Crab cavities for high currents

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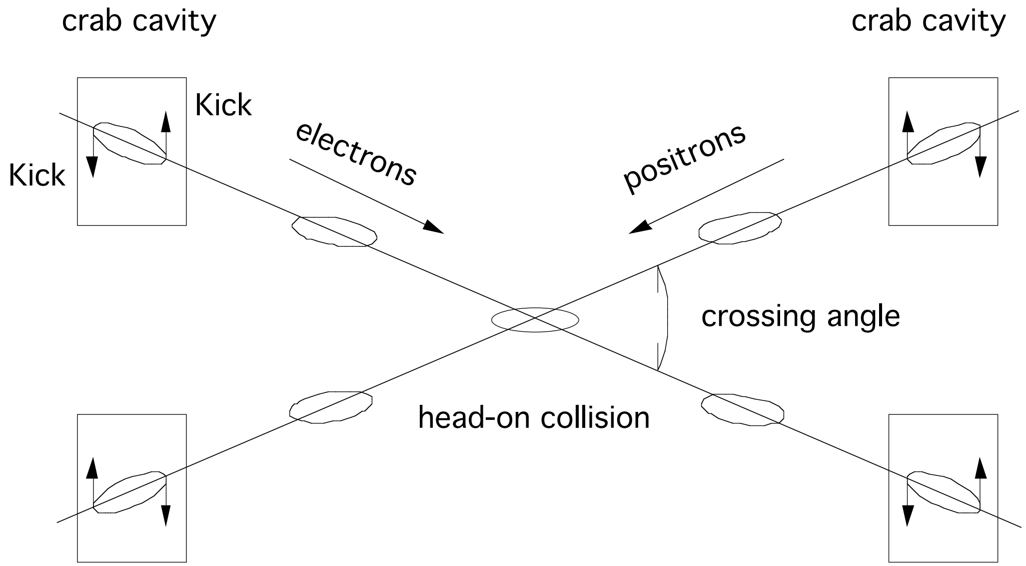
for KEKB Review Committee

Crab crossing



Palmer for LC (1988)
Oide and Yokoya for storage rings (1989)

Recent simulations by Ohmi showed significant increase of luminosity by several times by the crab crossing.

Parameters for the crab crossing

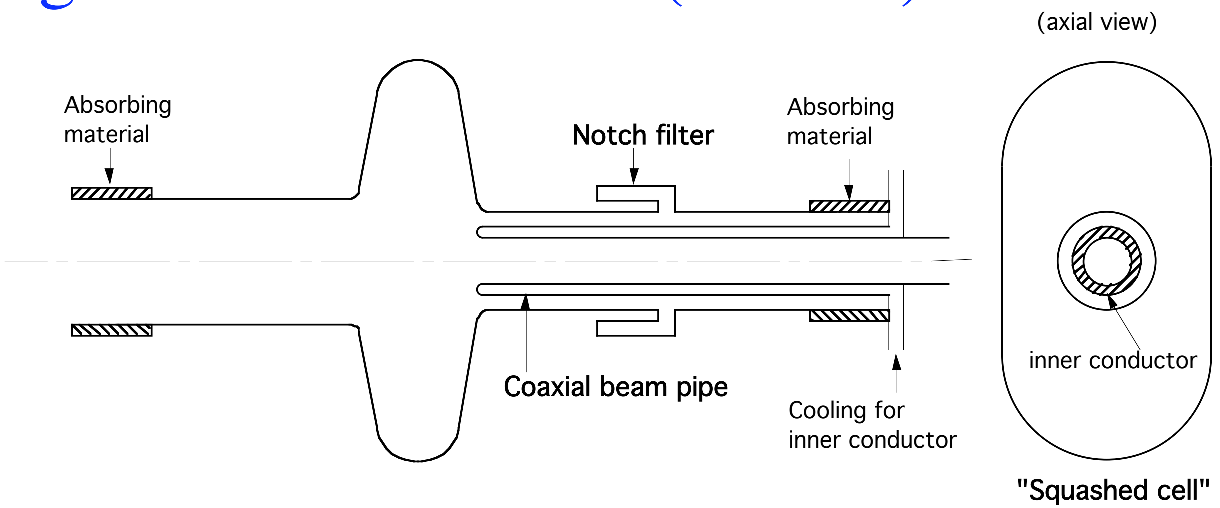
	KEKB		*Super-KEKB*	
Strategy	Backup scheme		Adopted as baseline	
Ring	LER	HER	LER	HER
Beam energy (GeV)	3.5	8.0	3.5	8.0
Beam current (A)	2.6	1.1	9.4	4.1
RF frequency (MHz)	508.887		508.887	
Crossing angle (mrad)	±11		±15	
βx* (m)	0.33	0.33	0.2	0.2
βx, crab (m)	20	100	100～200	300～400
Required kick (MV)	1.41	1.44	1.10 ～ 0.78	1.45 ～ 1.26

Damping parasitic modes

- Accelerating cavities
  - Operating mode (TM010) is the lowest frequency mode.
  - Any parasitic mode (HOM) has higher frequency than the operating mode.
  - Wave guides or beam pipe with cut-off frequency higher than the operating mode can damp all HOM's. (ARES, SCC, PEP-II cavity, etc)
- Crab cavity
  - Operating mode (usually TM110) is NOT the lowest frequency mode.
  - Frequency of several parasitic modes can be lower than (or close to) the crabbing mode.
  - Special cure is needed for the damping of parasitic modes.

Original crab cavity

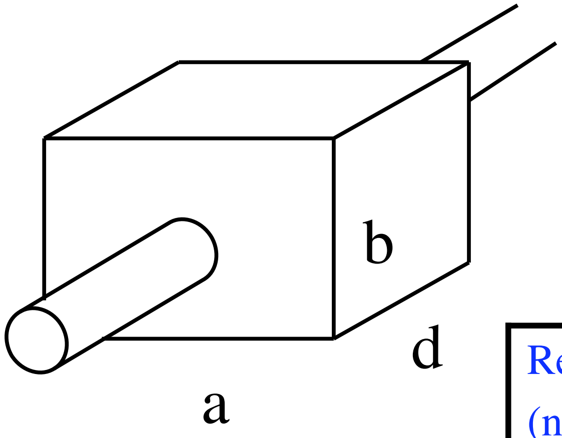
- Squashed cell operating in TM2-1-0 (x-y-z)
- Coaxial coupler is used as a beam pipe
- Designed for B-factories (1～2A)



Squashed Crab cavity for B-factories

(K. Akai et al., Proc. B-factories, SLAC-400 p.181 (1992).)

Analogy with rectangular cavity



$$f_{n,m,l} = c\sqrt{\left(\frac{n}{2a}\right)^2 + \left(\frac{m}{2b}\right)^2 + \left(\frac{l}{2d}\right)^2}$$

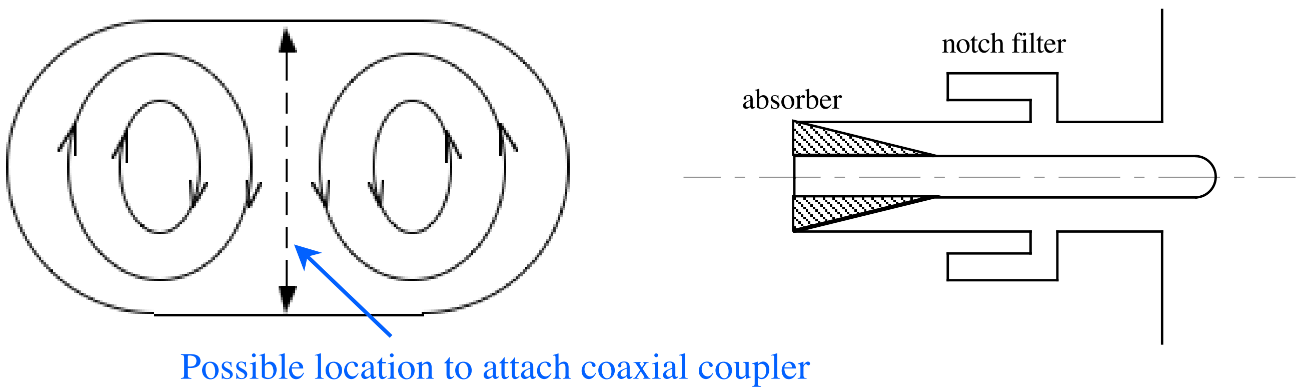
Rectangular (n-m-l)	Cylindrical	Beam coupling	Mode
TM1-1-0	TM010	monopole-like	Accelerating mode
TM2-1-0	TM110(H)	dipole-like	Crabbing mode
TM1-2-0	TM110(V)	dipole-like	Unwanted crabbing
TE0-1-1	TE111(H)	dipole-like	Lowest TE-like
TE1-0-1	TE111(V)	dipole-like	Lowest TE-like
TM3-1-0	-	monopole-like	
TM4-1-0	-	dipole-like	
TE0-2-1	TE211	quadrupole-like	

Squashed cell

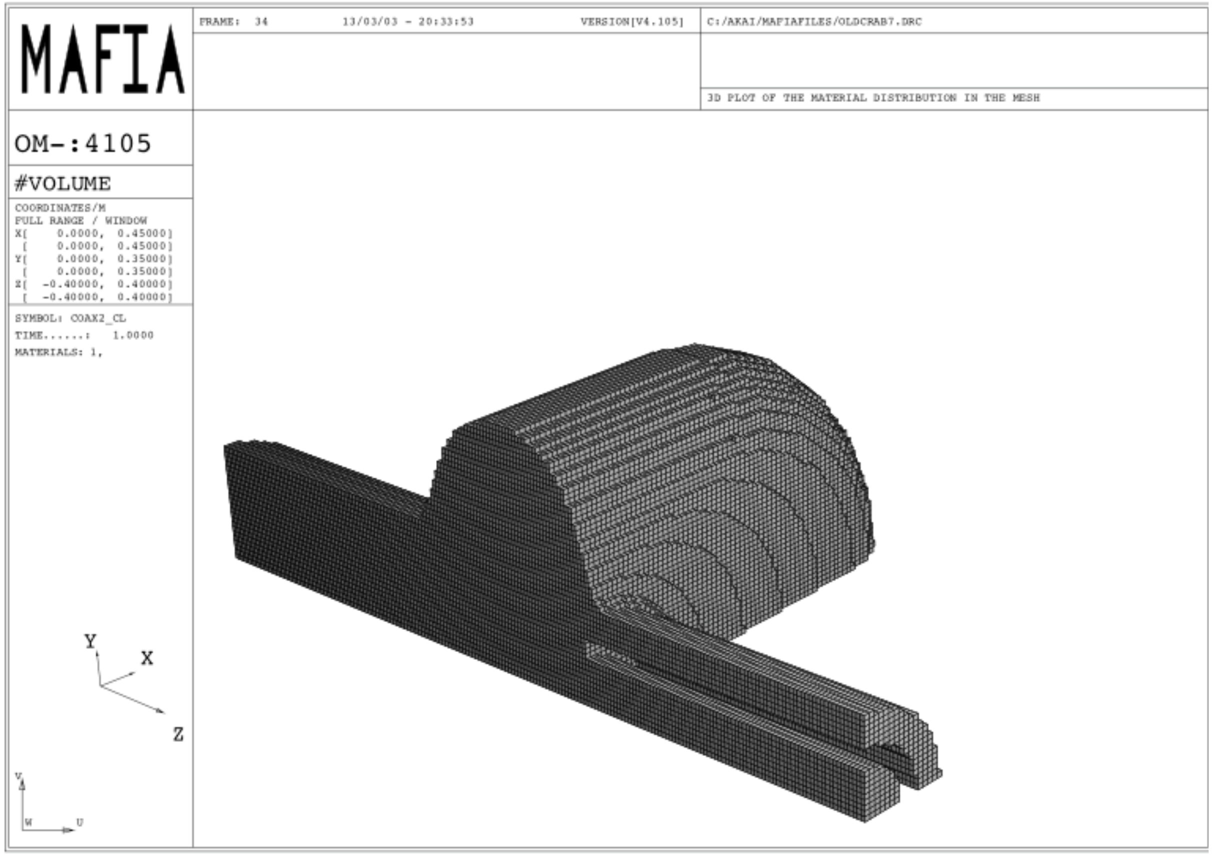
- Extremely polarized cell
  - Large eccentricity where horizontal size is about twice the vertical size.
  - Frequency of the unwanted crabbing mode increases.
- Relatively short cell length
  - The frequencies of lowest TE-like parasitic modes increase.
- Frequencies of all parasitic modes except the accelerating mode can be made higher than the crabbing mode.

Coaxial coupler with notch filter

- Monopole mode (including the Lower Freq. Mode)
  - Couples strongly and propagate in the coaxial line as TEM wave.
- Crabbing mode
  - Couples as dipole-like, but does not propagate in the coaxial line, if the cut-off frequency of TE11 mode is higher than the crabbing frequency.
  - Possible asymmetry or misalignment causes monopole-like coupling, which propagates in the coaxial line as TEM. A notch filter is attached to reject the TEM-coupled crabbing mode back to the cavity.



Original crab cavity (1/4 cell)



10A beam in Super-KEKB

- The original cavity is designed for 1 ～ 2A beam
  - Suitable for SC → High kick voltage obtained by one cavity.
  - Sufficient damping of parasitic modes.

- Possible problems for 10A beam
  - Large HOM power (200kW)
    - Loss factor is not very small, because beam pipe radius can not be widely opened due to the coaxial beam pipe.
    - Additional loss factor comes from the absorber on wide beam pipe.
  - Much heavier damping of HOM's may be needed, particularly for horizontal polarization of transverse modes.

Impedance requirement

- Longitudinal

$$\tau^{-1} = \frac{e\pi\sigma_z I_b}{CE\sigma_\varepsilon} \times \Sigma\left(f^+ \mathrm{Re}\, Z^+ - f^- \mathrm{Re}\, Z^-\right)$$

  – Growth rate (@9.4A, σz=3mm) ≦ radiation damping rate
  – → #cav x freq [GHz] x Re Z [Ω] ≦ 4230

- Transverse

$$\tau^{-1} = \frac{e f_{rev} I_b}{2E} \times \beta_{crab} \times \Sigma\left(\mathrm{Im}\, Z_T^+ - \mathrm{Im}\, Z_T^-\right)$$

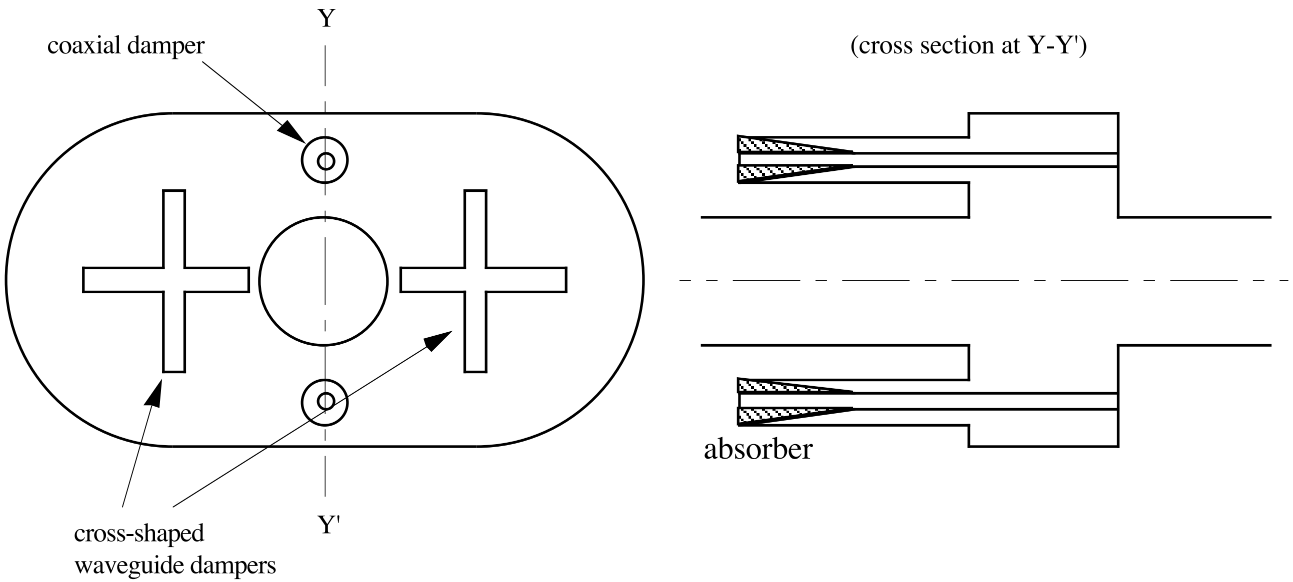
  – Large β_{crab} → required kick reduces, but growth rate increases.
  – Although the number of cavities is small, the impedance should be reduced even lower than that of the ARES.
  – 9.4A, β_{crab}=200m → τ^{-1}= 0.0267 x #cav x Im Z_T
  – #cav=4, τ≧1ms (bunch feedback) → ImZ_T ≦ 9.4 kΩ/m

Design concept of new crab cavity

K. Akai and Y. Morita,
submitted to PRST-AB.

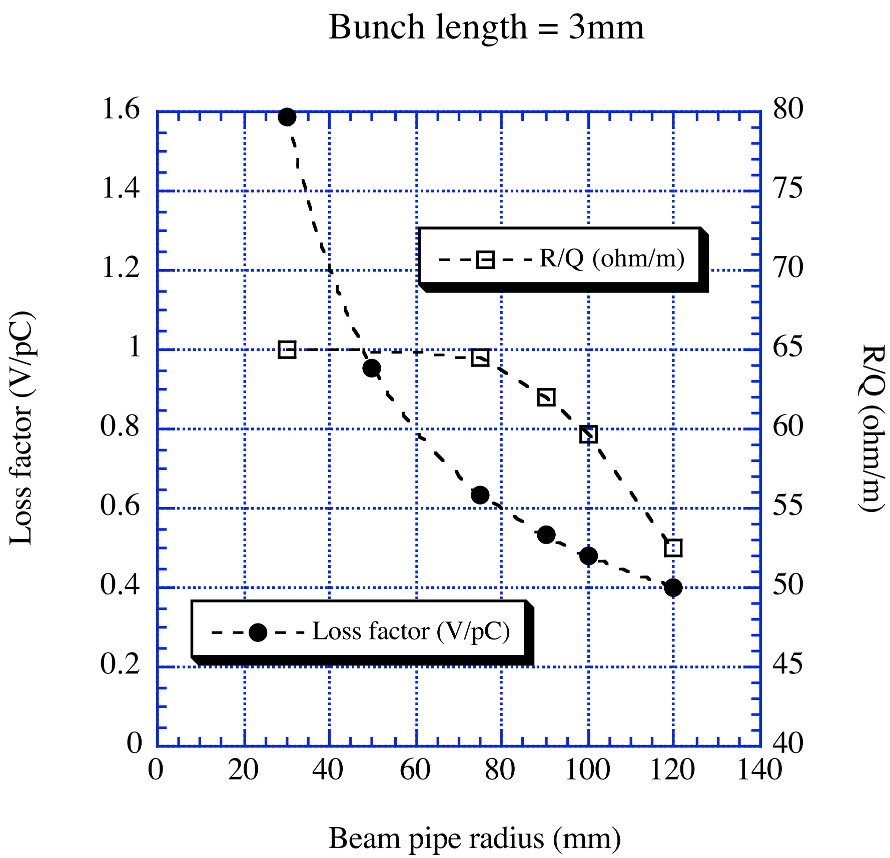
- Squashed cell operating in TM2-1-0 (same).
- Waveguide dampers are attached.
  - Much heavier damping of parasitic modes can be obtained.
  - Larger HOM power is allowed for the dampers.
- Coaxial dampers are used, but not as a beam pipe.
  - The TM1-1-0 is well damped.
  - Loss factor is reduced since widely opened beam pipes can be used.
- Optimization has been carried out for both the SC and NC versions.

Schematic drawing of new crab cavity



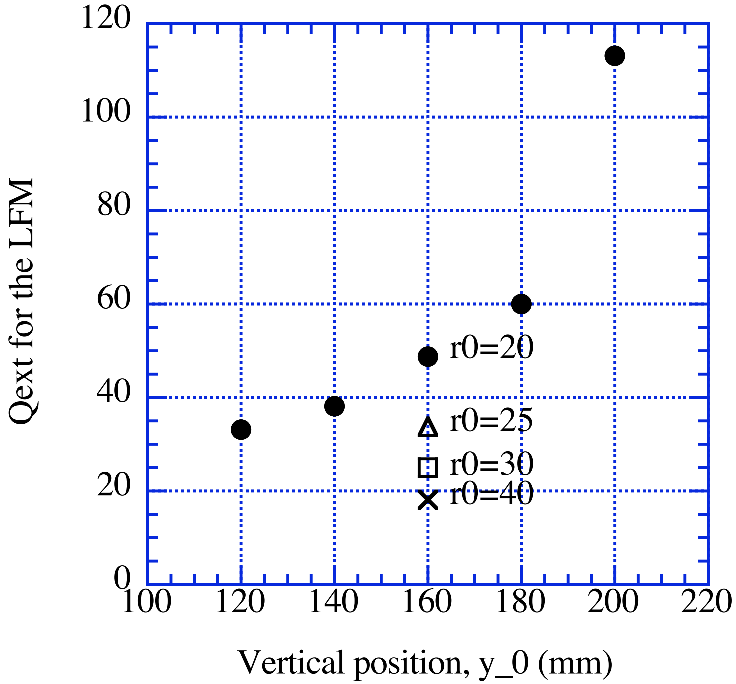
- (Left) The cross-shaped waveguide dampers and coaxial dampers are attached at the squashed-cell.
- (Right) Cross section of the coaxial damper at the cut plane of Y-Y'.

Beam pipe radius



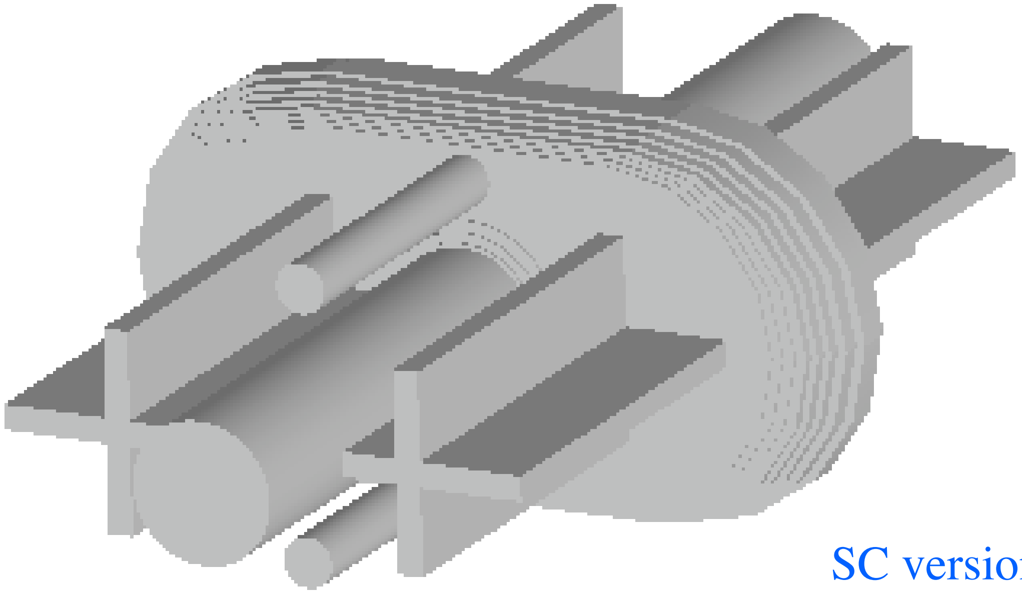
- Loss factor is calculated using analytical form.
- R/Q is calculated using MAFIA without wave guides
- Radius of 70～90mm gives sufficiently high R/Q and relatively low loss factor.

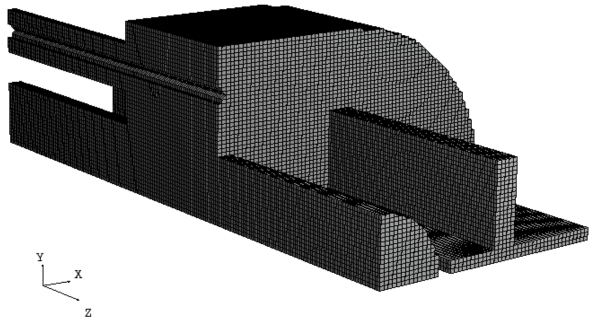
Damping of the Lower Freq. Mode



- Inner and outer radii of the coaxial damper are chosen 10mm and 30mm.
- The external Q value of the LFM is sufficiently reduced to 25.
- The effect of the coaxial damper on the crabbing mode is small; the R/Q is decreased by only 1%.

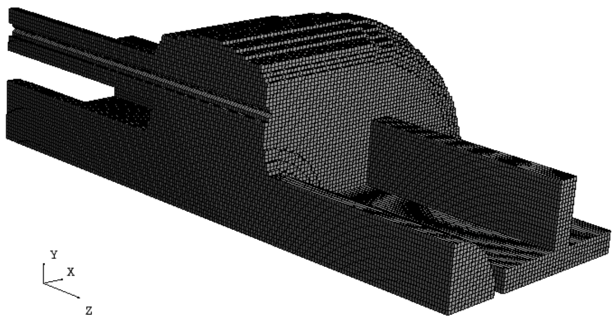
3-D drawing of new crab cavity



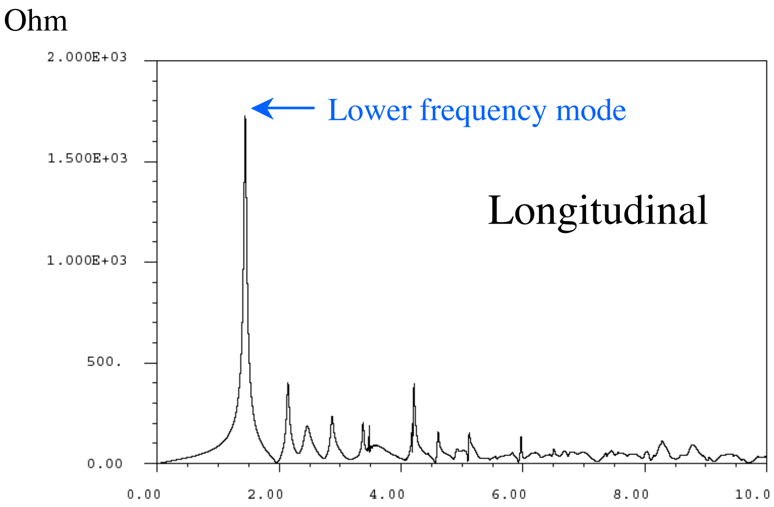


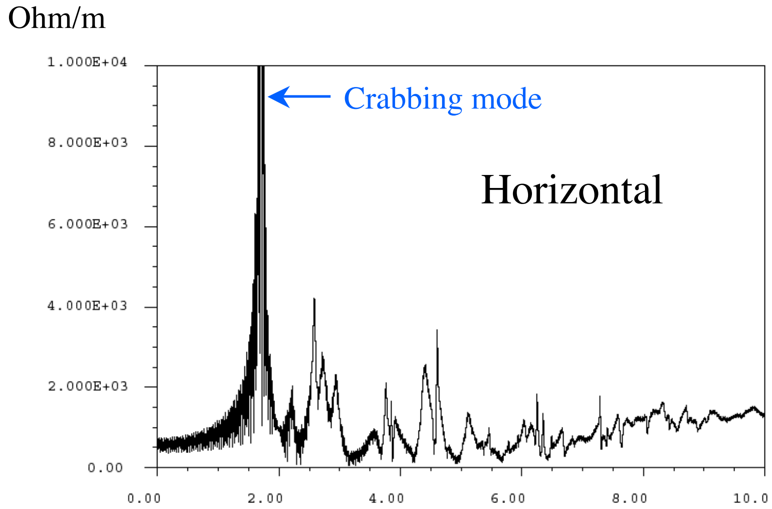
NC version

SC version



Coupling impedance of parasitic modes





	Original	New(SC)	New(NC)	unit
Highest value of Z_T (H)	25.0	5.6	4.4	kΩ/m
Highest value of Z_T (V)	15.0	3.2	10.1	kΩ/m
Highest (Z// x freq./GHz)	2070	1020	760	Ω GHz
Kloss@3mm	0.73	0.56	0.56	V/pC

Crabbing mode property

- SC: 1.5 MV kick can be obtained.
- NC: 0.4 MV kick @P_{wall}=70kW.

	SC	NC	unit
Frequency	508.9	508.9	MHz
R/Q	58	60.8	Ω/m
Q_0 (Copper)	-	36000	
E_{peak}/V_{kick}	11.7		(MV/m)/MV
H_{peak}/V_{kick}	424		Gauss/MV

Crab crossing experiment in KEKB

		Original cavity
KEKB (LER) βcrab=40m V_{kick}=1.47MV	No. of cavities	1
	Growth time (horizontal)	36ms
	Growth time (longitudinal)	96ms
	Total HOM power	23kW
KEKB (HER) βcrab=200m V_{kick}=1.51MV	No. of cavities	1
	Growth time (horizontal)	33ms
	Growth time (longitudinal)	415ms
	Total HOM power	6kW

The crab crossing experiment in KEKB is planned in FY 2005.
The original crab cavity will be used for the experiment.

Crab crossing in Super-KEKB

		Original	New design	
		SC	SC	NC
SuperKEKB (LER) β crab=170m V_{kick}=0.84MV	No. of cavities	1×2	1×2	2×2
	Growth time (horizontal)	0.9ms	8.4ms	4.2ms
	Growth time (longitudinal)	21ms	146ms	73ms
	Total HOM power	214kW	97kW	
SuperKEKB (HER) β crab=350m V_{kick}=1.34MV	No. of cavities	1×2	1×2	3×2
	Growth time (horizontal)	2.7ms	25ms	8.4ms
	Growth time (longitudinal)	107ms	763ms	254ms
	Total HOM power	44kW	20kW	

New crab cavity has advantages for Super-KEKB, especially in LER.
Original crab cavity could also be used in HER, if HOM absorber is OK with 44kW.

Summary

- We have designed a new crab cavity for high-current accelerators.
- Parasitic modes are sufficiently damped.
  - The lower frequency mode is also damped.
  - Instability can be suppressed with the present FB system, even at a beam current of 10A.
- The problem for the dampers due to a large parasitic power is greatly eased:
  - Loss factor of the cell is reduced.
  - The absorbers do not contribute to the loss factor.
  - The parasitic power to each damper is further reduced since it is divided into the waveguide and coaxial dampers.
- The new crab cavity is promising in Super-KEKB.