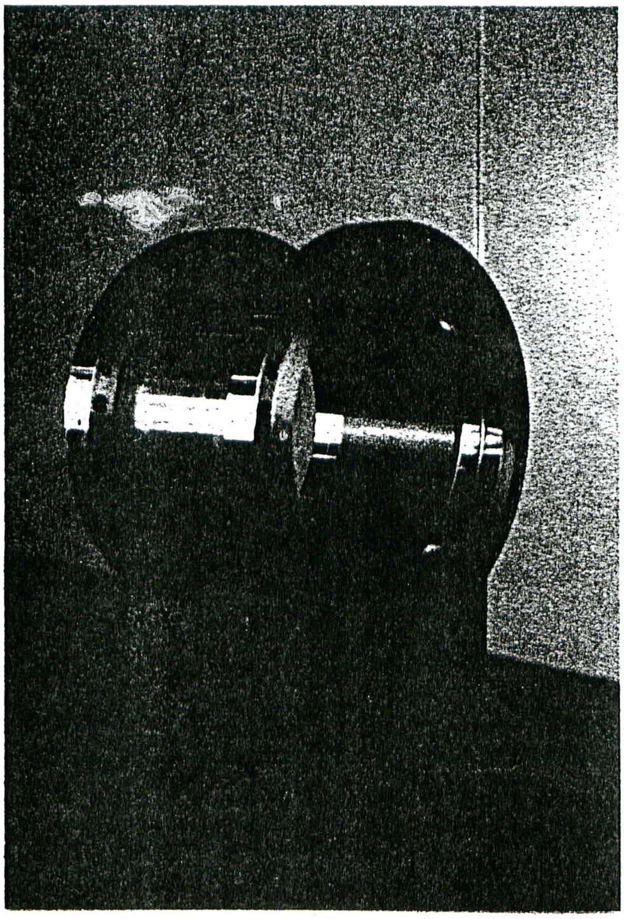


Gap Voltage 3 MV/cav.

Figure 7.31: Q vs Eacc at vertical cold tests of superconducting Nb cavities.

T. Tajima, et. al.,

HOM load with HIPped Ferrite Layer



Ferrite : 22cmϕx12cmx0.4cm

Beam Test in TRISTAN-AR

Mar.-Dec. 1996
(Dedicated machine time is about 100 days)

electron, 2.5GeV, 500mA

- HOM-damped cavity for ARES
- ARES total system
- Superconducting cavity
- Feedback system
- Other hardware components

RF Operation Parameters

Ring	LER (w/wiggler)		HER		HER		
Cavity	ARES		ARES		SCC		
Synchrotron tune	0.01	0.02	0.01	0.02	0.01	0.02	
RF voltage	4.9	9.4	8.7	16.2	8.7	16.2	MV
Number of cavities	10	20	36		10		
R/Q	12.8		12.8		93		Ω
Q_0	1.33E5		1.33E5		>1.E9		
Q_L (x10^4)	2.6	3.6	3.9		5.0		
Input coupling	4.2	2.7	2.41		-		
Cavity voltage	0.49	0.47	0.24	0.45	0.9	1.6	MV/cav.
Input power	591	355	157	233	~500	~400	kW/cav.
Wall loss	141	130	34	119	-	-	kW/cav.
Detuning frequency	16.2	17.7	13.5	7.8	33.6	18.8	kHz
Growth time (acc.)	49	30	100	180	23	54	msec
Number of klystrons	10		18		10		
Klystron power	640	760	340	500	~500	~400	kW

Accelerating Cavity of the ARES

Table 4.2: HOM impedances of the accelerating cavity of the ARES

monopole			
f(MHz)	$R/Q(\Omega)$	Q	$(R/Q) \times Q$ (Ω)
76.2	17.4	71.5	1243
190	4.5	24.5	109
662.6	2.8	25.4	72.2
731.7	11.0	35.7	394
821.8	7.9	22.7	180
925.2	3.8	16.6	62.4
1331.9	3.2	28.7	90.7
1389.5	3.1	27.8	86.4

dipole			
f(MHz)	R/Q (Ω/m)	Q	$(R/Q) \times Q$ $(k\Omega/m)$
275.4	50.7	63.4	3.21
670.0	16.6	37.1	0.62
766.2	167	50.9	8.51
826.7	113	30.4	3.43
905.8	109	20.5	2.23
986.8	210	23.2	4.85
1067.5	68.1	10.4	0.70

Growth Time

	LER (20 ARESs)	HER (40 ARESs)
longi.	60 ms	150 ms
trans.	30 ms	80 ms

SCC

Table 4.3: HOM impedances of the superconducting cavity

monopole f(MHz)	mode	R/Q (Ω)	Q	$(R/Q) \times Q$ (Ω)
783	TM01(LBP)	0.12	132	16
834	TM01(LBP)	0.34	72	25
1018	TM011	6.6	106	700
1027	TM020	6.4	95	608
1065	TM01(SBP)	1.6	76	122
1076	TM01(SBP)TM02(LBP)	3.2	65	208
1134	TM01(SBP)	1.7	54	92
dipole f(MHz)	mode	R/Q (Ω/m)	Q	$(R/Q) \times Q$ ($k\Omega/m$)
609	TE11(LBP)	1.9	92	0.18
648	TE11(LBP)	40.2	120	4.82
688	TE11(LBP)	170.4	145	24.7
705	TM110	227.3	94	21.4
825	TE11(SBP)	6.2	60	0.37
888	TE11(SBP)	3.5	97	0.34

LBP:larger diameter beam pipe on one side of the cavity.

SBP:smaller diameter beam pipe on the other side of the cavity.

Growth Time	HER (10 SC cavities)
longi.	420 ms
trans.	110 ms

Table 4.4: Accelerating mode of the cavities

	ARES	SCC	
R/Q	9.8	93	Ω /cavity
Q_0	1.67×10^5	$> 1 \times 10^9$	

Growth time (summary)

	<----- LER ----->		<----------- HER ----------->		
	ARES	Crab	ARES	SCC	Crab
number of cav.	20	2	36	10	2
	(msec)	(msec)	(msec)	(msec)	(msec)
acc. mode	30-50	-	100-180	23-54	-
0 and π mode	10-35	-	40-150	-	-
HOM (longi.)	60	70	150	420	300
HOM (trans.)	30	200	80	110	1100

High Power System

Most of high power components that have been used in TRISTAN will be re-used in KEKB.

- 1 MW CW klystrons (Toshiba, Phillips)
- Power Supply for the klystrons
- RF Transmission system
  including 1MW circulators, magic tees, dummy loads
- Cooling system

They have been successfully operated in TRISTAN (~10 years).
~ 800 kW (32GeV), ~600 kW (29GeV).

The number of RF units:

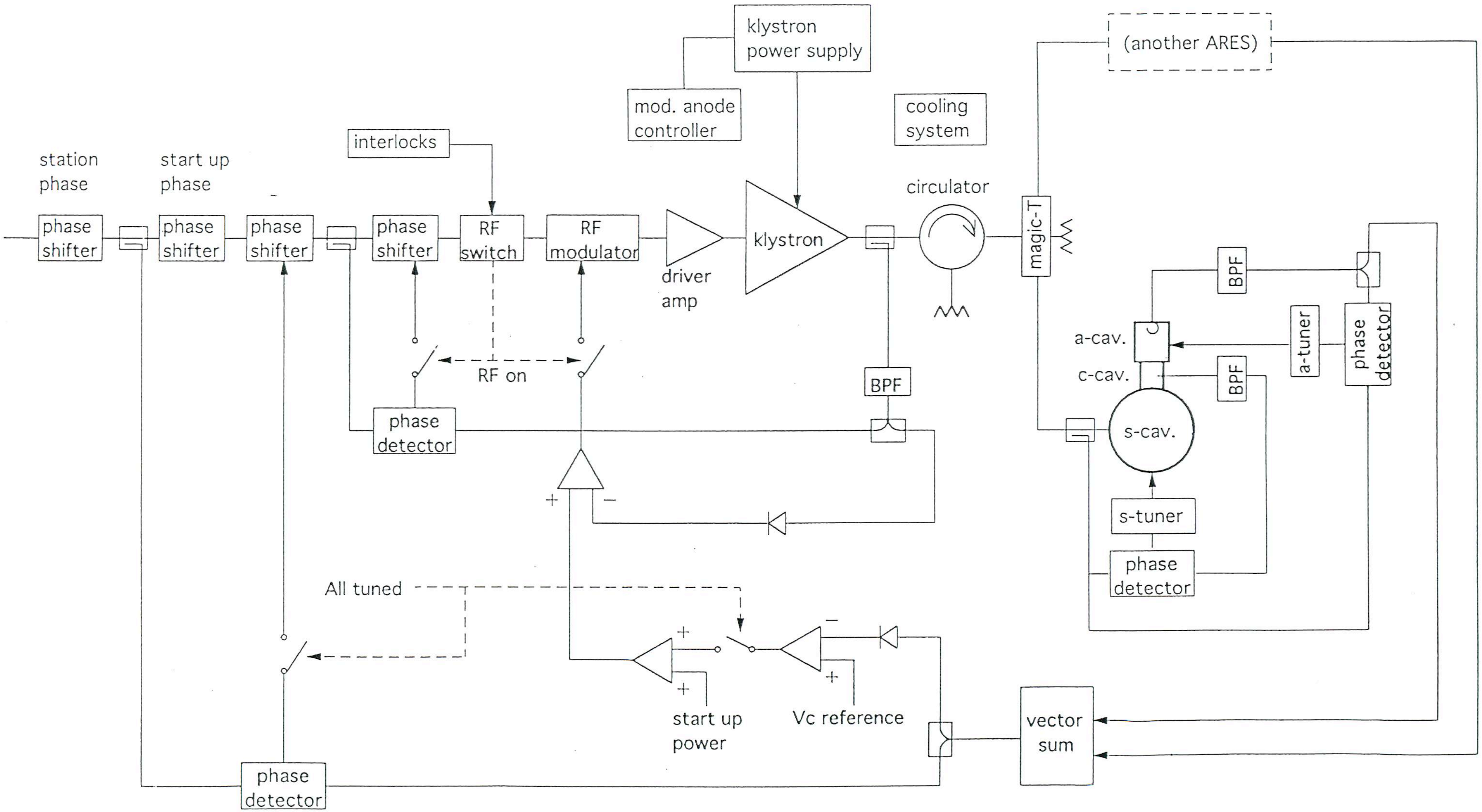
(TRISTAN)	34
(KEKB)	10 in LER and 10~18 in HER

Low Level Control

- Conventional components:
  - Master oscillator (phase-locked to Linac)
  - Reference line to provide RF to each station
  - Control loops to stabilize the cavity voltage
  - Control loops to stabilize the klystron output
  - Control loops to adjust the cavity tuner
  - Interlocks
  - front-end circuit to computers

- Required accuracy for phase control is 1 degree.

- R&D of RF feedback system using parallel comb filters (tested with a beam in TRISTAN-MR)


station
phase
start up
phase
phase shifter
phase shifter
phase shifter
phase shifter
interlocks
RF switch
RF modulator
RF on
phase detector
mod. anode controller
klystron power supply
driver amp
klystron
cooling system
circulator
BPF
magic-T
(another ARES)
a-cav.
c-cav.
s-cav.
BPF
BPF
a-tuner
phase detector
s-tuner
phase detector
All tuned
+
−
+
+
−
+
start up power
Vc reference
vector sum
phase detector

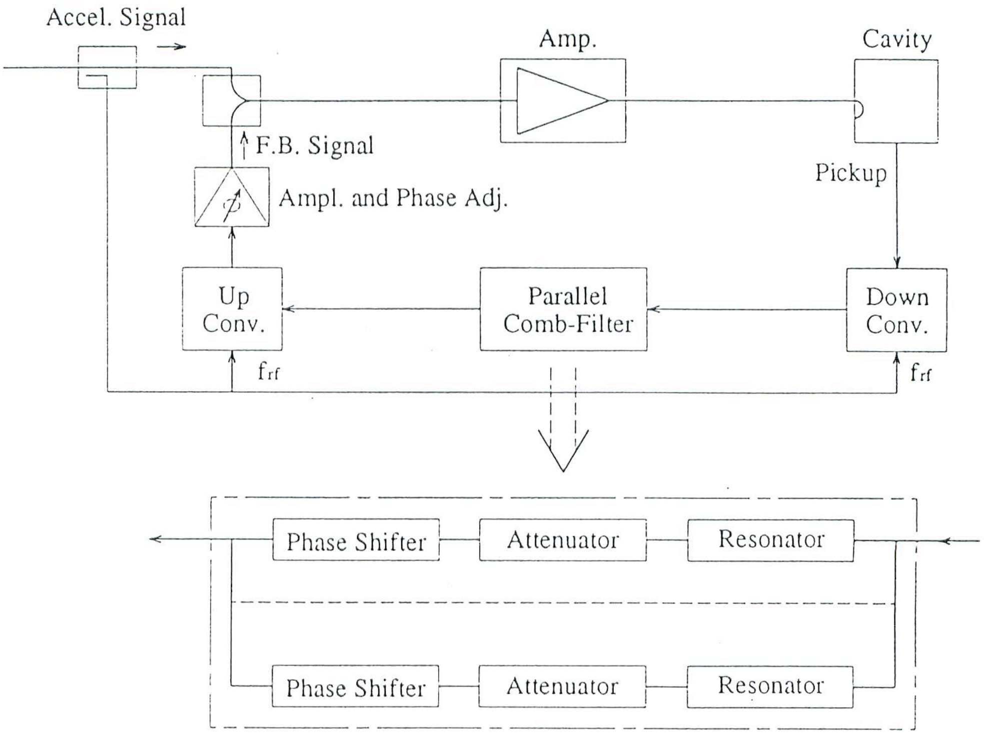


Figure 7.2: Block diagram of the RF cavity feedback system using a parallel comb-filter.

E. Ezura, et. al.,

Response to a Bunch Gap

An ion-clearing gap will be introduced in the HER. The bunch gap modulates the RF voltage.

Colliding point will shift bunch-by-bunch. (β^*_y=10mm,σ_z=4mm)

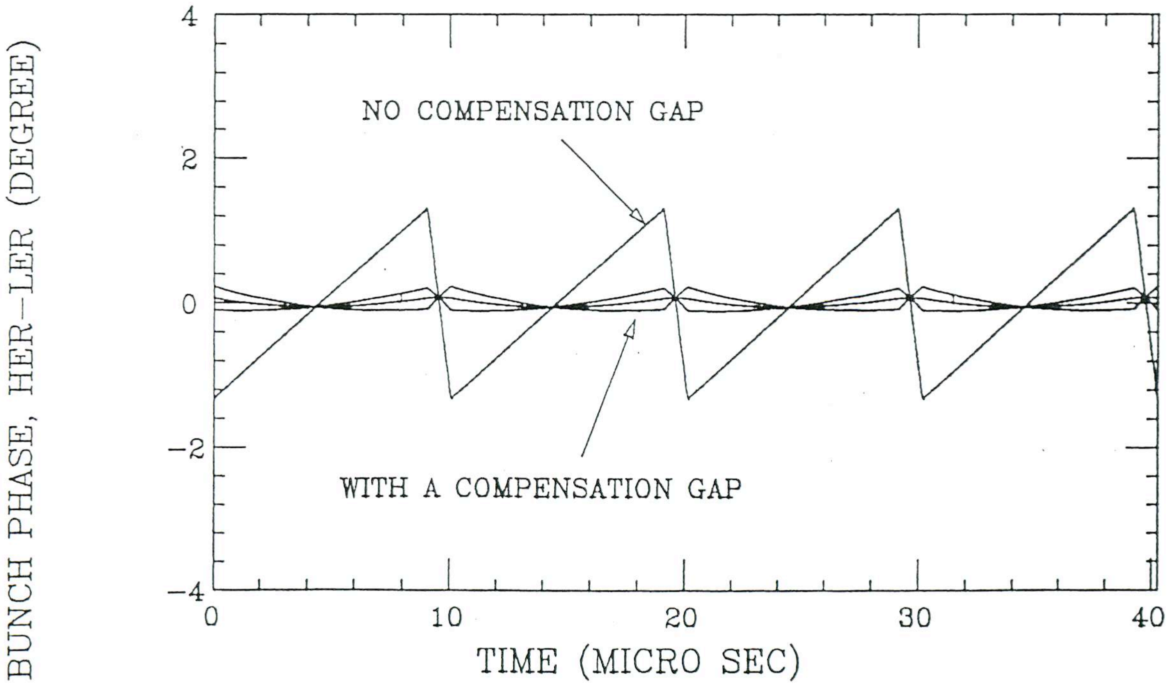
Cavity	gap length	bunch phase modulation (colliding point shift)	
		with compensation gap?	
		No	Yes
ARES	10%	2.7°p-p (±1.1mm)	~0.3°p-p (±0.1mm)
	5%	1.3°p-p (±0.5mm)	~0.1°p-p (±0.04mm)
SCC	10%	4.9°p-p (±2.0mm)	~0.5°p-p (±0.2mm)
	5%	2.4°p-p (±1.0mm)	~0.3°p-p (±0.1mm)

- The shift is small, owing to a large stored energy in ARES and SCC.
- The shift can be further reduced by the compensation gap.

EFFECT OF A COMPENSATION GAP IN LER (10% GAP)

HER, 1.1A, 20MV, 40ARES, I2/I1=0%

LER, 2.6A, 10MV, 20ARES, I2/I1=50%-60%, STEP=5%



Crab Cavity R&D

We started the R&D of crab cavity to prepare for the crab crossing.

- R&D under KEK-Cornell collaboration (1991-1992)

  - Design
    - Superconducting cavity operating in the TM110 mode
    - HOM damping scheme (Coaxial beam pipe + Notch filter)
    - Extremely polarized cell ("Squashed")

  - Measurement of damping property (1/3 scale, Cu, Al)
  - High field performance (1/3 scale, Nb)

  The feasibility was realistically demonstrated.

- R&D at KEK (1994 -)
  aiming at fabricating full scale Nb crab cavities in three years.

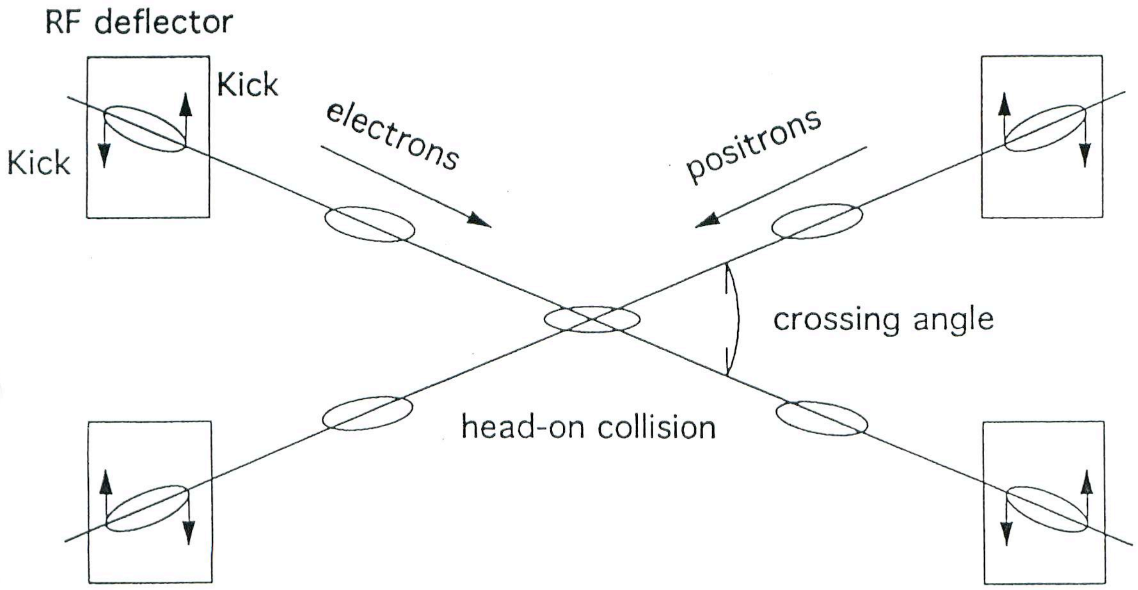


Figure 1 Crab crossing scheme

Crab Crossing

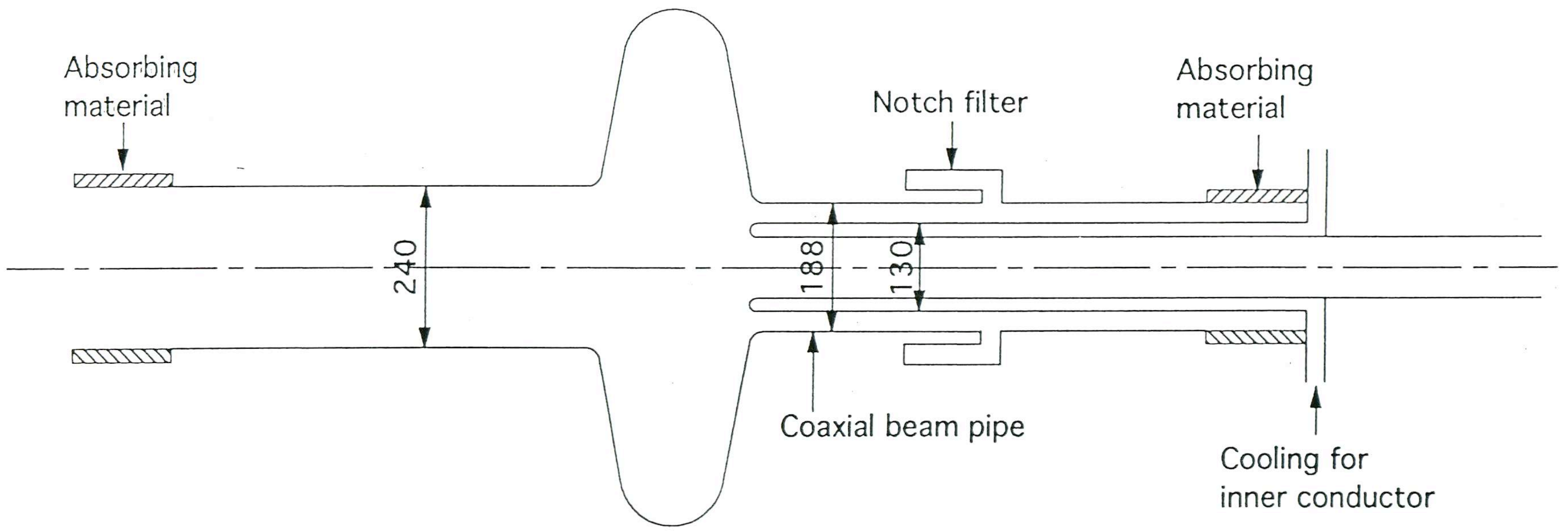
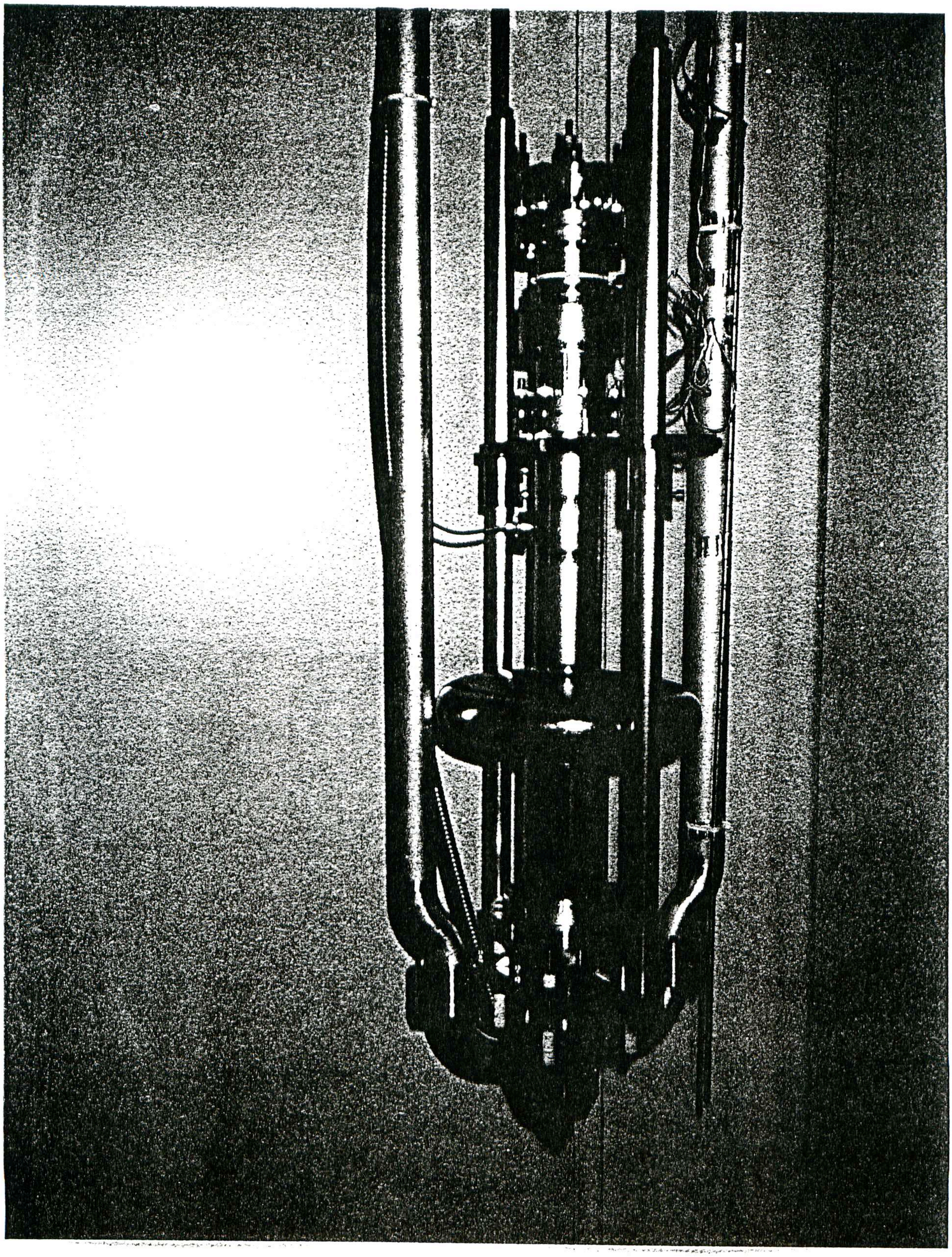


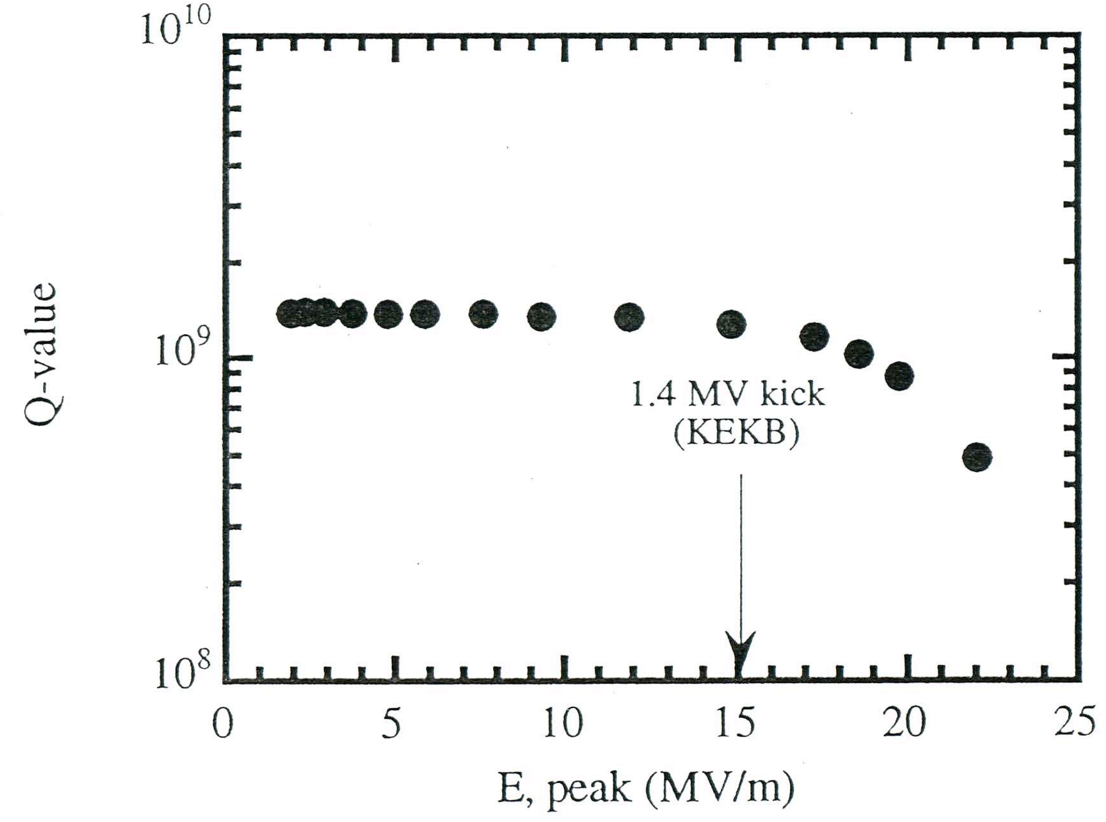
Figure 2 Crab cavity for the B-factories

K. Akai et al., Proc. B Factories SLAC, Apr 1992.



Crab Cavity 1/3 scale Nb cavity

Cold Test



Conclusion

- Extensive R&D is in progress on ARES and SCC.
- A consistent set of operating parameters was obtained for ARES in LER and HER, and for SCC in HER: coupled-bunch instability due to the accelerating mode is sufficiently suppressed.
- RF feedback system will provide additional damping, when necessary.
- The growth time of coupled-bunch instability caused by the cavities is expected to be longer than 10 msec.
- Klystrons, other high power components, and a 6.5kW refrigerator that have been used in TRISTAN can be re-used in KEKB.
- Response to an ion-clearing gap is small owing to a large stored energy of ARES and SCC. It can be further reduced by a compensation gap in LER.
- Full scale crab cavities will be fabricated in three years.