Results of Beam Tests at AR

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KEK

KEKB Machine Advisory Committee Meeting
Jan. 1997

Outline

- Purposes
- AR parameters
- Preparation
- Progress of Beam Tests
- Beam Test Results
  - Overview
  - ARES (T. Kageyama will give detailed talk)
  - SCC (T. Furuya will give detailed talk)
  - Bunch Feedback System (E. Kikutani will give detailed talk)
  - Instabilities (H. Fukuma will give detailed talk)
- Conclusion

Purposes of the AR High Current Beam Tests

- ARES cavity
- Superconducting Cavity
- Bunch-by-bunch Feedback System
- Instability Study
  (Fast Ion, Coupled-bunch, etc.)

- Other Hardware Tests (parasite)
  (BPM, Kicker ceramic chamber, BT line BPM, DCCT, Shield Bellow)

Machine Parameters of AR and KEKB

		AR	LER	HER
Particles		e^-	e^+	e^-
Beam energy	GeV	2.5(3.5)	3.5	8.0
Beam current	A	0.5	2.6	1.1
RF frequency	MHz	508.58	508.887	508.887
Harmonic number		640	5120	5120
Revolution frequency	kHz	795	99.4	99.4
Momentum compaction		0.0129	$1\text{-}2 \times 10^{-4}$	$1\text{-}2 \times 10^{-4}$
Radiation loss/turn	MeV	0.146	0.81	3.5
Energy damping time	ms	22	45	23
Bunch length	mm	>15	4	4

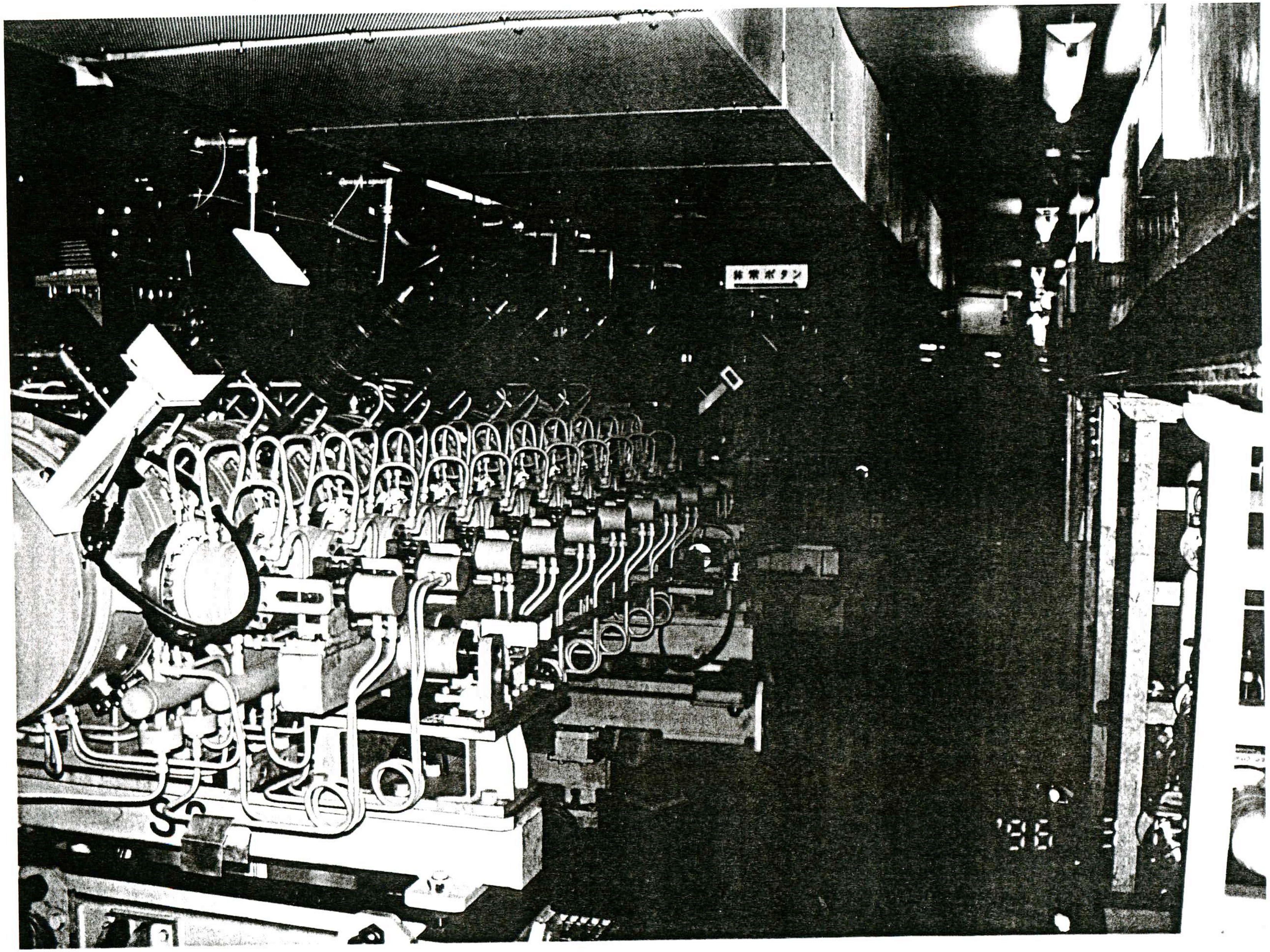
Comparison between AR and KEKB

- Growth rate of coupled-bunch instability
  longitudinal: AR is ten times higher than KEKB at the same impedance.
  transverse: AR is about the same as KEKB at the same impedance.
- Bunch length: AR (>15mm) is longer than KEKB (4mm).
- Radiation power: AR is much smaller than KEKB.
- HOM power: can be increased by increasing bunch current in AR.
  (decrease #bunch at the same total current)
- High frequency component of HOM:
  can not be tested in AR (long bunch length).
- Accelerating mode beam loading (Vb/Vc, Pb/U):
  roughly proportional to total current.

Preparation for the Beam Tests

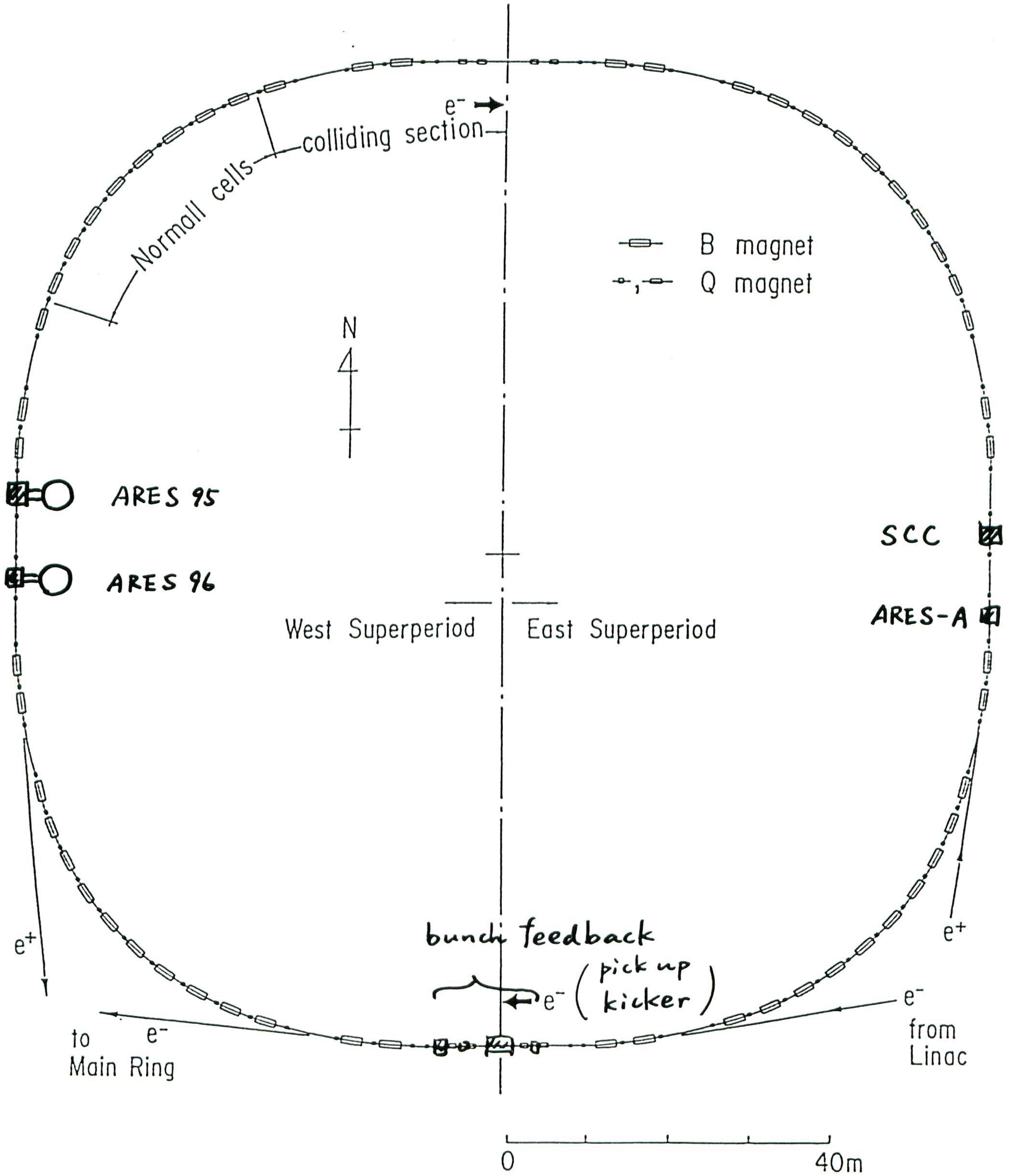
Besides ARES, SCC, Feedback system and other components to be tested, following work was done to prepare for the tests.

- Search for current limit in AR
  - Estimation of coupled-bunch instability
  - Preliminary Study with 8APS cavities
    174mA stored (by reducing #cavities and avoiding HOM of APS)
- Temperature monitor system for vacuum components
  (bellows, GV, ceramic chambers, CT, etc.)
- Beam monitor
  bunch current, streak camera, photo diode array
- Vacuum system (replacement of ion pump cables, NEG installation)
- Radiation shield
- Operation software and data logging
- Remove/replace heat-up components (GV, ceramic chambers, CT)
- APS cavities line-off



APS Cavities

AR for KEKB Beam Tests



Milestones of the Beam Tests

Date	Study	Main Purposes
1994 Dec.	Preliminary Study	
1995 Mar.	Preliminary Study	
1996 (Jan.-Mar.)	(Install SCC and ARES-A, Remove half of APS)	
Mar.28-Apr.2	1st Beam Test	SCC system check (target=100mA)
(Jun.)	(Install another ARES-A, Remove the rest of APS)	
Jul.1-22	2nd Beam Test	SCC, ARES-A, Feedback, etc. (target=520mA)
(Aug.-Oct.)	(Install 2 ARES full system, Remove one ARES-A)	
Oct.17-Dec.2	3rd Beam Test	ARES, SCC, Feedback, Instability, etc.

Progress of the Beam Tests

1st Beam Test (Mar.1996, 1week) ----- with SCC, ARES-A, 4APS cavities

- SCC system check was done up to 100mA.
- SCC (2.3MV) stored 110mA(1 bunch) and 100mA(32 bunches).
- We did not try much higher current.

2nd Beam Test (Jul.1996, 3weeks) ----- with SCC, 2ARES-A

- Current increased gradually as the ring was getting conditioned.
- After 10 days of ring conditioning, we reached 520mA(16 bunches), the maximum current approved by office for radiation safty. (2 ARES-A were operated, 0.5MV each)
- Various studies were conducted by using high current beam.
- SCC stored 500mA (16 bunches).

Progress of the Beam Tests (cont'd)

3rd Beam Test (Oct.-Dec.1996, 7weeks) ---- with 2 full ARES, SCC, ARES-A

- ARES operated for 4 weeks, stored 500mA, various tests done.
- SCC operated for 2 weeks, stored 500mA, various tests done.
- Bunch Feedback system worked well (longitudinal, transverse).
- Ion-trapping study done by introducing N2 gas.
- The maximum current increased to 570mA with SCC (1.2MV) .
  (the approved current had been increased)

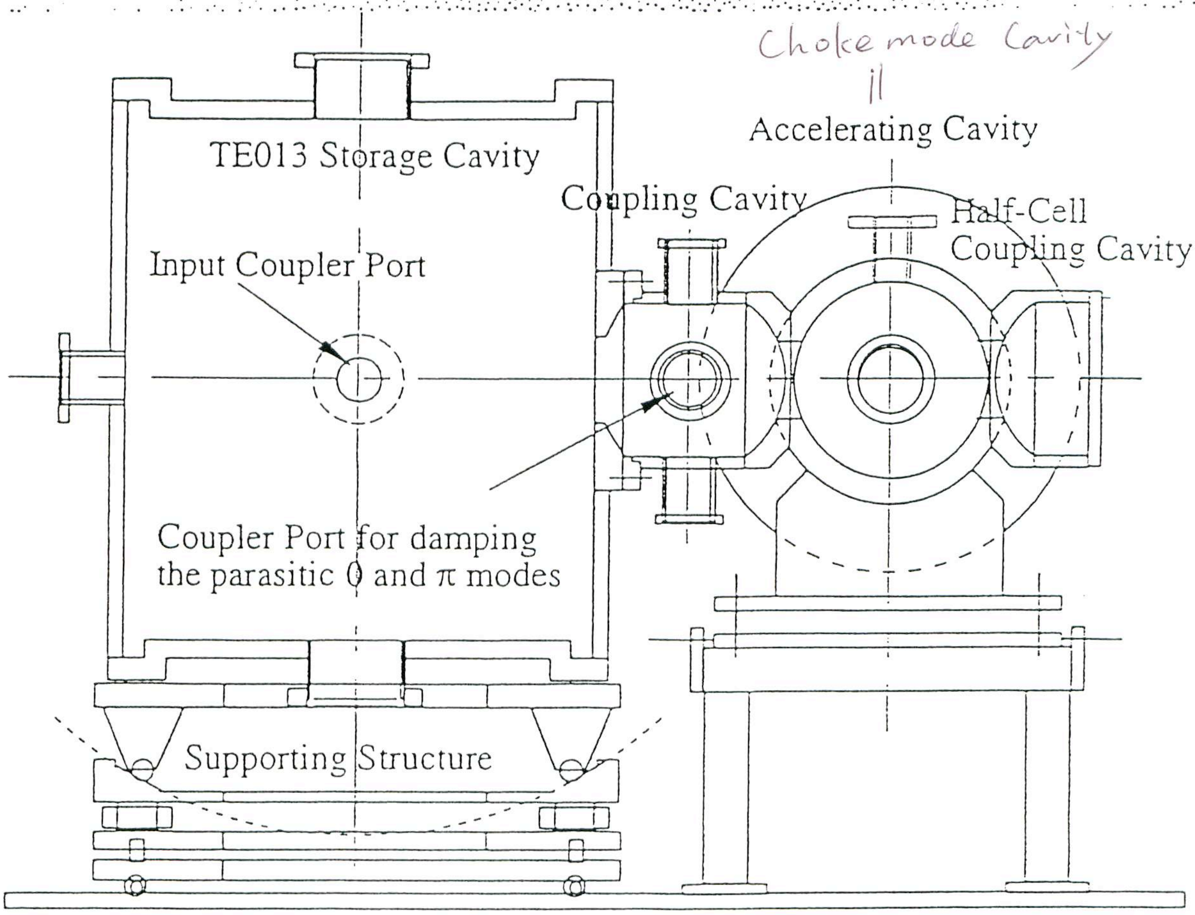
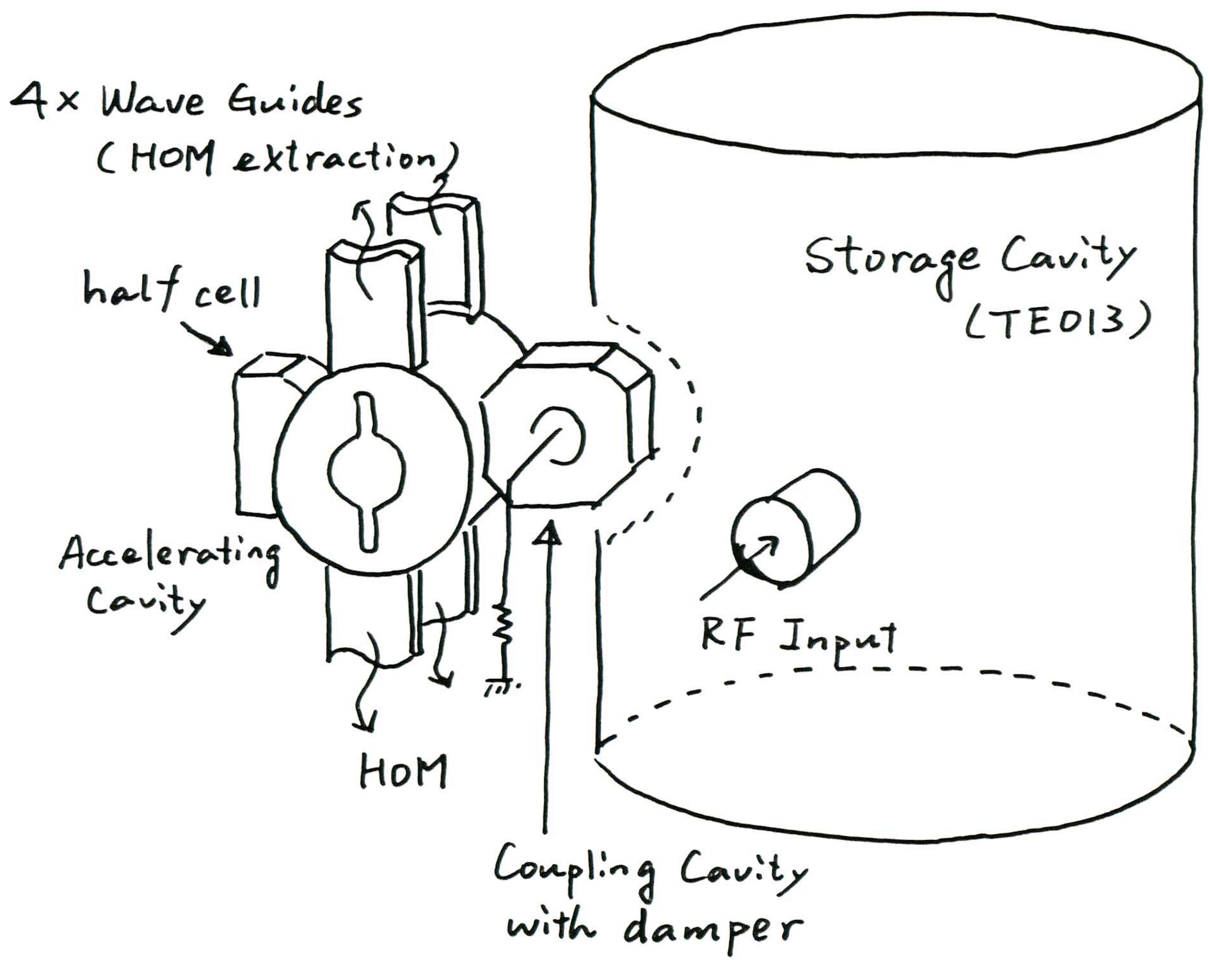


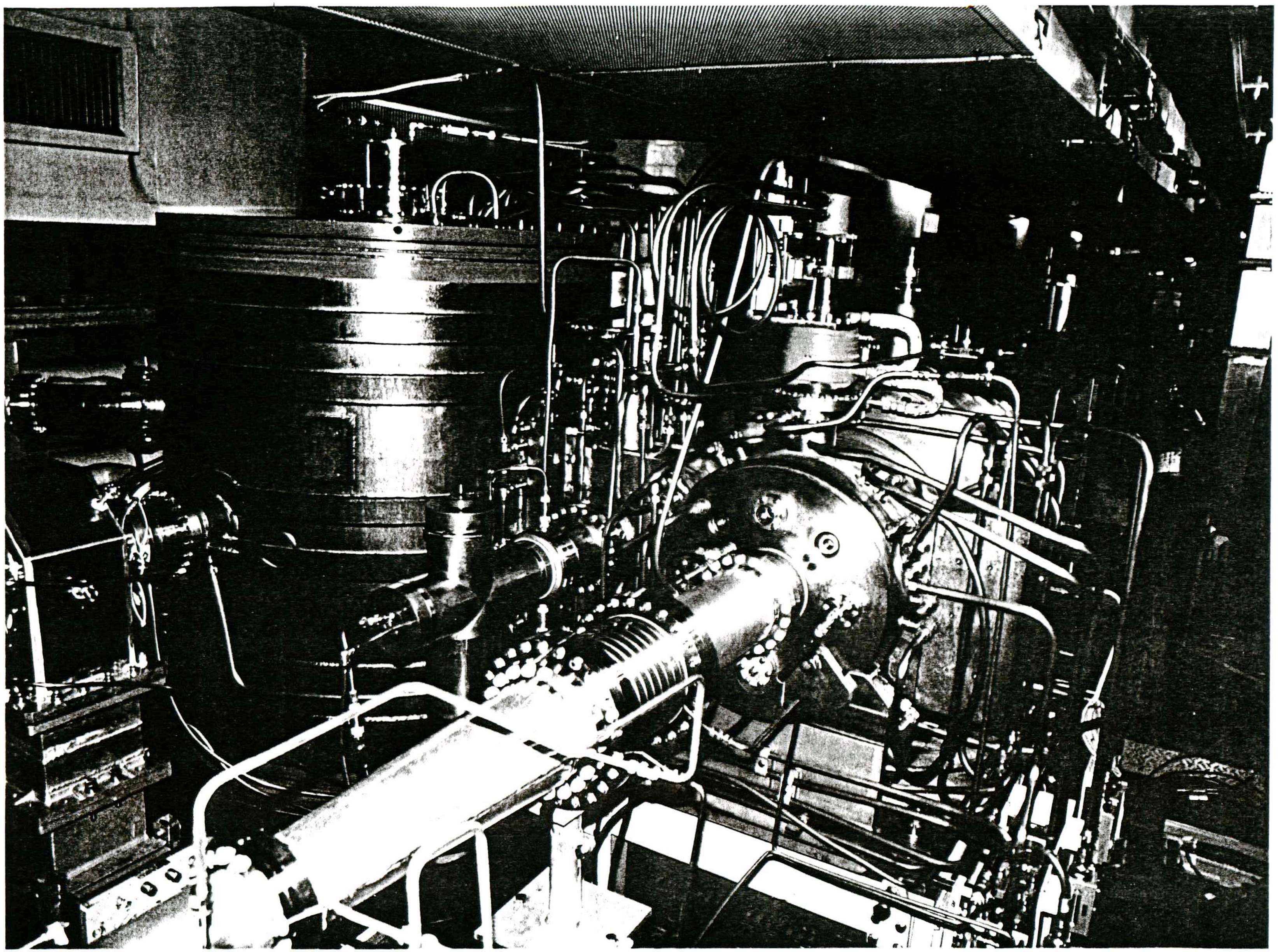
Figure 1: A schematic drawing of the first high-power ARES cavity.

ARES '95

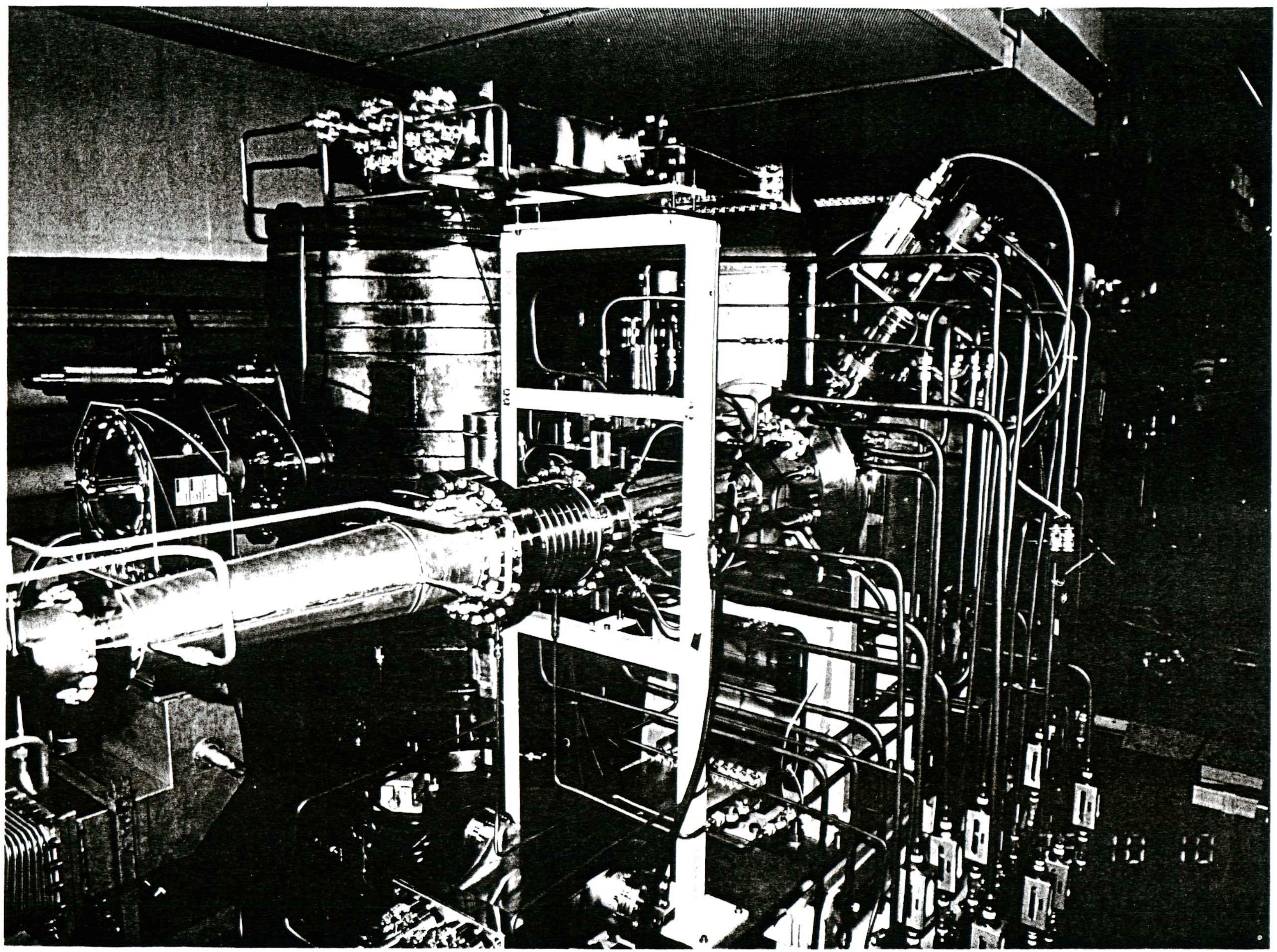
ARES'96 (Wave guide HOM damping instead of the choke mode cavity)

by T. Kageyama et al.





ARES'95 in AR



ARES'96 in AR

ARES Test Results

- Fundamental mode characteristics with beam

  Good agreement with ARES principles
  - 0 and pi mode damping
  - Detuning frequency due to beam loading
  - Power from the coupling cavity
  - Ratio of the stored energy in a- and s- cavity

  Beam loading changes according to station phase, as expected.
  Heavy beam loading was tested up to Pb/Pc=0.83.
  Maximum power transfered to beam was 74 kW. (KEKB: 250 kW)

- High power operation

  Both ARES stably operated with ~500mA beam at design voltage, 0.5 MV (Pc=155 kW).
  ARES96 + APS coupler: for 4 weeks
  ARES95 + new coupler: for 2 days

ARES Test Results (cont'd)

- Dampers

(A-cavity damper and beam pipe damper)
Up to 3.2 kW was absorbed by the dampers. No damage.
(C-cavity damper)
Up to 3.2 kW was absorbed by the c-cavity damper.
Maximum peak power was 30 kW (well beyond KEKB). No damage.

- Input couplers

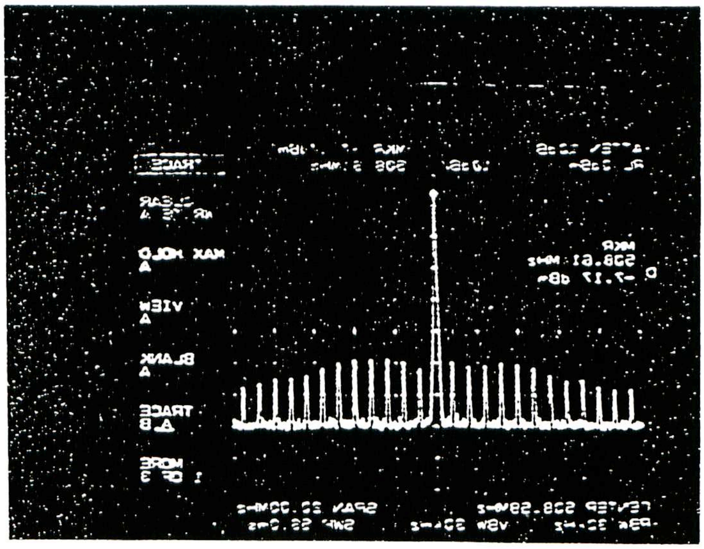
Two new-type couplers were broken before the beam test (at 40-50 kW).
No more trouble occured up to 200 kW by conditioning more carefully (better vacuum pressure, interlocks). (KEKB: 350 kW)

- HOM spectrum

Good agreement between measurement and calculation.
No clear HOM-related instabilitiy was observed.

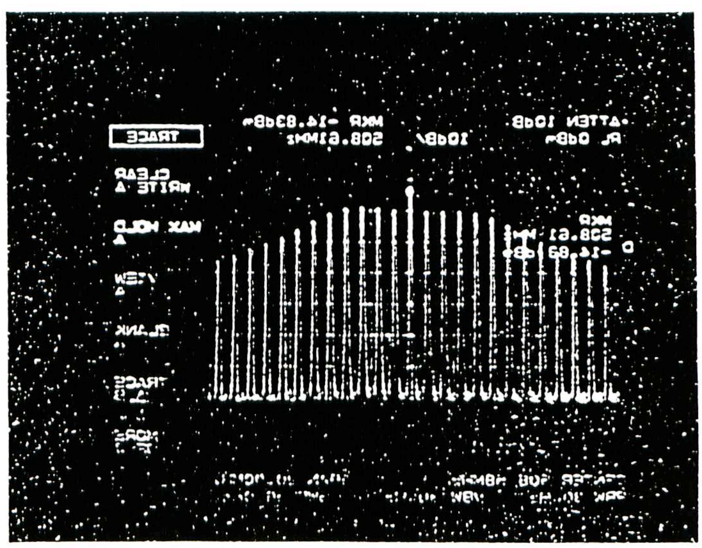
0 and π mode damping of ARES

(single bunch 96 mA)



pick up at A-cavity

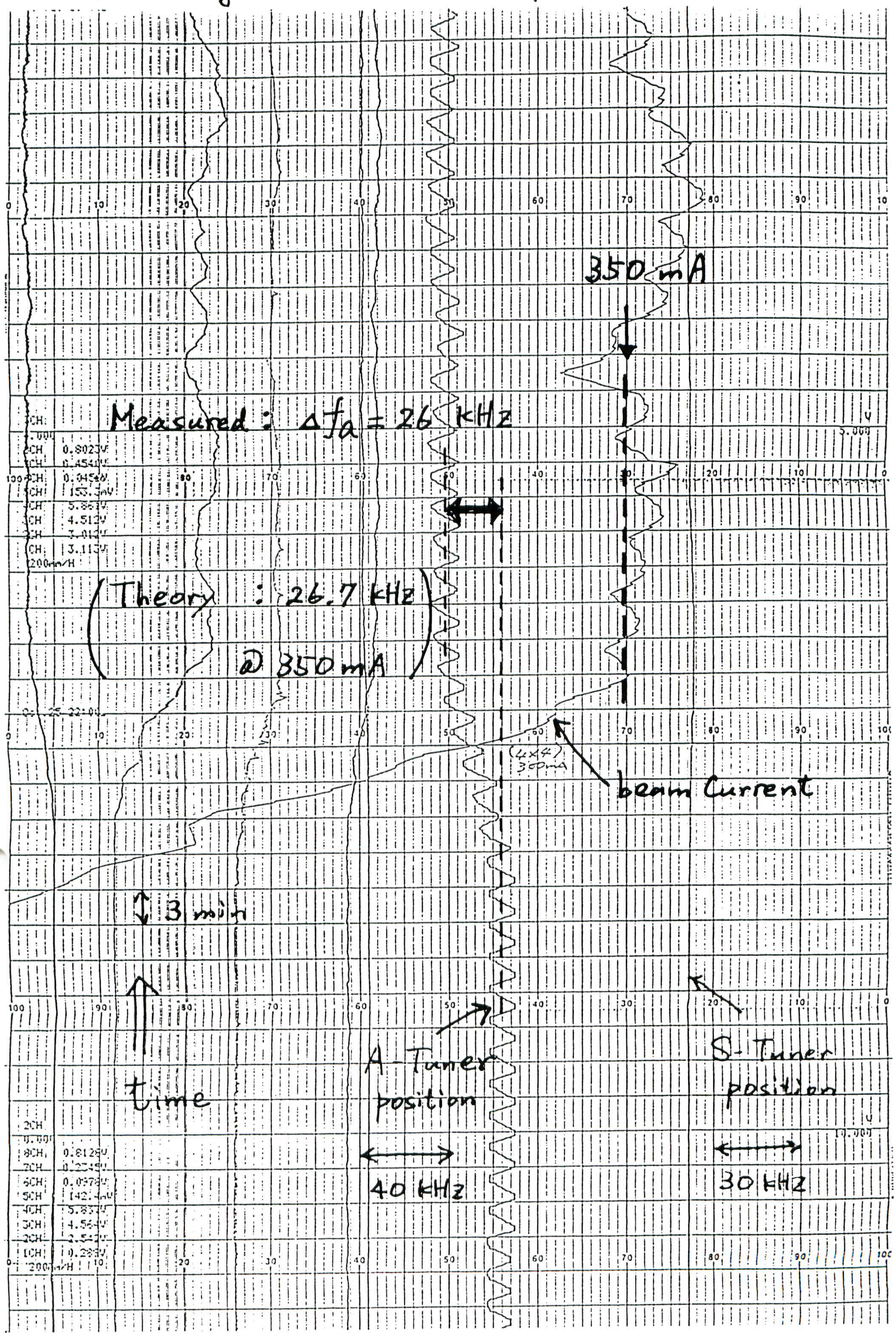
0 mode | operating (π/2) mode | π mode



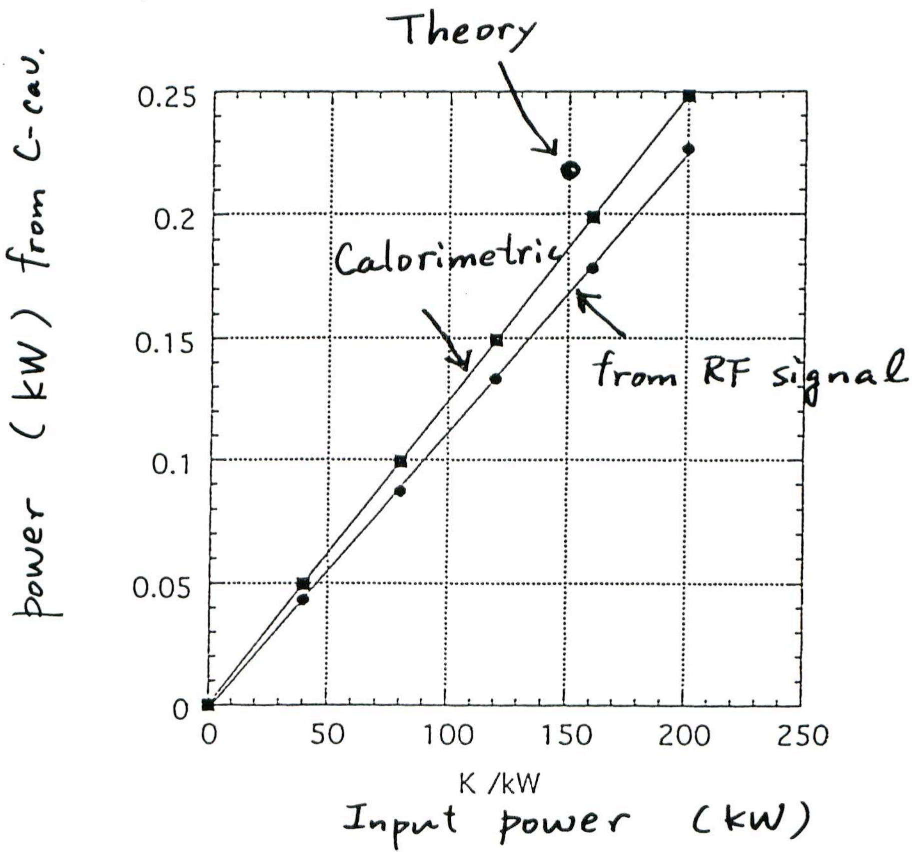
signal from C-cav damper

span = 20 MHz

Detuning as a function of Beam Current

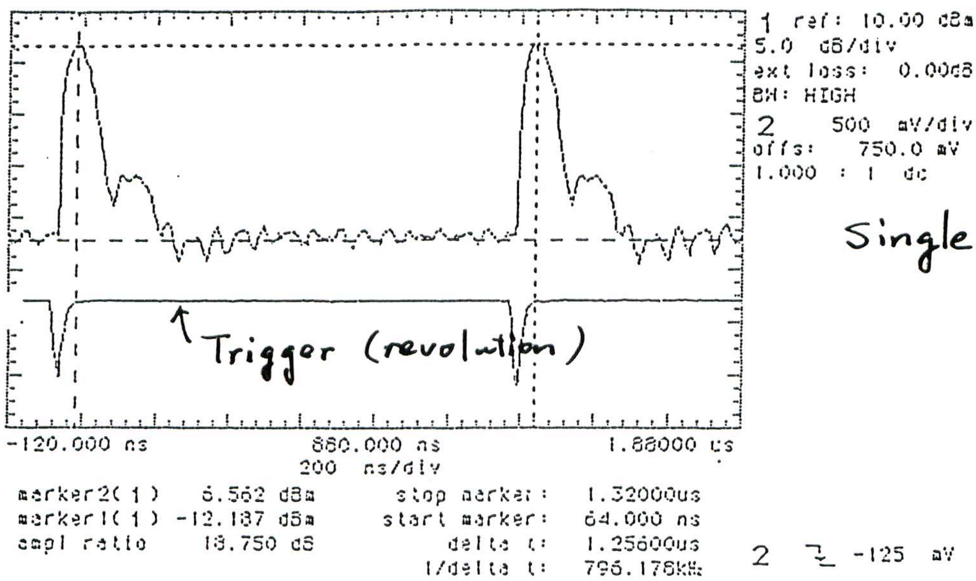


Power from Coupling-Cavity of ARES
(no beam)

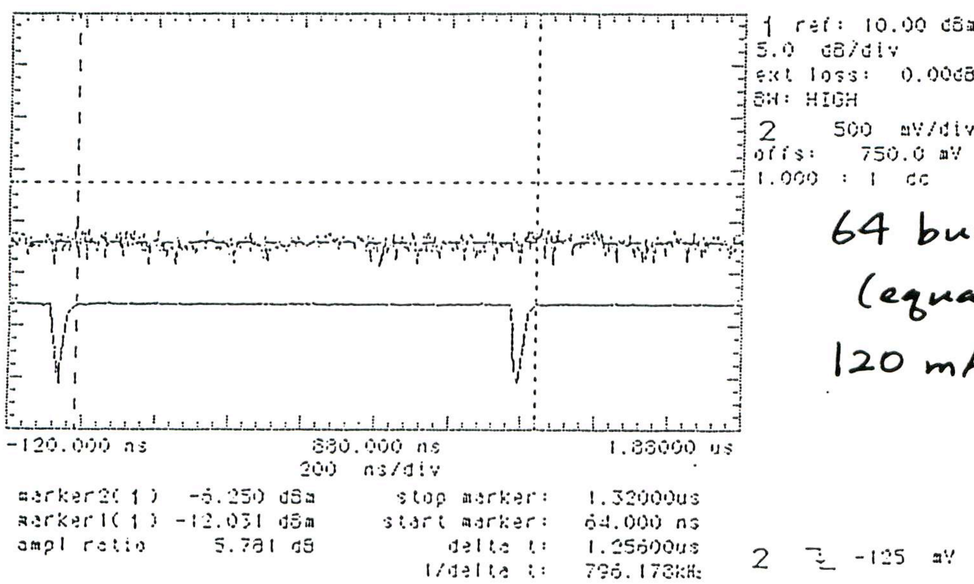


(Calculation from theory
220 W at 150 kW
assuming $Q_c = 55$
$f_\pi - f_0 = 7.2$ MHz)

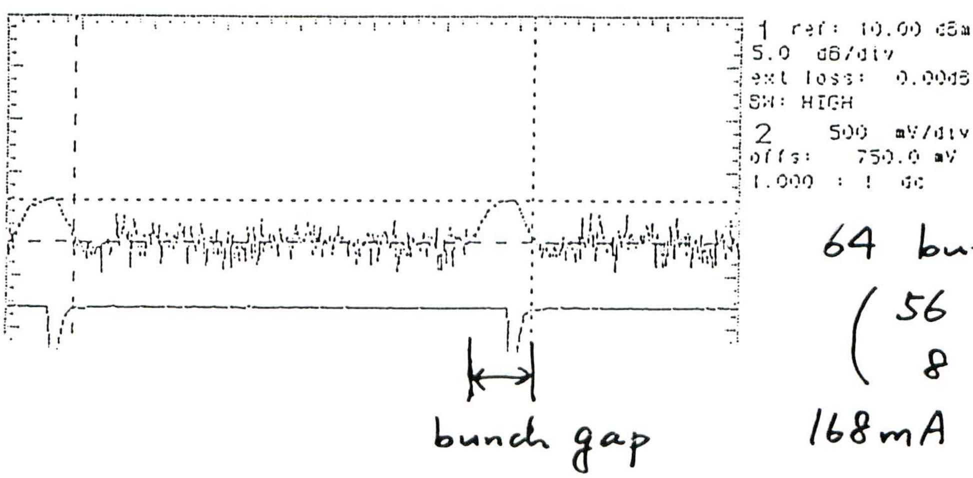
Coupling Cavity Damper Power (with Beam)



Single bunch
100 mA

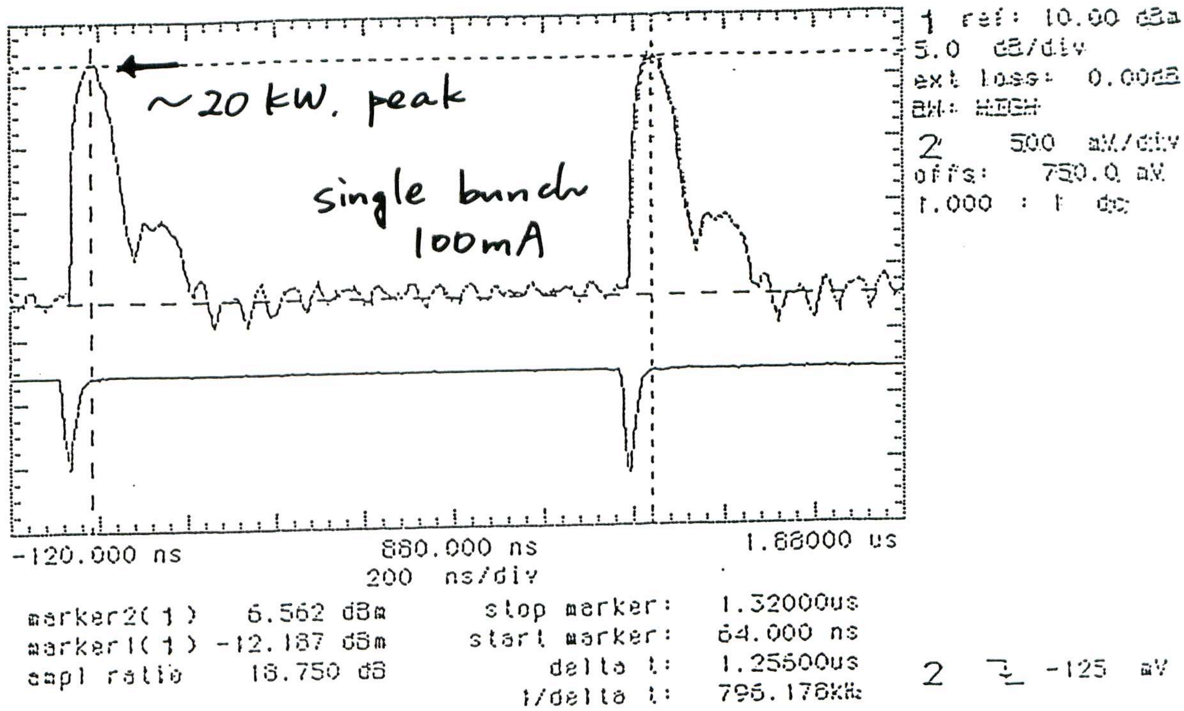


64 bunches
(equally-spaced)
120 mA

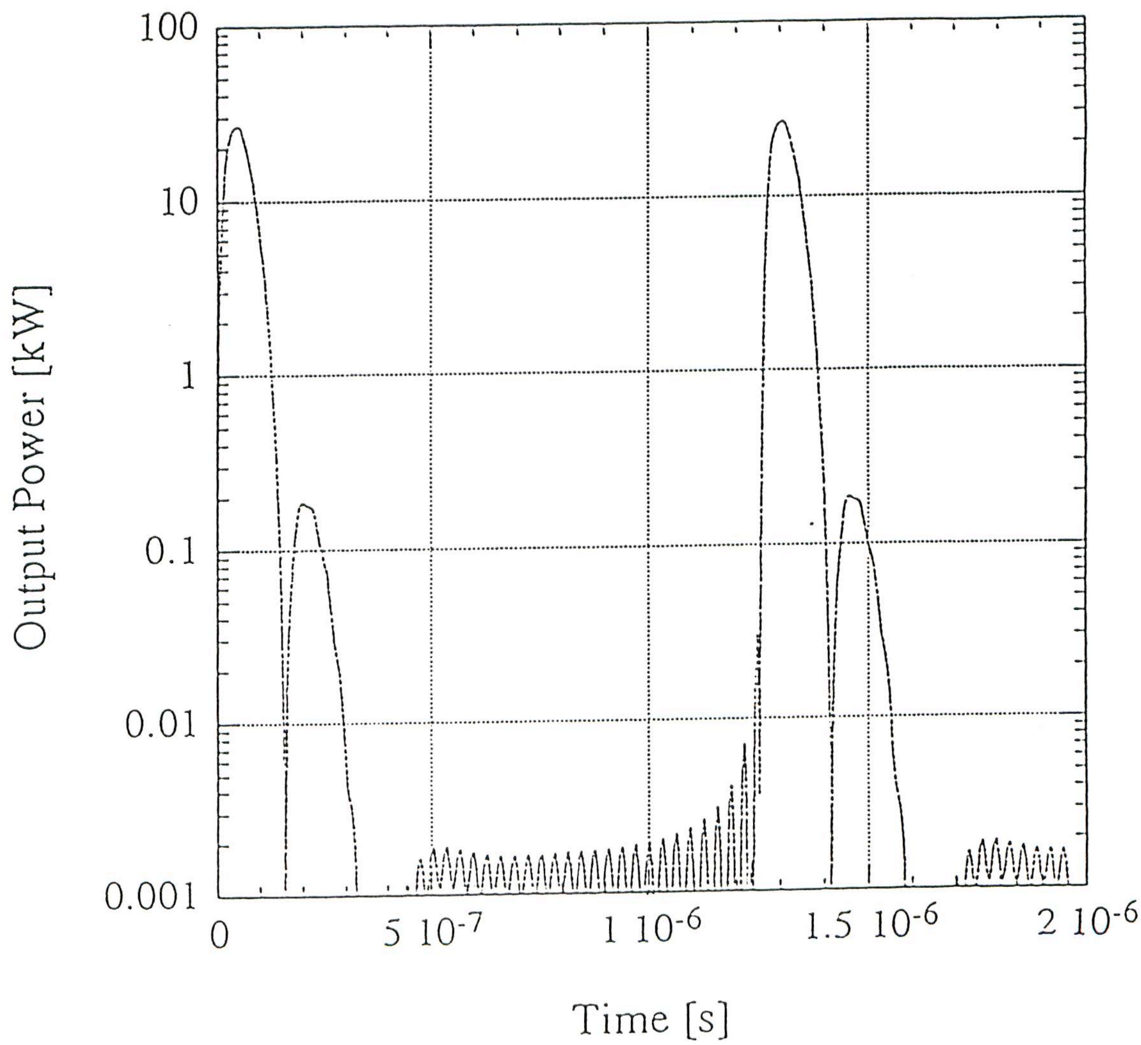


64 bunches
(56 filled
8 missing)
168mA

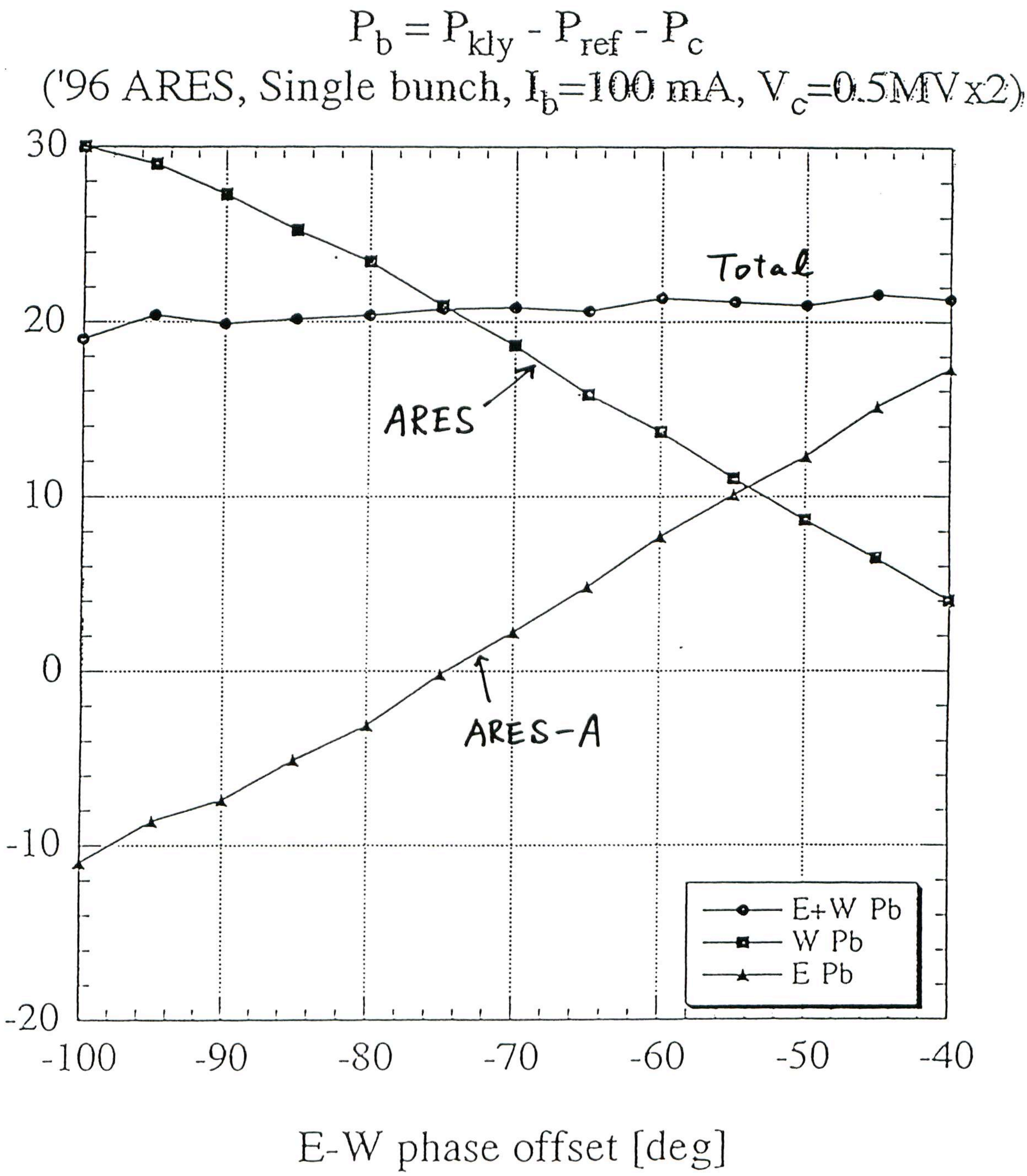
Comparison between Measurement and Calculation



Single Bunch Simulation (by N. Akasaka)



Beam Power

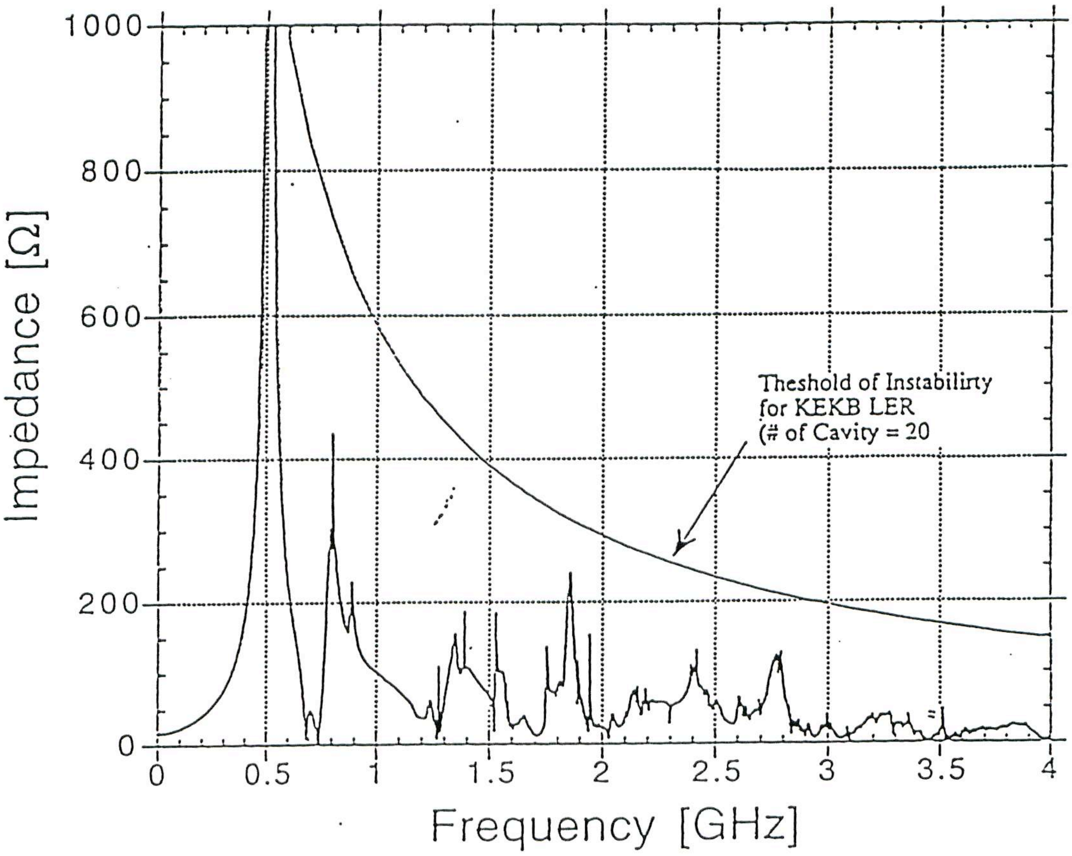


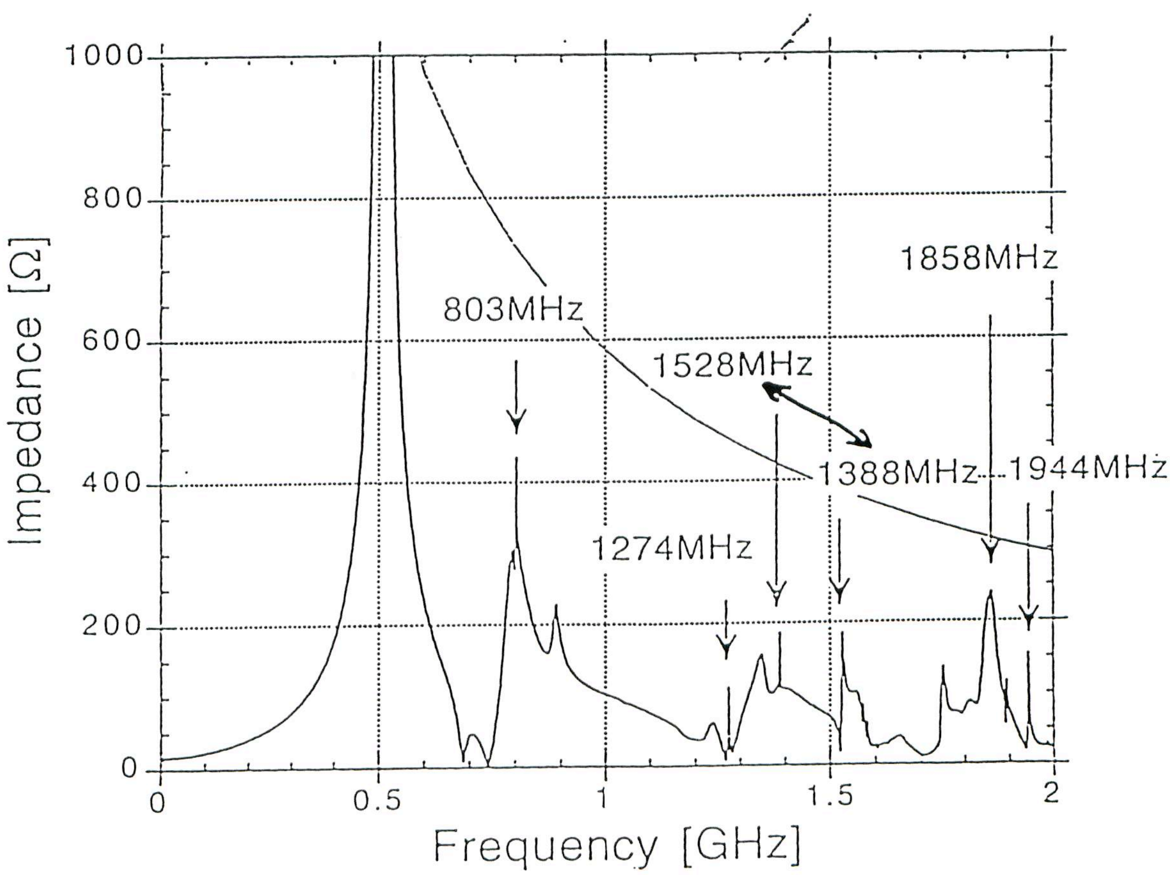
P_b = P_kly - P_ref - P_c
('96 ARES, Single bunch, I_b=100 mA, V_c=0.5MV x2)
30
20
10
0
-10
-20
-100
-90
-80
-70
-60
-50
-40
P_b [kW]
E-W phase offset [deg]
Total
ARES
ARES-A
E+W Pb
W Pb
E Pb

Longitudinal Coupling Impedance for ARES96

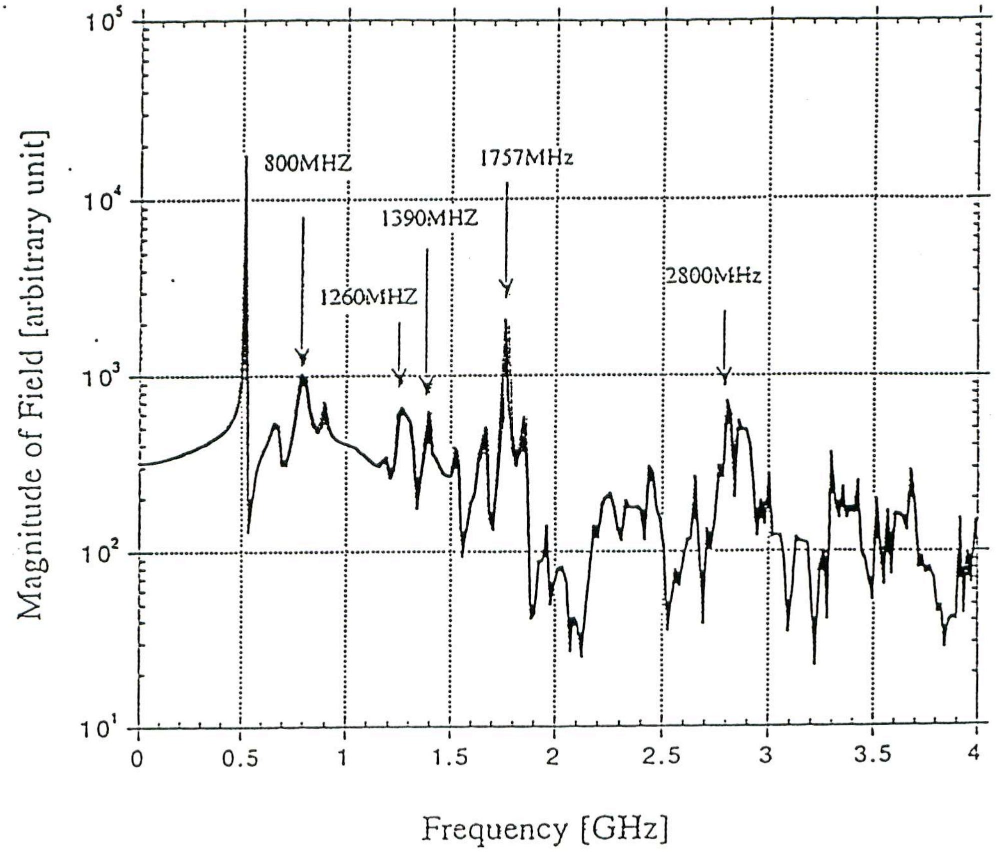
(MAFIA T3 , Bunch Length σ_z=20mm, $0<s<130$)

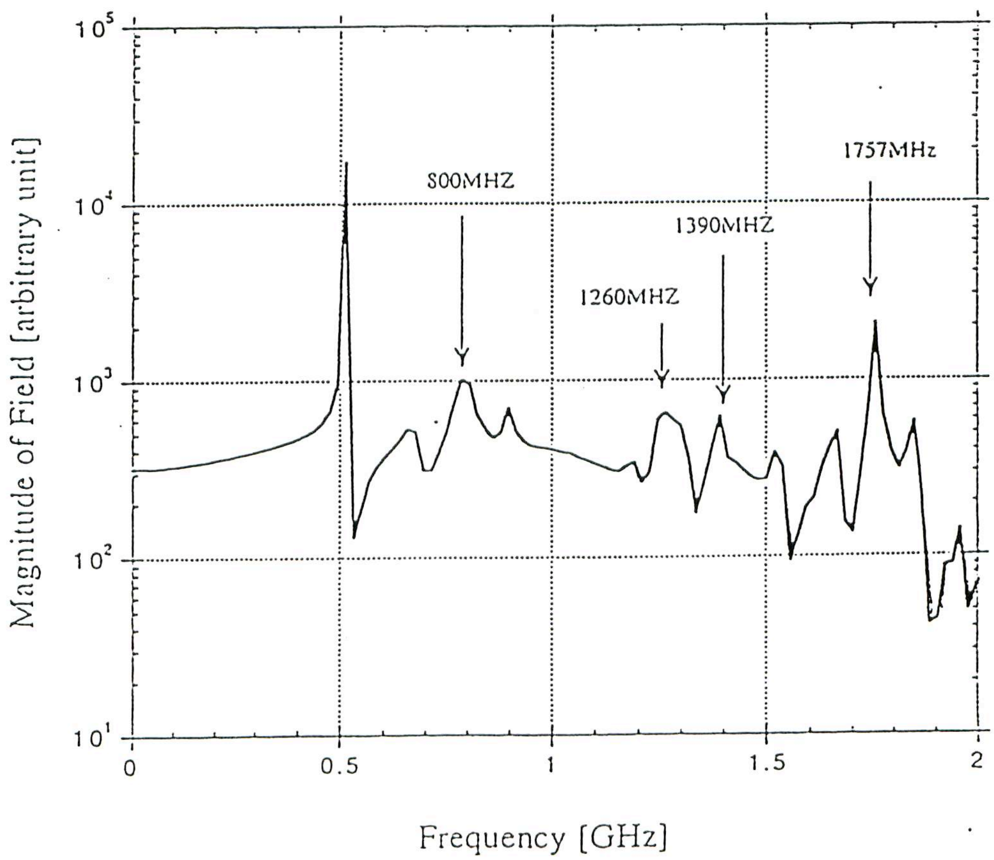
(by T. Kobayashi)



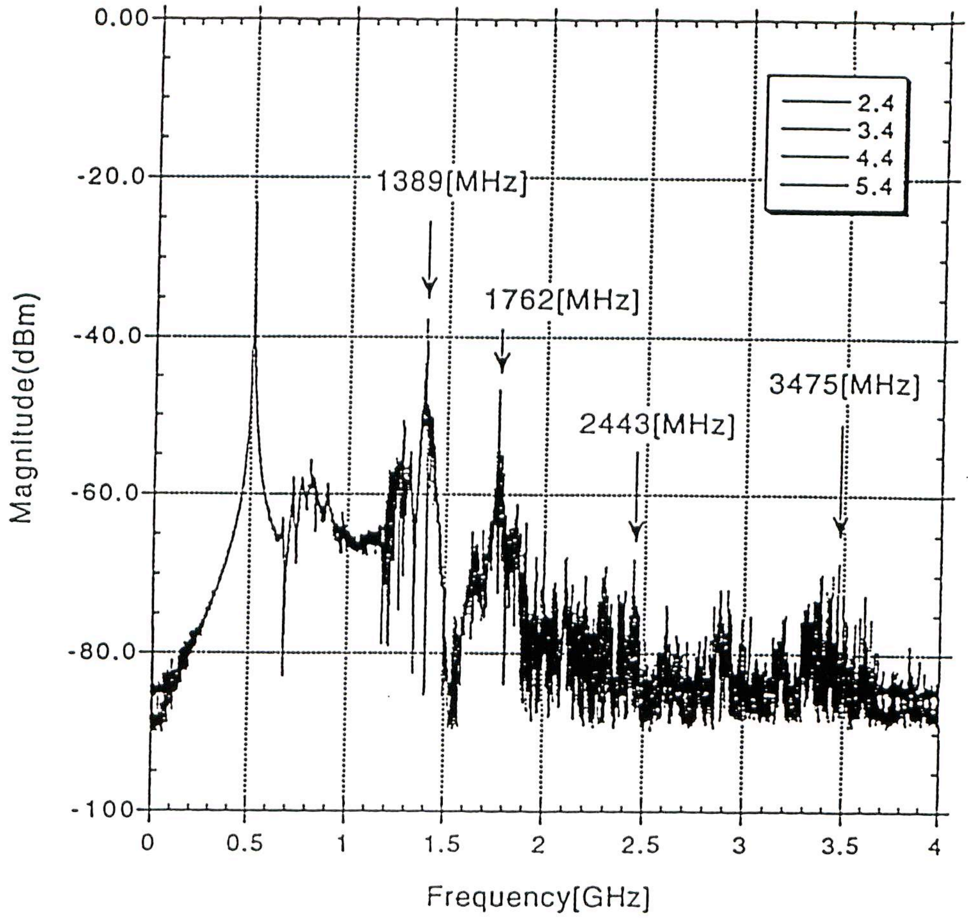


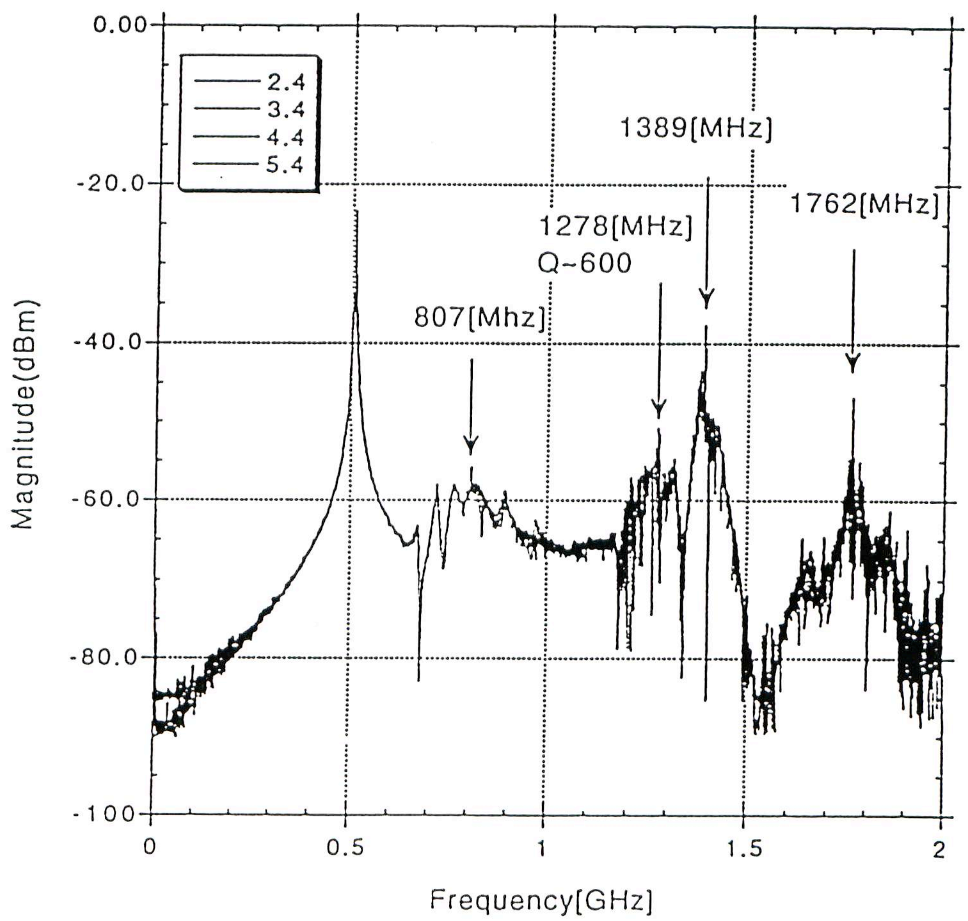
Spectrum of the Field at the pick-up port
for ARES96
(MAFIA T3 , Bunch Length σ_z =20mm, 0<s<66) (by T. Kobayashi)



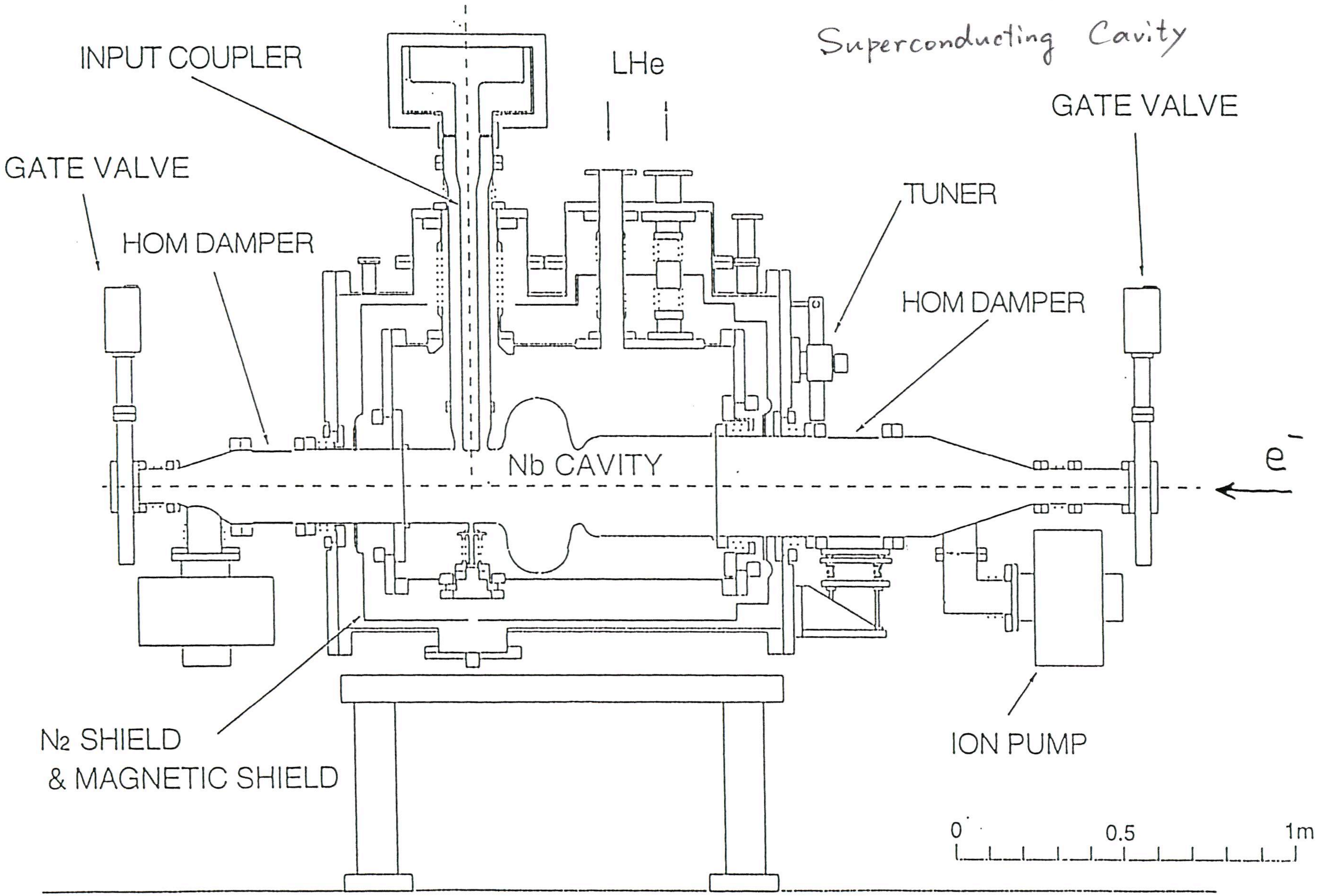


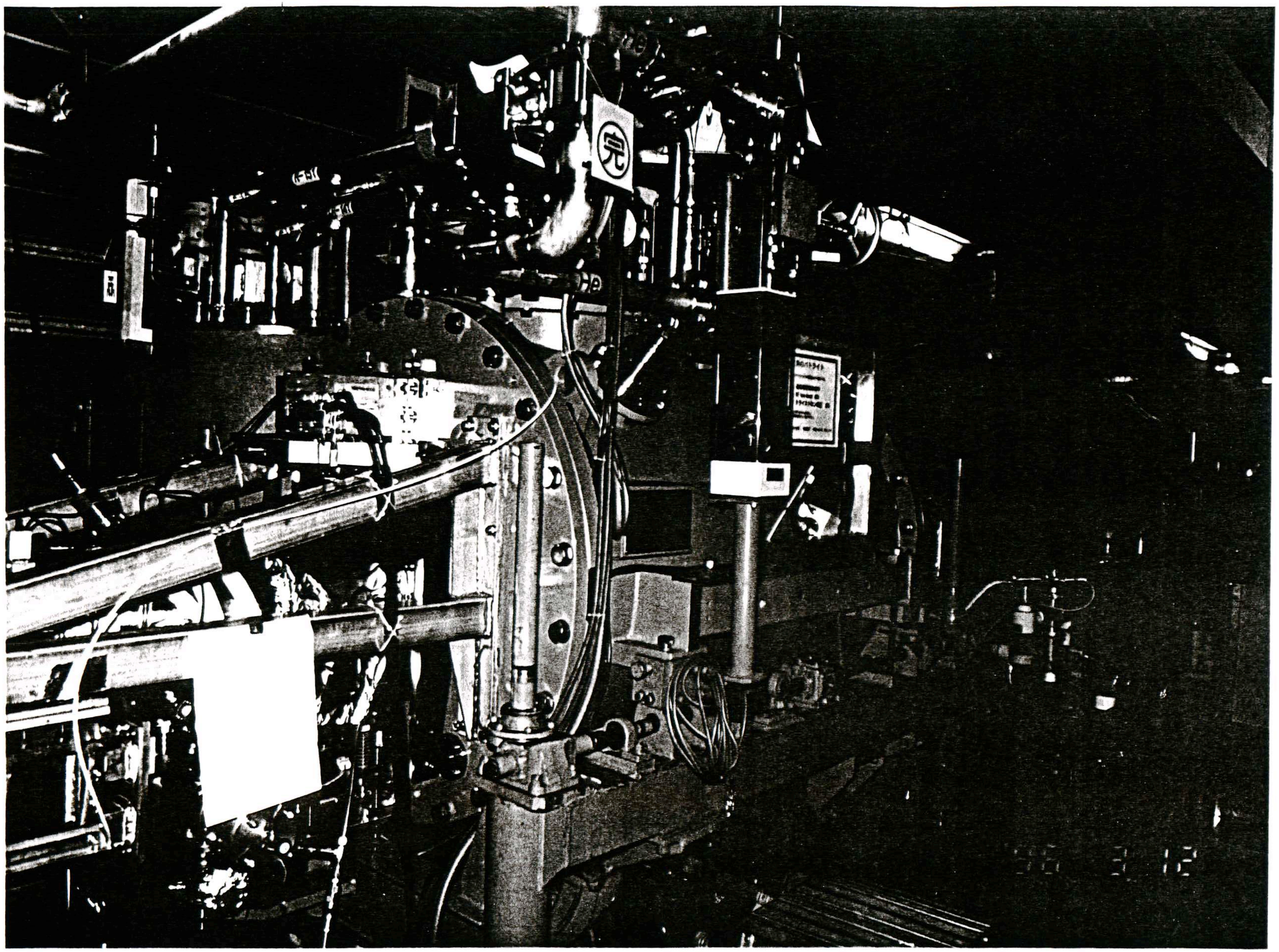
HOM Spectra
ARES96-A(S-tuner3.0V)





Superconducting Cavity





SCC in AR

SCC Test Results

- Accelerating voltage and maximum beam current
  570mA (V_c=1.2MV), 500mA (V_c=2.0MV), 350mA (V_c=2.5MV)
  Current limitations were NOT by cavity performance.

- HOM damper
  Up to 4.2 kW HOM power was absorbed by HOM dampers. No damage.
  Most of the time 2-3 kW HOM power absorbed.
  No clear HOM-related instability was observed.

- Input coupler
  Maximum power applied was 280 kW (no beam, total reflection).
  (850 kW at coupler test bench)
  Maximum power transfered to the beam was 160 kW.

- Trips and Cure

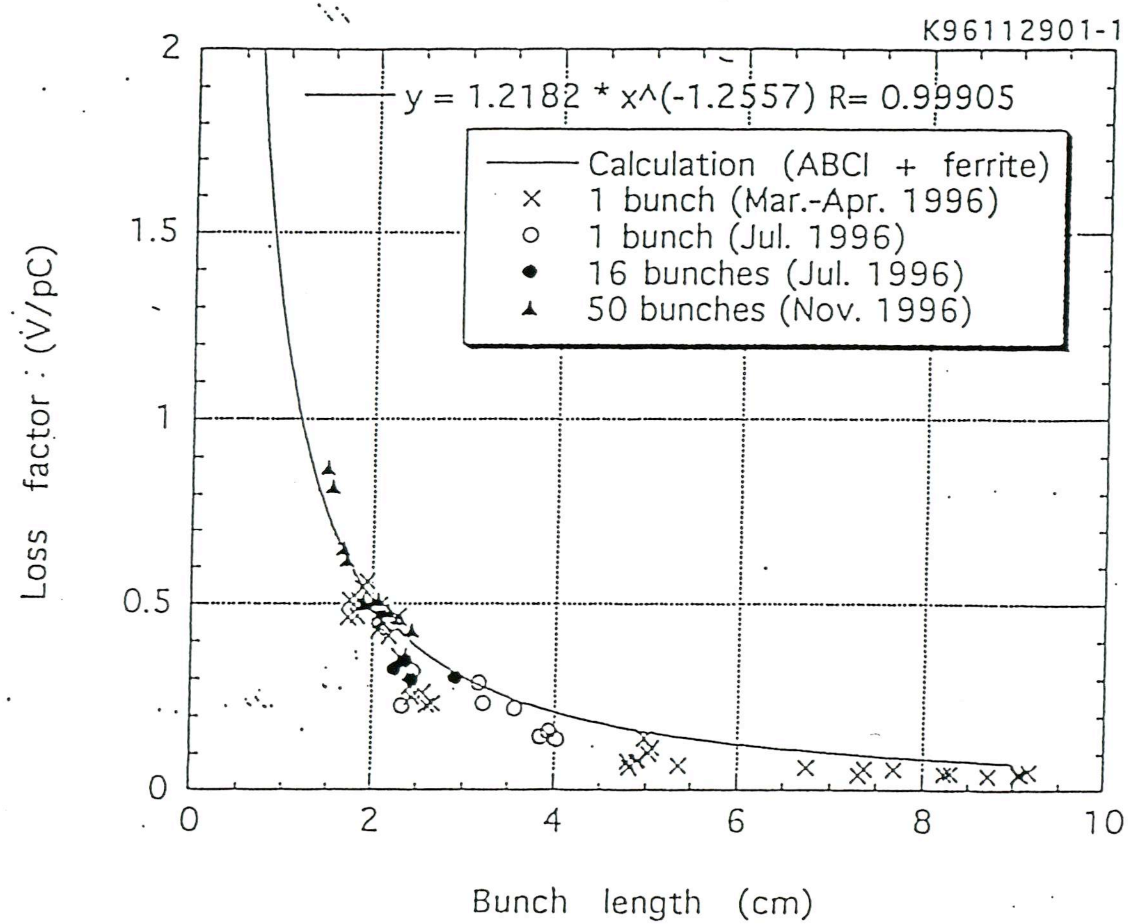
- Heat load

- Direct RF feedback

Records of SCC achieved in AR

	CESR-B SCC	AR Test SCC	KEKB-HER SCC
Beam current	220 mA	570 mA	1100 mA
Acc. voltage with high current beam	1.8MV(120mA) 1.4MV(220mA)	2.5MV(350mA) 1.2MV(570mA)	~1.5 MV
HOM power absorbed	2 kW	4.2 kW	~5 kW
Beam power transfered	155 kW	168 kW	~400 kW

SCC group


K96112901-1
y = 1.2182 * x^(-1.2557) R= 0.99905
Calculation (ABCI + ferrite)
1 bunch (Mar.-Apr. 1996)
1 bunch (Jul. 1996)
16 bunches (Jul. 1996)
50 bunches (Nov. 1996)
Loss factor : (V/pC)
Bunch length (cm)
0
0.5
1
1.5
2
0
2
4
6
8
10

Trips and Cure

- TRISTAN SCC operation

  - Frequent trips occurred after several weeks operation.
  - It was found that the trip is a discharge around coupler/cavity region, and that adsorbed gas on the surface is source of the trips.
  - After warm-up to RT or even 20 K to release the adsorbed gas, trip rate drastically reduced.

  However, increased again after several weeks.

- 1st and 2nd AR Beam Test

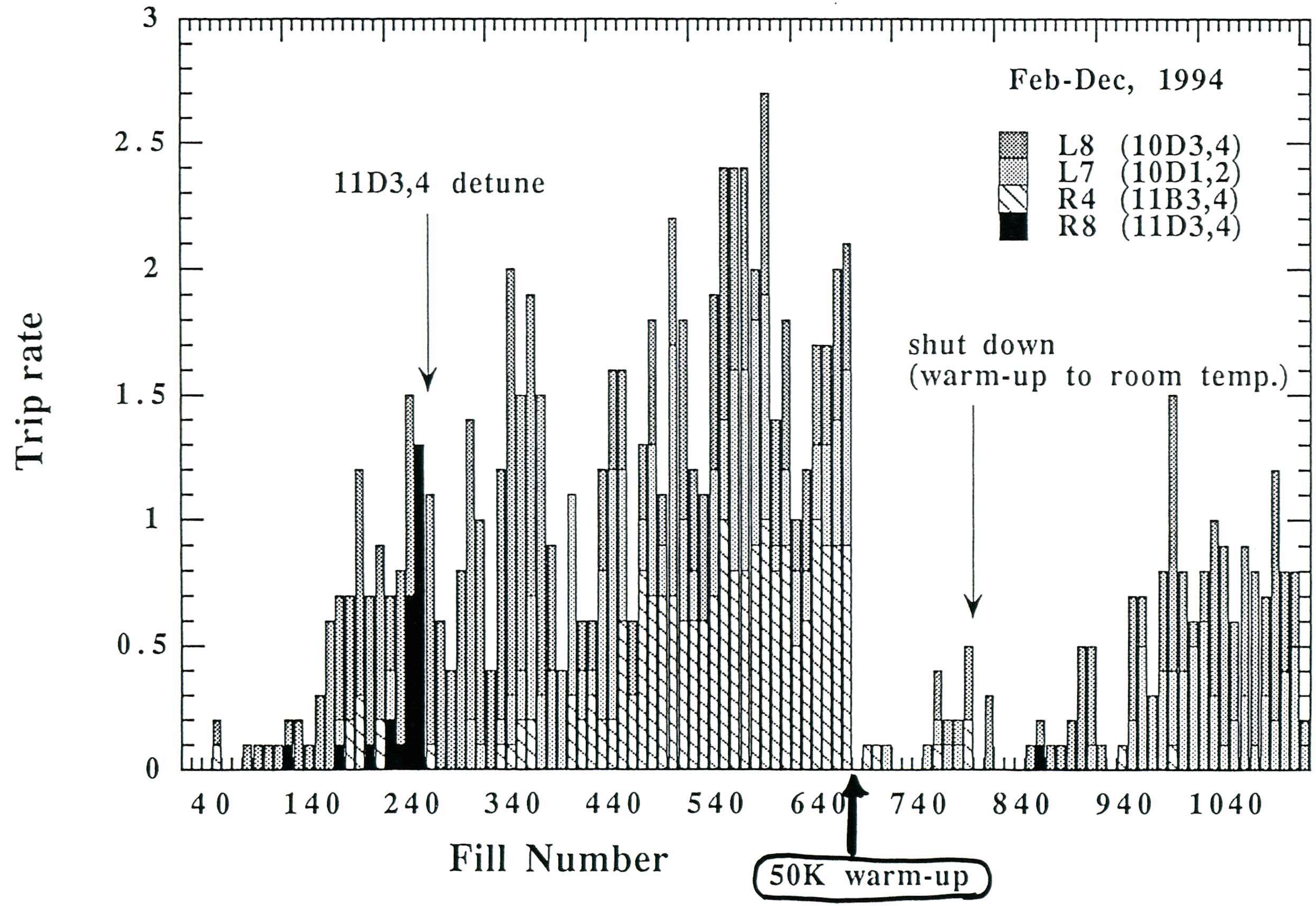
  - Frequent trips occured, very similar to those observed in TRISTAN.
  - After warm up to 85K, trip rate reduced, but increased again within a day (too bad vacuum pressure in AR at that time).
  - Gas around coupler region responsible? When temperature at outer conductor of input coupler changed, trip rate reduced.

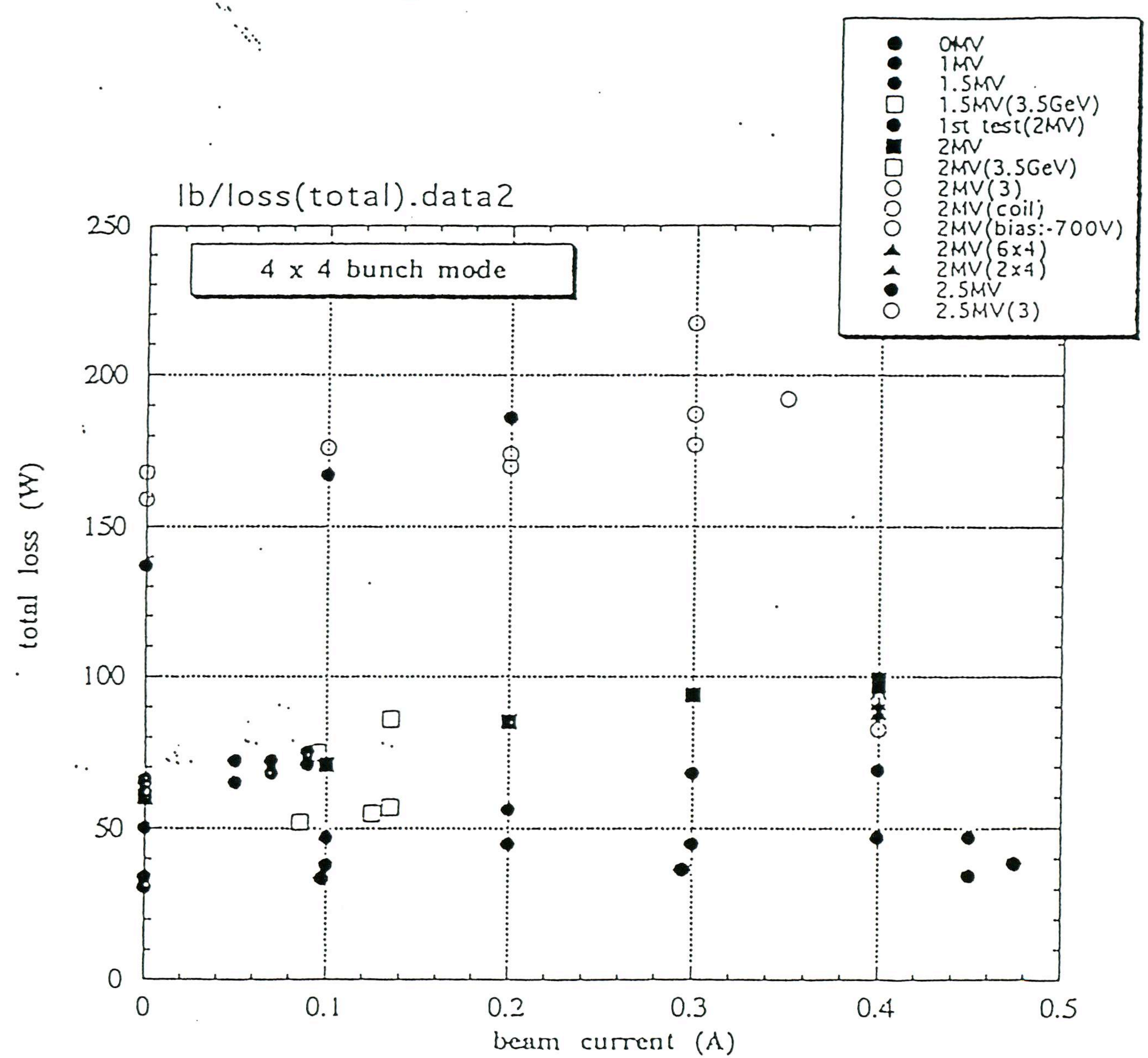
Trips and Cure (cont'd)

- Cures taken before the 3rd test
  - Reinforced vacuum pumps at both sides of SCC, cleaned and baked ducts.
  - Installed DC bias device for inner conductor of input coupler.

- 3rd AR Beam Test
  - SCC was operated stably for 2 weeks. Trip rate drastically reduced.
  - The effect of DC bias could not be tested clealy.

Trip rate of 8 cavities (warmed-up to 50K) in TRISTAN




lb/loss(total).data2
4 x 4 bunch mode
0MV
1MV
1.5MV
1.5MV(3.5GeV)
1st test(2MV)
2MV
2MV(3.5GeV)
2MV(3)
2MV(coil)
2MV(bias:-700V)
2MV(6x4)
2MV(2x4)
2.5MV
2.5MV(3)
total loss (W)
beam current (A)
0
50
100
150
200
250
0.1
0.2
0.3
0.4
0.5

SCC group

Bunch Feedback System

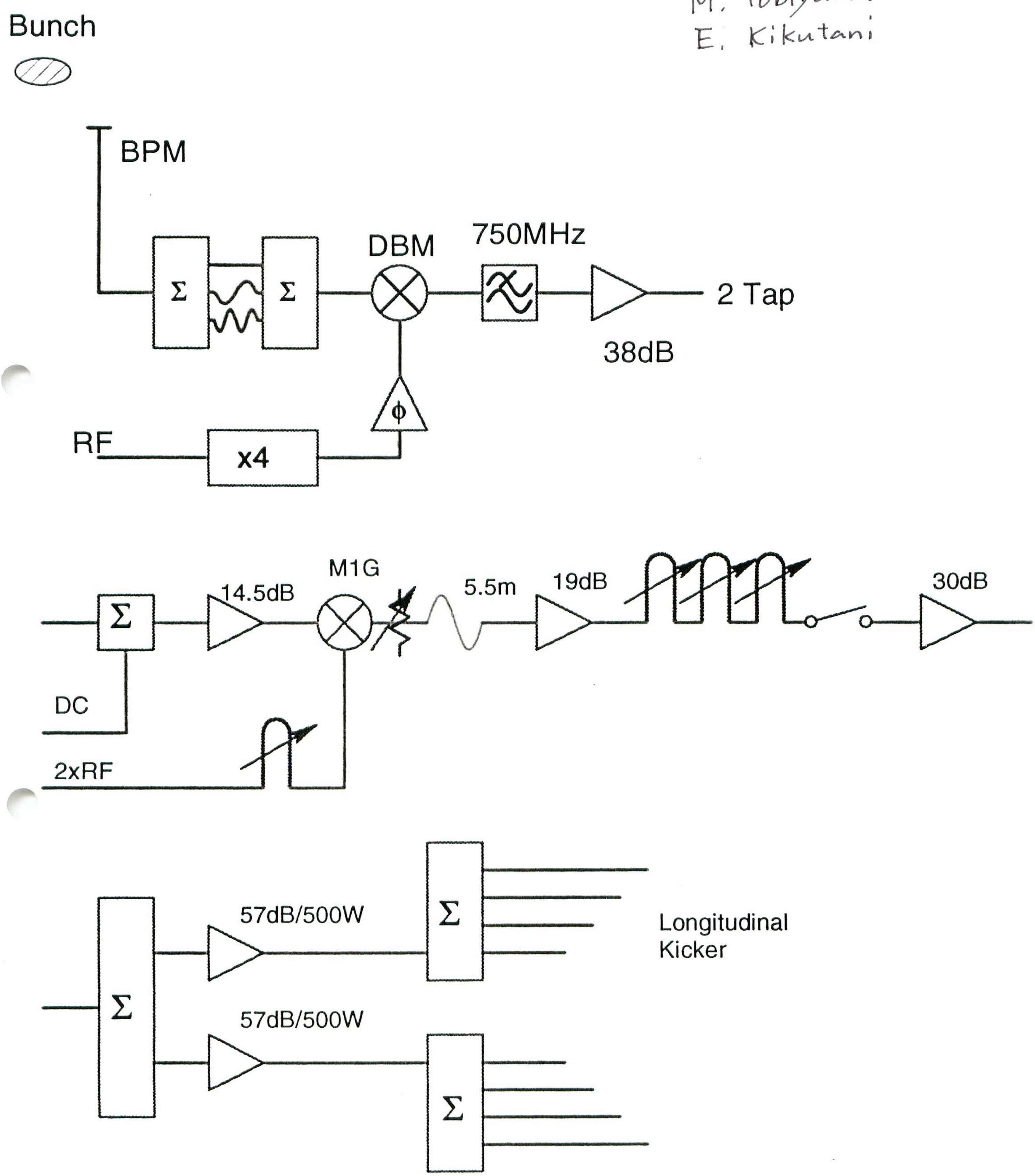
- Signal detection and signal processing with 2-Tap FIR filter was tested in longitudinal feedback system. It worked well with 2ns bunch spacing. It was effective to reduce bunch oscillation.

- Transverse feedback system was tested (V and H).
It effectively reduced bunch oscillation.
With FB on, we could store more than 300 bunches (1mA/bunch) with 2ns spacing. (Without FB, beam loss with 20-30 bunches.)

- No serious hardware trouble with high current beam. Heat-up was observed at connectors and power splitters with much higher bunch current than KEKB.

Detailed talk will be given by Kikutani.

M. Tobiyama
E. Kikutani



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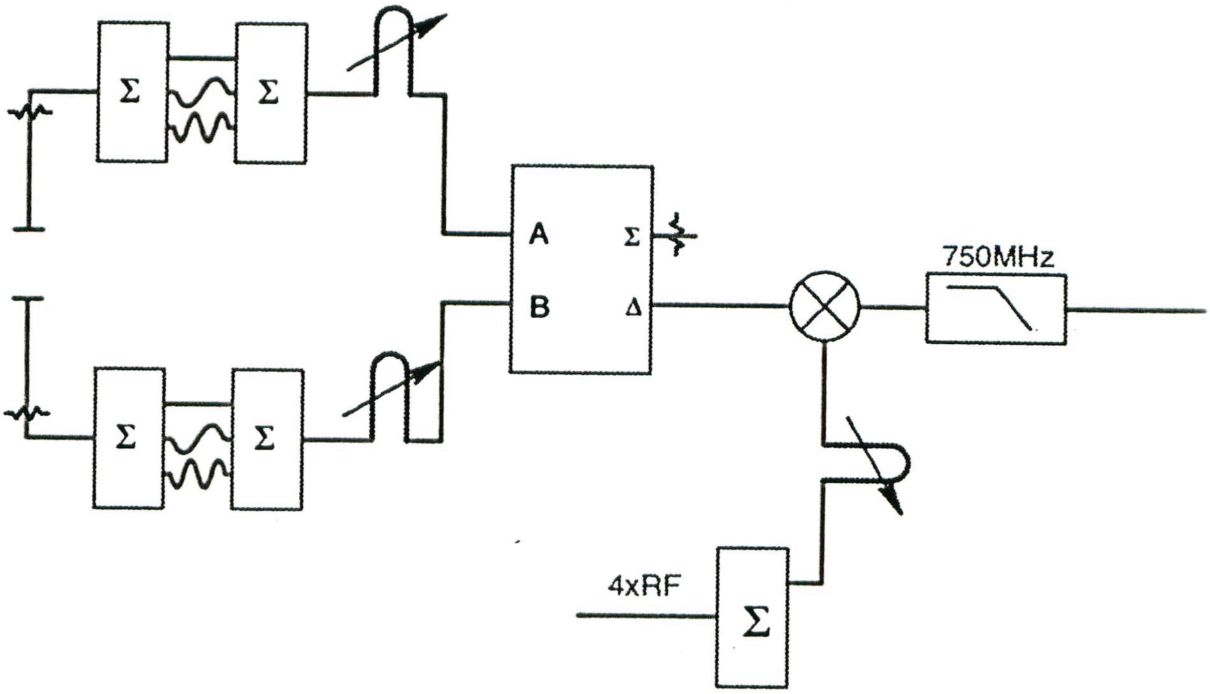

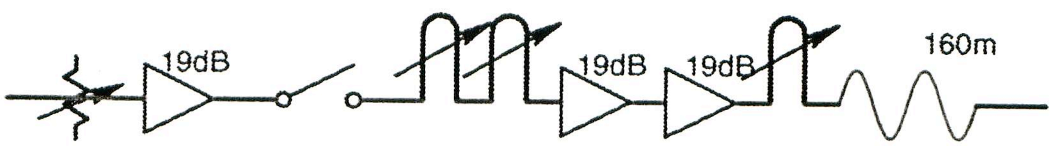

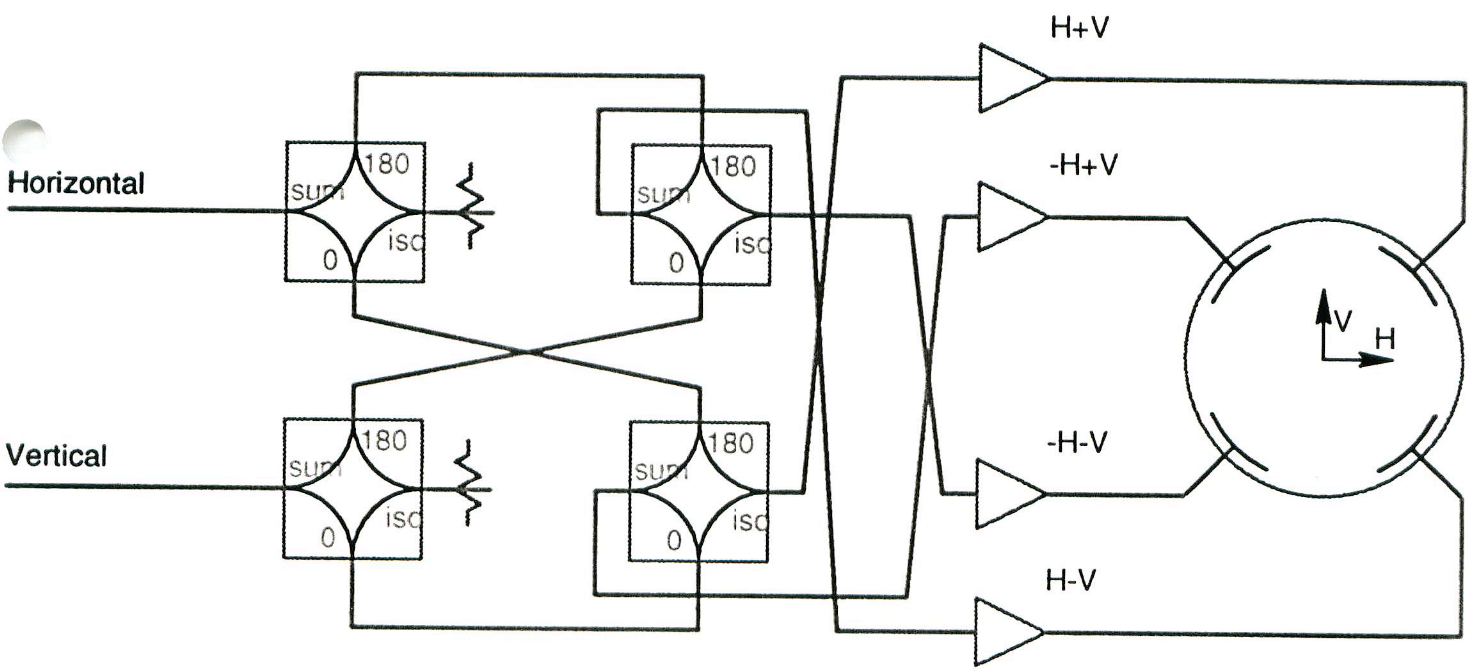

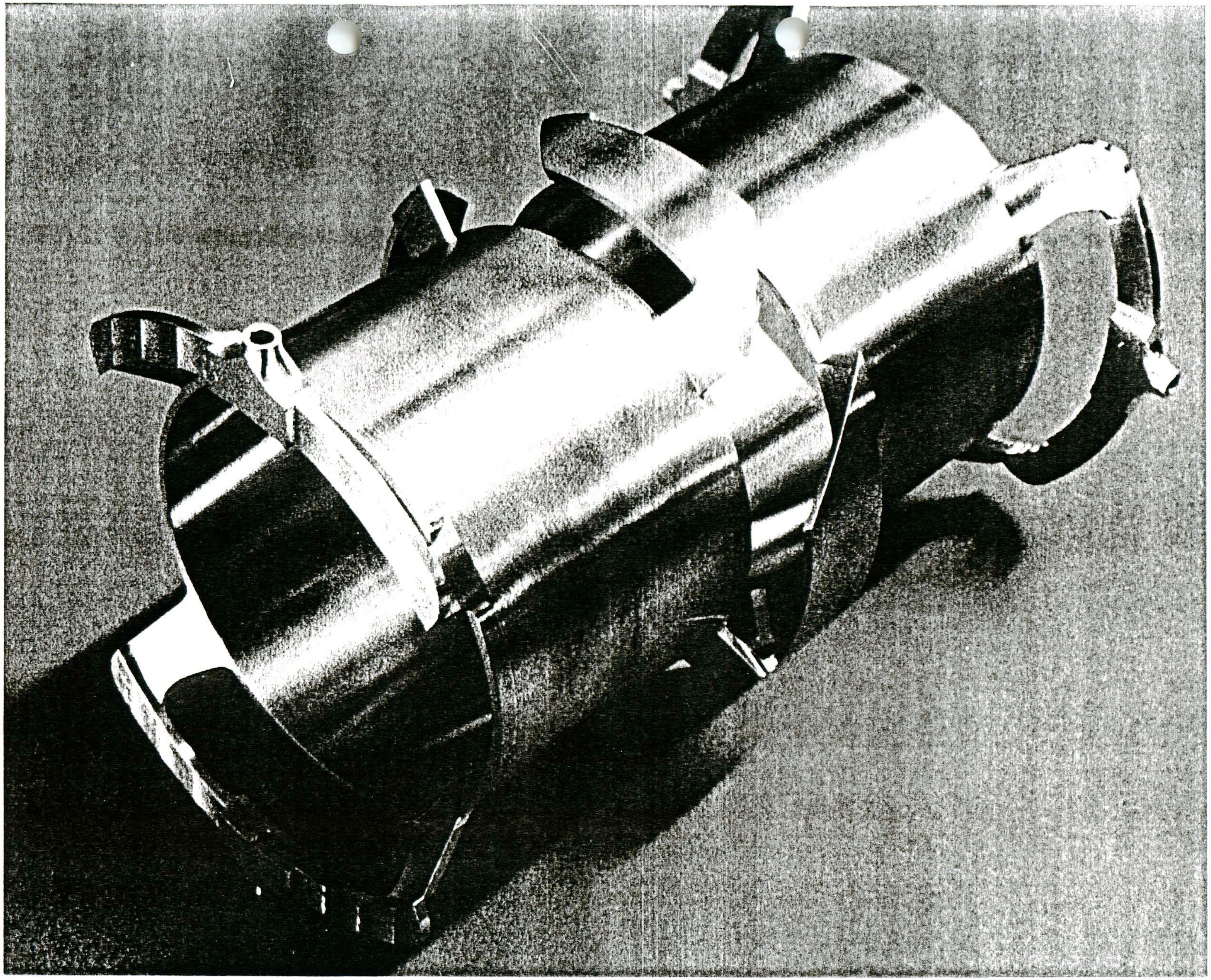

Longitudinal Kicker

Instabilities

(Bunch train)

- When beam is filled in bunch train (short bunch spacing), transverse feedback was needed to store 400mA. Without the feedback, beam loss at 20-30 bunches. It was dependent on vacuum pressure. It is considered to be due to ion effect.

- Ion instability study was done by introducing N2 gas. Vertical oscillation related to ions was obserbed.

-----> H. Fukuma will give detailed talk.

(Eqally-spaced bunch)

- When 64 equally-spaced bunches were filled, vertical tune shift was observed, which was considered to be due to the ion-trapping.

Conclusion

- ARES
  - Principles of ARES were confirmed experimentally with beam.
  - Performance with high power and high current beam in AR was good.
  - We found no serious problem up to the parameters tested in AR.

- SCC
  - SCC system operated well with high current beam. Many new records were made.
  - We gained confidence to use SCC in HER.
  - Long-term stable operation depends on avoiding trips: excellent vacuum condition must be kept.

- Bunch feedback system
  - It showed good performance in each component and total system.

- No trouble with other hardware components for KEKB tested in AR. (BPM, shielded bellow, DCCT, ceramic chamber, etc)

- We obtained some operational experience with high current beam.