Experiences on High Current

Y.Suetsugu, KEKB

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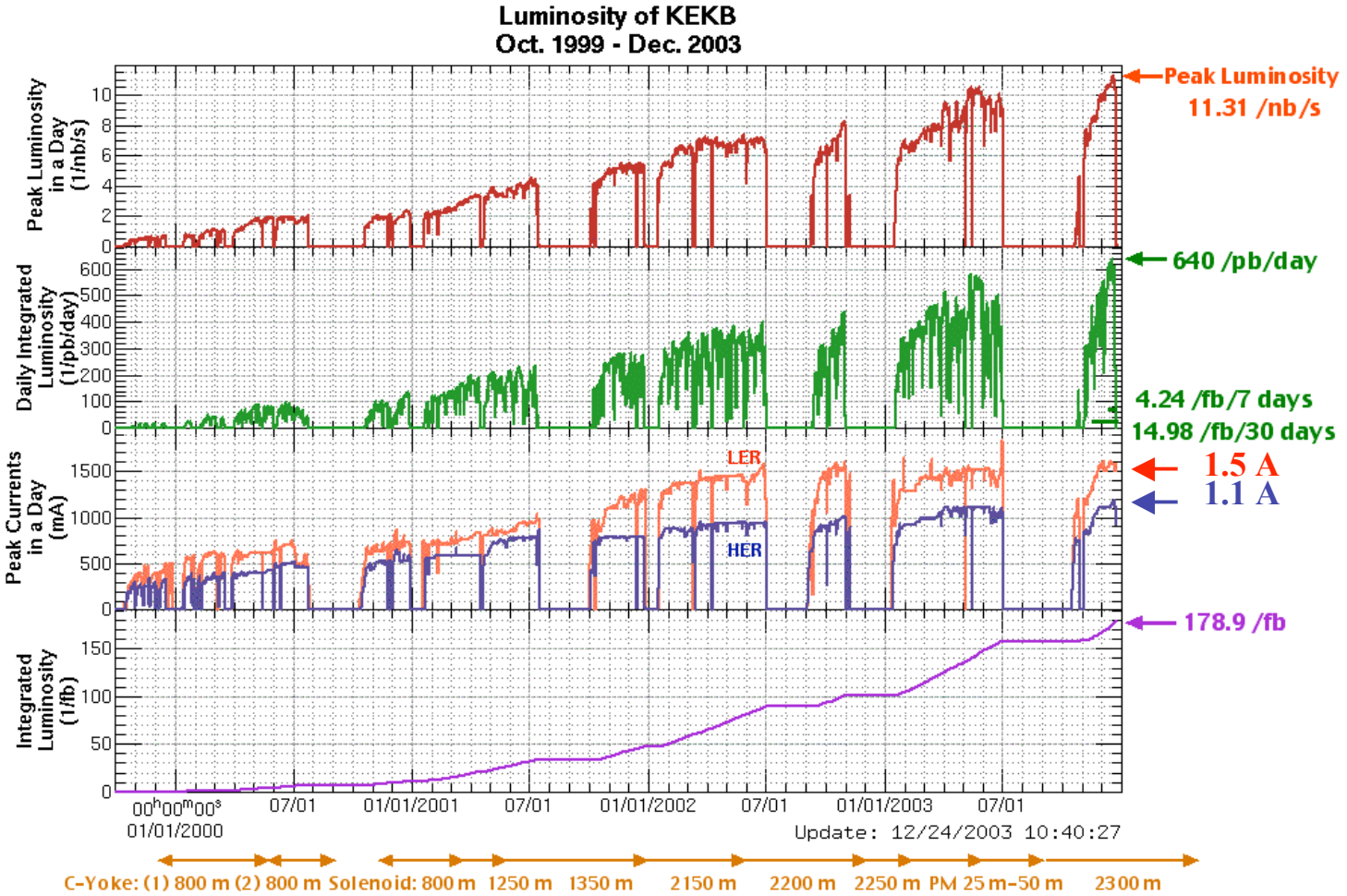
Issues in High Current

- History of KEKB



Issues in High Current

- SR Power $P = 88.4 \times 10^3 E^4 \times I / \rho$ [kW] (total)
  - For E = 3.5 GeV, I = 2.6 A, ρ =14.1m ➡ Max.15 kW m^{-1}
- Photon Number $N = 8.08 \times 10^{20} E \times I$ [photons s^{-1}] (total)
  - For E = 3.5 GeV, I = 2.6 A ➡ 3×10^{18} photons s^{-1} m^{-1}
  - Gas load
    - For η of 1×10^{-6} molecules photon^{-1} ➡ ~1×10^{-8} Pa m^3 s^{-1}
  - Photoelectron emission (LER)
- HOM Power $P = k(\sigma_z) I^2 \tau_b$ [W]
  - For k = 1 V pC^{-1}, I= 2.6 A ➡ P = 14 kW (@τ_b =2 ns)
- Beam Intensity
  - Wall current (~500 A m^{-1} at peak)
  - Multipactoring (especially in positron ring)
  - RF power [Beam Power]
  - Beam instability

Issues in High Current

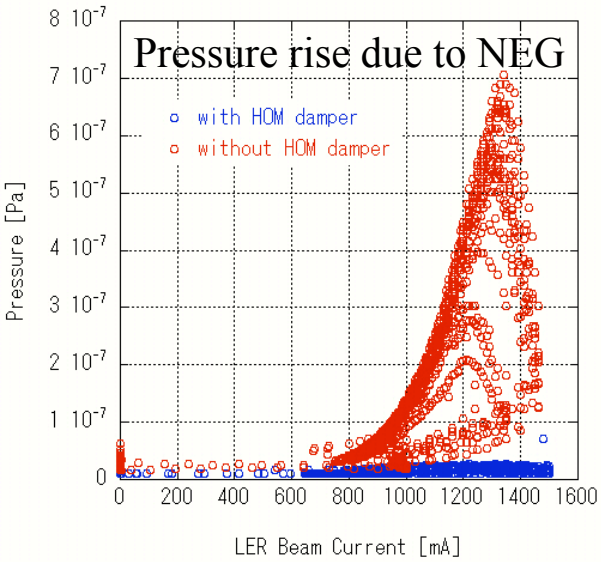
- Beam Currents at Present

	Design		Typical Run	
	LER	HER	LER	HER
Total Current [A]	2.6	1.1	1.5	1.1
Bunch #	~5000		1284	
Bunch Current [mA]	0.52	0.22	1.17	0.86

- Beam currents are same or near to design value
- Bunch number is lower than design value (1/4)
  - ➡ High bunch current
    - ➡ Intense HOM power:
      Major issues for hardware at present

Vacuum-related Problems

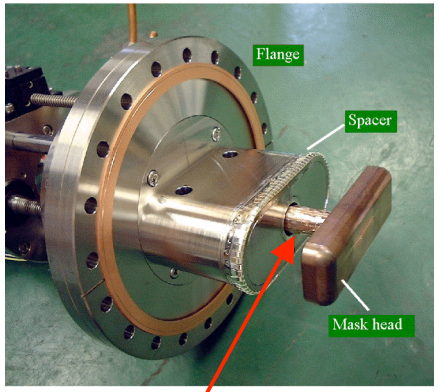
- High HOM Power
  - Heating of bellows and gate valves
    - Bellows near movable masks and IR (big HOM sources)
    - Especially for bellows and GV with a race-track cross section or big size
    - Shows resonance behavior
    - Objects beam injection, Beam oscillation
      - ➡ Cooling fan or exchange
      - ➡ Major problems at present
  - Heating of NEG elements
    - Near Movable masks
    - Abnormal pressure rise
    - Affect background
      - ➡ HOM absorber
      - ➡ RF shield gasket

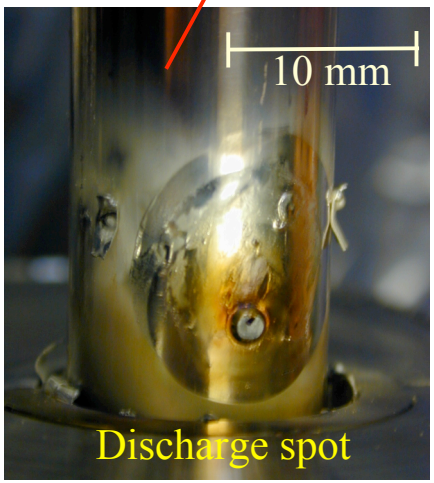


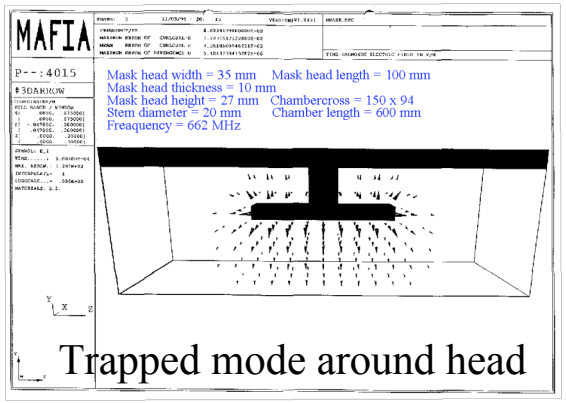
Vacuum-related Problems

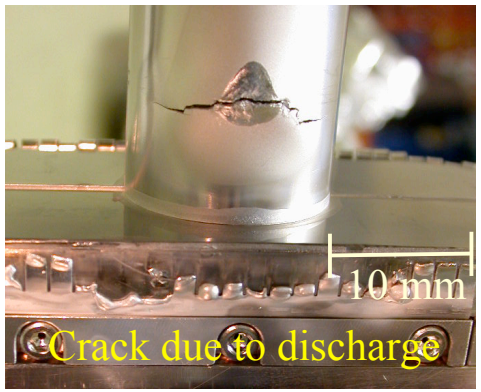
- High HOM Power
  - Discharges in early versions of movable masks
    - Trapped mode
    - No HOM absorber
    - Excess heating & discharge ➡ Vacuum leak
      - ➡ Improvement of structure (version up)
  - Excitation of synchrotron oscillation

Early versions of MM







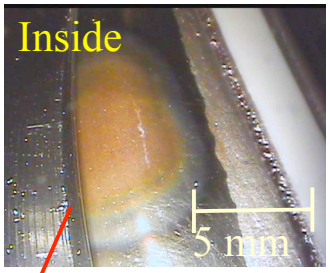


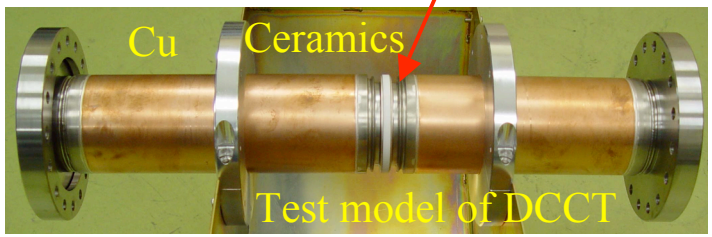
Vacuum-related Problems

High HOM Power

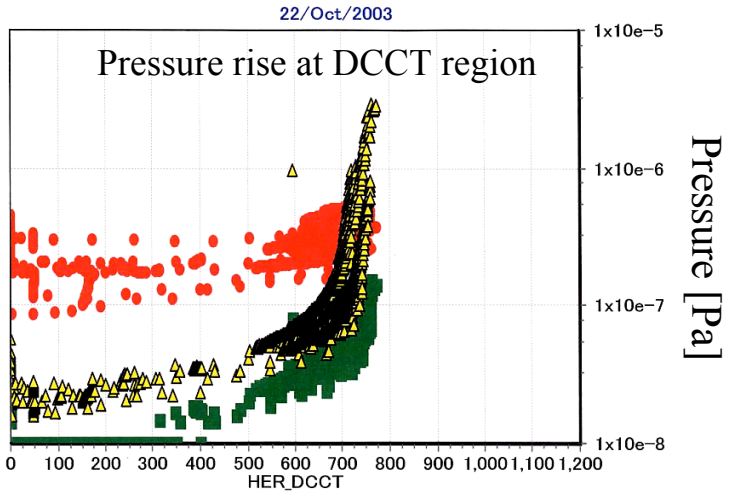
- Discharge in a test-type DCCT for upgrade
  - Test : stain-less steel → copper
  - Discharges at Kover joint blazed on ceramics ring
  - Rapid pressure rise vs. current
    - ➡ Improve structure

[from M.Arinaga]



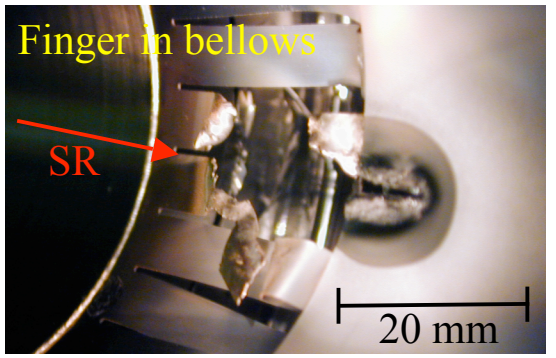


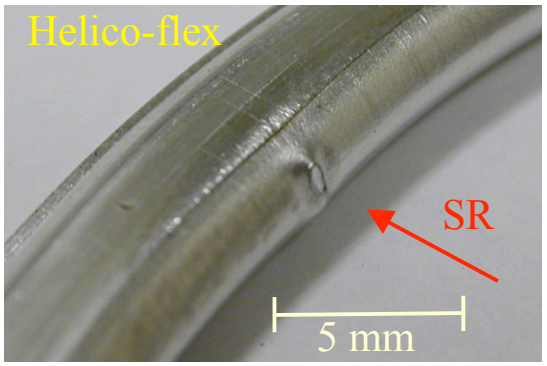
- Rapid pressure rise even for present type
  - Over 1100 mA
  - Similar to test-type
    - ➡ keep watching

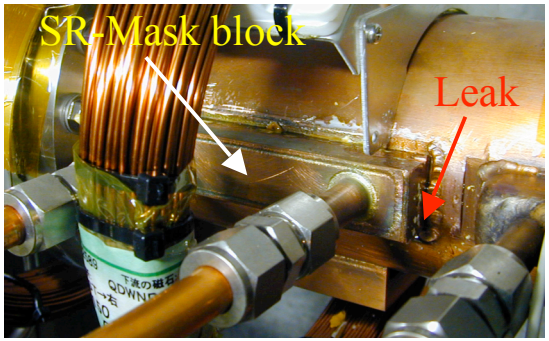


Vacuum-related Problems

- High SR Power
  - Melting of RF shield of bellows
    - SR hit RF-shield finger in bellwos → Leak
      - ➡ Re-alignment of beam chamber
      - ➡ Add SR mask at upstream
  - Melting of Helico-flex
    - SR hit Helico-flex gasket → Leak
      - ➡ Re-alignment of beam chamber
      - ➡ Add SR mask at upstream
  - Vacuum leak at SR Masks
    - Welding point of SR-mask block
    - Due to heat cycle and defect of welding
      - ➡ Exchange of chamber



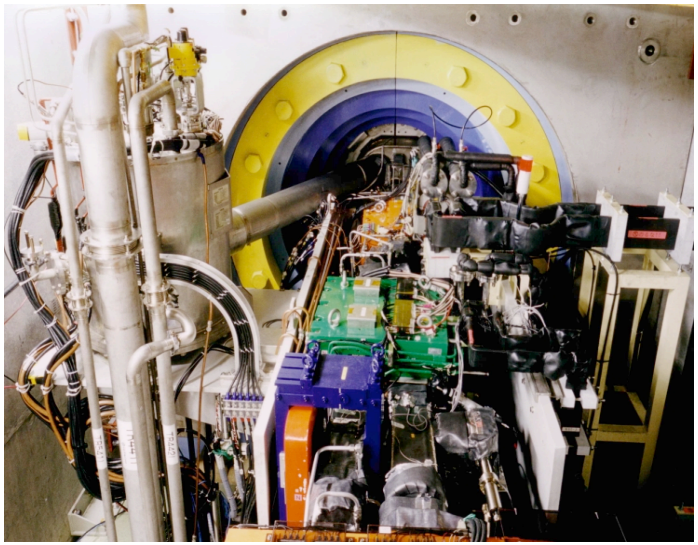




Vacuum-related Problems

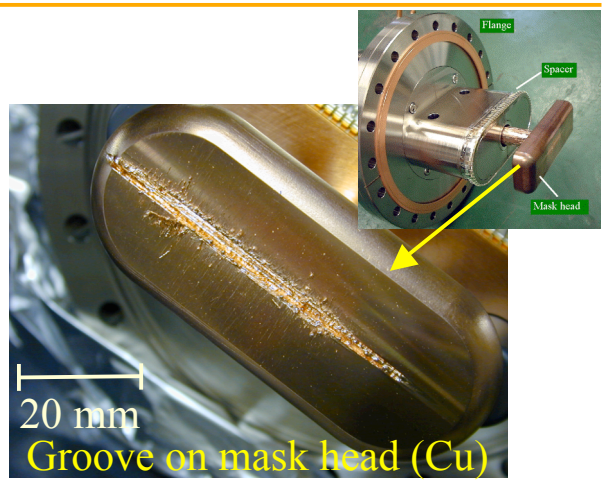
- High HOM and SR Power at IR
  - IR: Complicated configuration
  - Deformation of beam chamber
    - Al chamber at downstream side of IR was heated and squashed by SR
      - ➡ Change structure & material (Cu)
  - Heating of bellows and chambers
    - Due to mainly HOM
      - ➡ Increase cooling capacity
  - Movement of beam chamber
    - Due to heating by HOM or SR
    - Make collision tuning difficult
    - Cause of slow recovery of luminosity after beam abort ?
      - ➡ Feedback movement to BPM signal

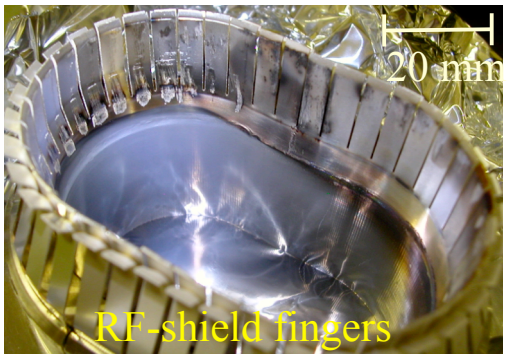
Complex at IR



Vacuum-related Problems

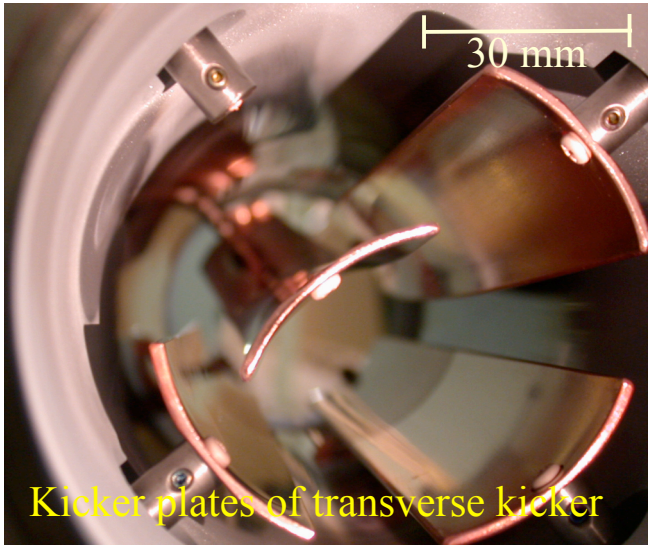
- High Current (Direct damage)
  - Grooves at mask head
    - Damaged by steered beam
      - ➡ Change material copper →Ti
      - ➡ Rapid beam abort system
      - ➡ Not completely solved
  - Vacuum leak at abort window
    - Beams pass just near the wall
    - Leak at transition from Al to Ti (window)
    - Thermal stress?
      - ➡ Change structure
  - Discharge at RF-shield
    - Discharges due to wall current
      - ➡ Change structure & material





Vacuum-related Problems

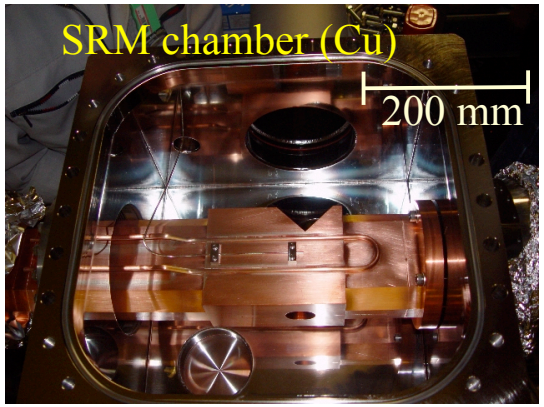
- High Current (Ohmic loss)
  - Several problems on transverse kicker [from M.Tobiyama]
    - Damage at flexible structure of feedthrough (Ver.1)
    - Sagging of kicker plate(Cu), break down of fixing bolt (Ver.2)
    - Sagging and annealing of kicker plate (Ver.3)
    - Due to large ohm loss
      - ➡ Change of material (Cu+SUS)
      - ➡ Improve flexibility of feedthrough
  - Heating of feedthrough itself is low enough up to now



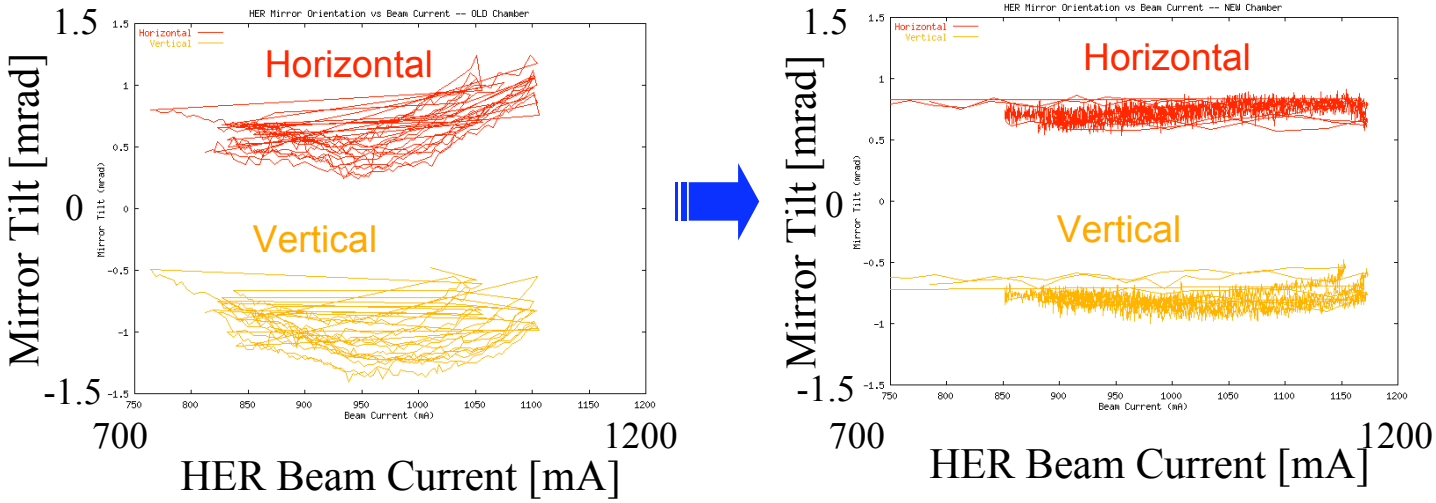
Kicker plates of transverse kicker

Vacuum-related Problems

- High Current (Ohmic loss)
  - Heating of SR monitor chamber [from J.Flanagan]
    - Heating at Stainless-steel chamber
    - Heating by ohmic loss
    - Leads to drift of mirror orientation with beam current
      - ➡ Change to Cu chamber

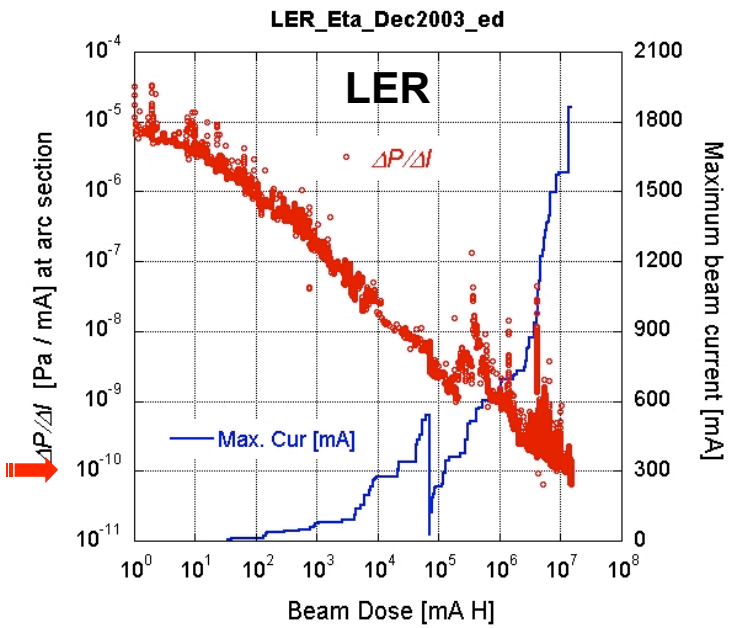


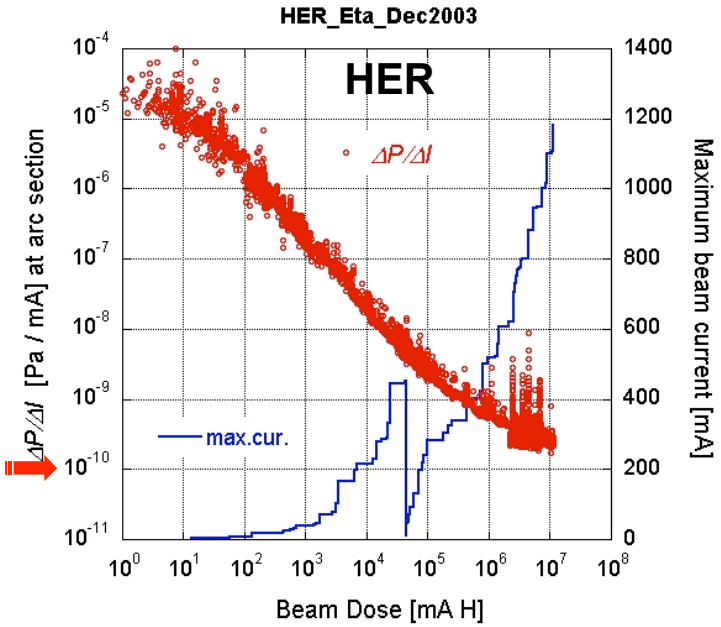
Mirror orientation drift with beam



Vacuum-related Problems

- High Gas Load
  - Design : $\Delta P/\Delta I = \sim 1\times10^{-10}$ Pa mA^{-1} ($\eta = 1\times10^{-6}$)
    - Pumping speed ~ 0.07 m^3 s^{-1} m^{-1} with NEG + Ion pump





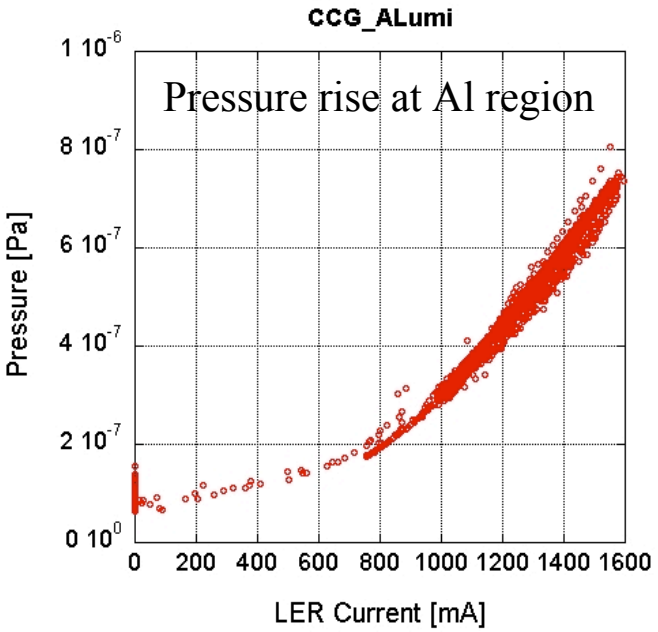
  - Almost achieved, but
    - Scrubbing is slowing down in HER. Why?
    - NEG activation >20 in some regions. Capacity?

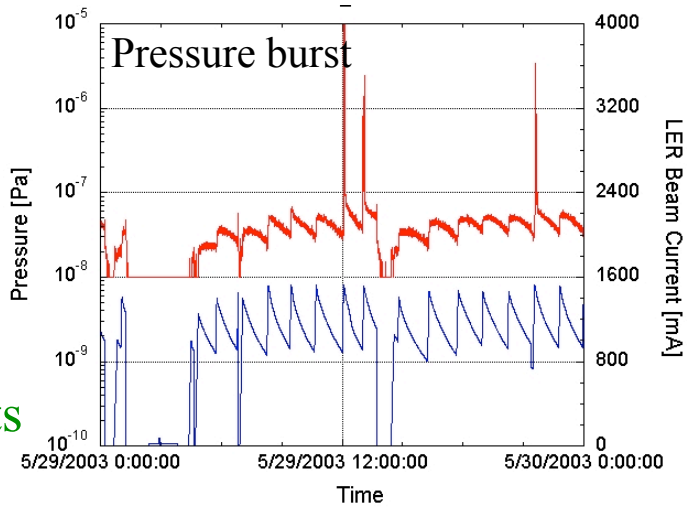
Vacuum-related Problems

Abnormal Pressure Rise

- Pressure rise due to multipactoring
  - Observed in whole LER at initial stage
  - Disappeared by solenoid
  - Especially aluminum chamber region now
  - Injection region? (both rings)
    - ➡ More solenoid

- Pressure burst
  - Observed at new current frontier
  - Sometimes depends on fill pattern
  - Sometimes causes beam oscillation and abort
    - ➡ Wait aging
    - ➡ Exchange of suspicious components

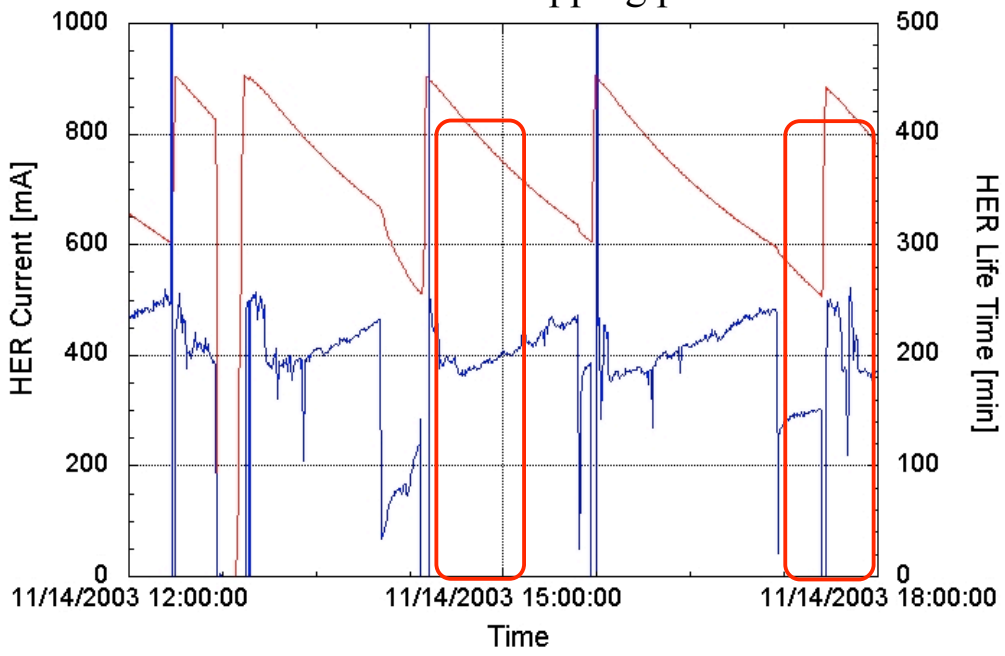




Vacuum-related Problems

- Dust Trapping (electron ring)
  - Abrupt decrease of beam life time
    - Sometimes the life time recover soon but sometimes not
    - Usually recovered by re-fill
    - Seen frequently after long shut down (lots of vacuum work)
      - ➡ Improve environment during work
      - ➡ Wait aging

Dust trapping phenomena



RF-related Problems

- Issues in RF System
  - Necessary RF Power ∝ ~SR and HOM power
  - RF power per cavity is large

	LER	HER	
	ARES	ARES	SCC
Total Current [A]	1.5	1.1	
# of Cavity	20	12	8
RF Voltage/Cavity [MV]	0.4	0.35	1. 4
Beam Power/Cavity [kW]	130	170	300

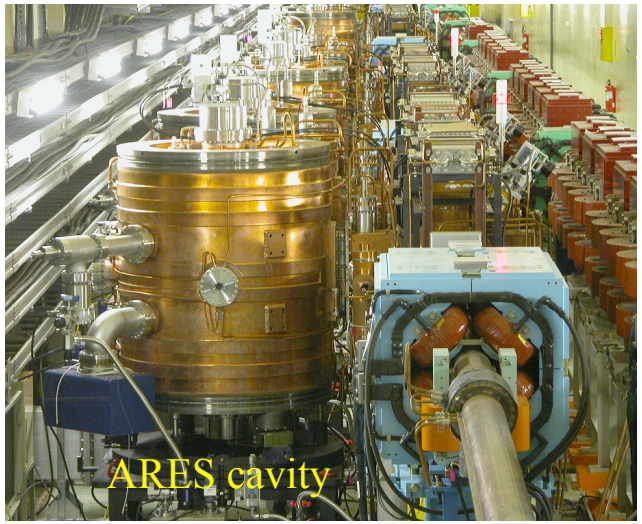
  - HOM due to cavity should be well damped
  - Instability due to acceleration mode should be well damped

RF-related Problems

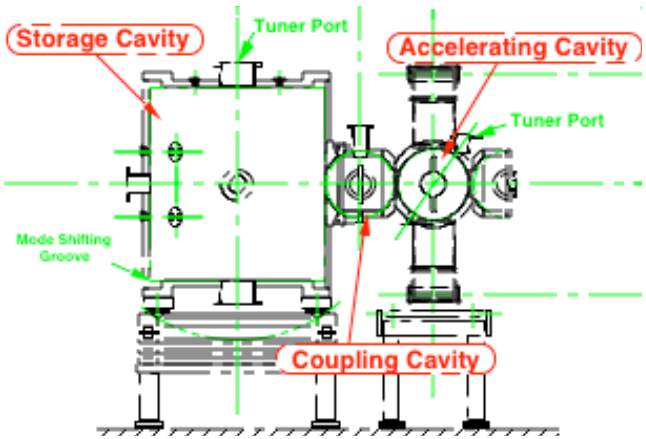
ARES Cavity : LER, HER

[from K.Akai]

- Discharges at input coupler
  - Sometimes lead to vacuum leaks
    - ➡ Arc sensors in vacuum and atmosphere
    - ➡ Rapid beam abort system
    - ➡ Regular maintenance



- Burn out of RF damper at coupling cavity
  - Due to leak of cooling water or bad RF contact at dummy load
    - ➡ Improve temperature monitoring system
    - ➡ Improve RF contact



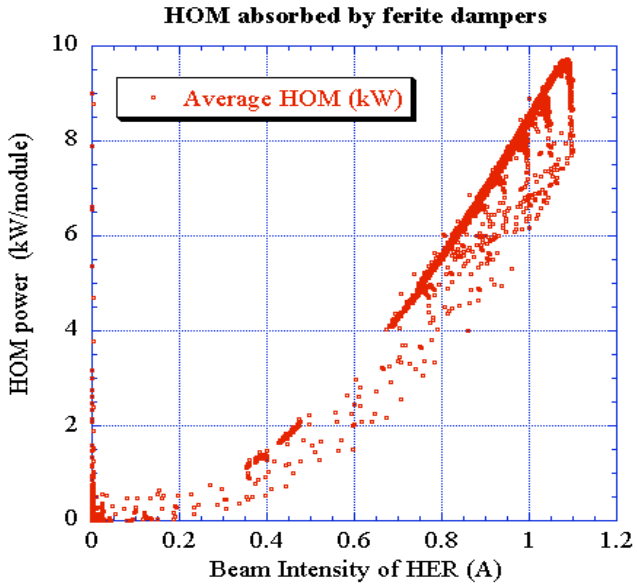
- No severe troubles these 2 years

RF-related Problems

Super Conducting Cavity : HER

[from K.Akai, T.Furuya]

- No severe troubles so far
- Heating of HOM absorber
  - Due to higher bunch current than design value
  - Design: 5 kW ➡ now:10 kW
  - No problem up to now
    ➡ keep watching
- Coupler
  - Design: 250 kW/cav.
    ➡ now:300 kW/cav.
  - No problem up to now



RF-related Problems

Instabilities Caused by Cavities

[from K.Akai]

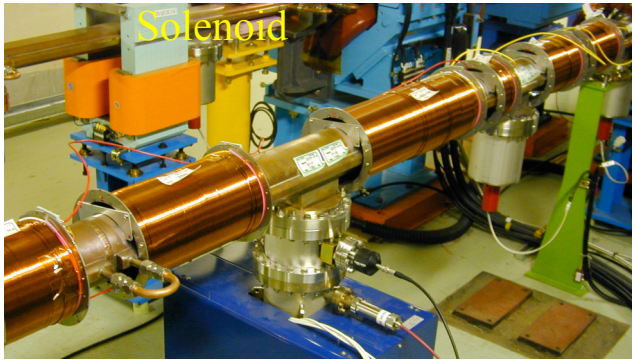
- -1 mode coupled bunch instability
  - Due to low operating RF voltage
  - Expected at ~ 2A, but observed at ~1A
    - ➡ Prepare –1 mode damper
- 0 mode oscillation and instability
  - Due to noise?
    - ➡ Prepare 0 mode damper
    - ➡ Tuning of RF feed back system
    - ➡ Increase RF voltage
- Coupled bunch instability due to HOM of cavities
  - Not observed yet

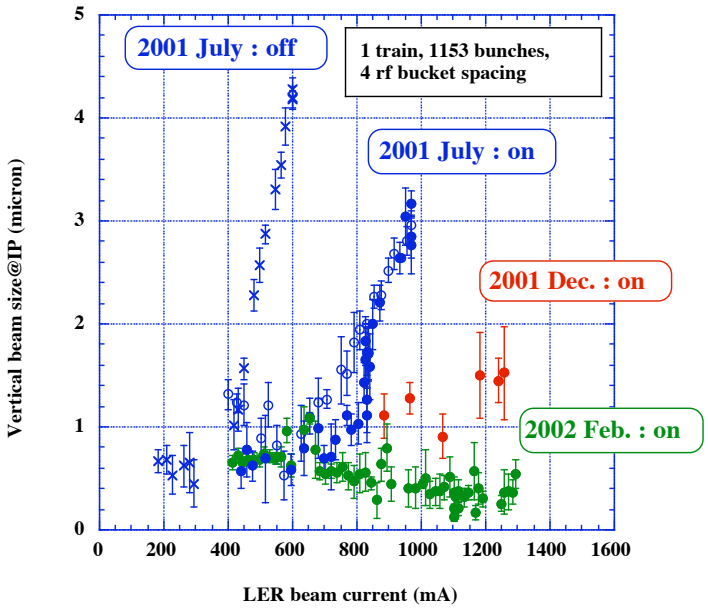
Beam Instability

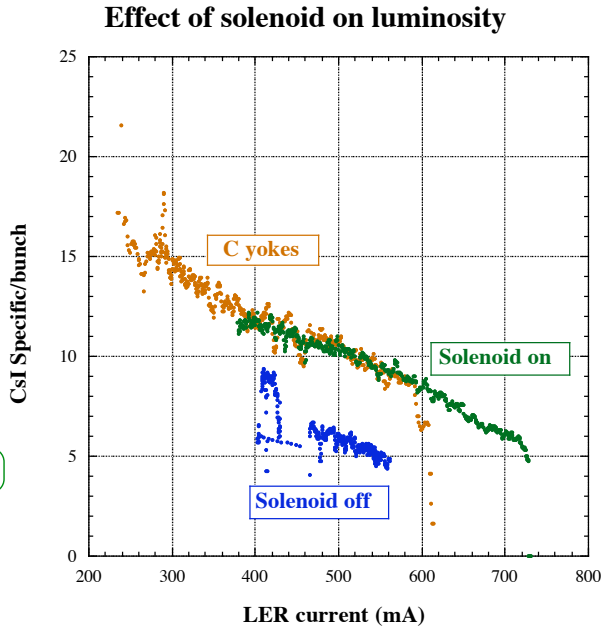
Electron Cloud Effect in LER

[from H.Fukuma]

- Blow up of vertical beam size
  - Explained by head-tail instability caused by electron cloud
  - Mitigated by solenoid winding, but not perfect yet
    - ➡ Continue solenoid winding further





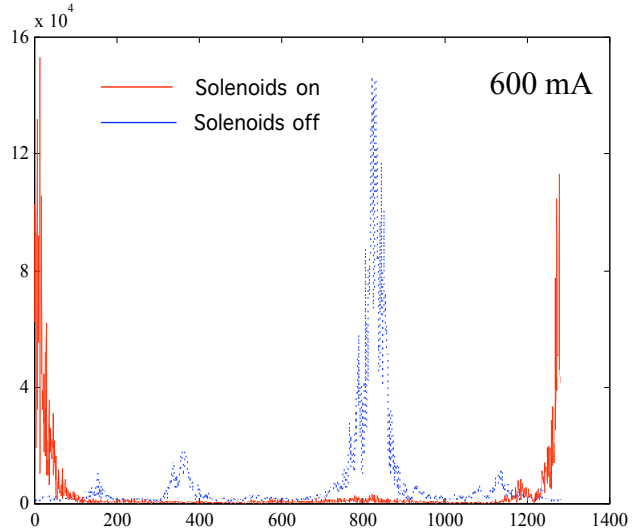


Beam Instability

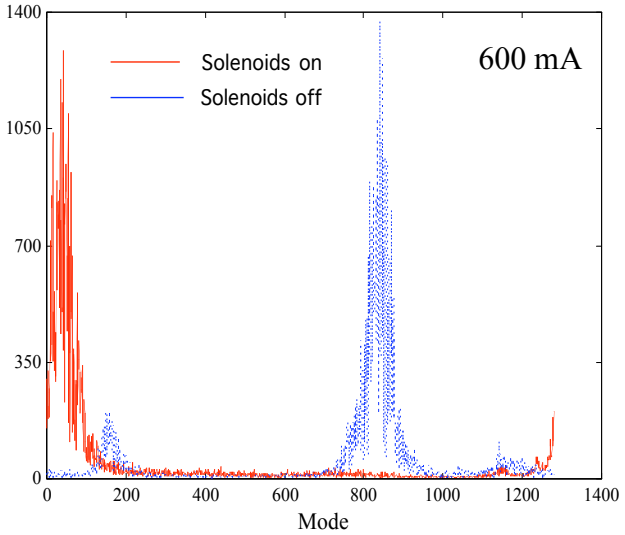
Coupled Bunch Instability (CBI) in LER

[from H.Fukuma]

- CBI has been observed in LER
  - Mode spectrum and growth rate depend on solenoid
  - Horizontal/Vertical growth rate is 0.5/0.3 ms^{-1} at 600 mA with solenoid
  - CBI is suppressed by a bunch by bunch feedback at present



Horizontal



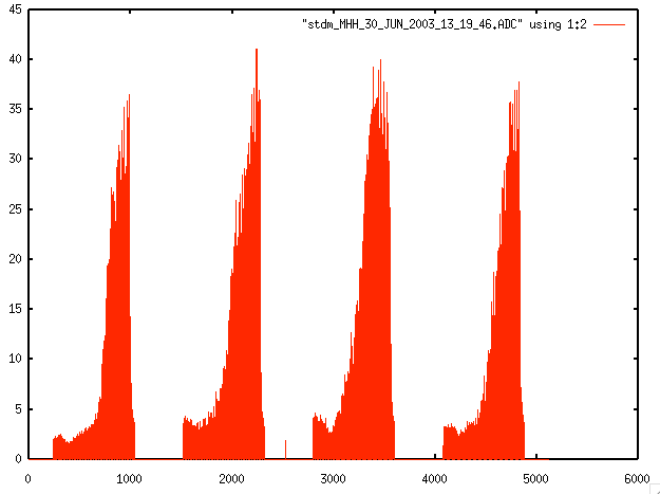
Vertical

Beam Instability

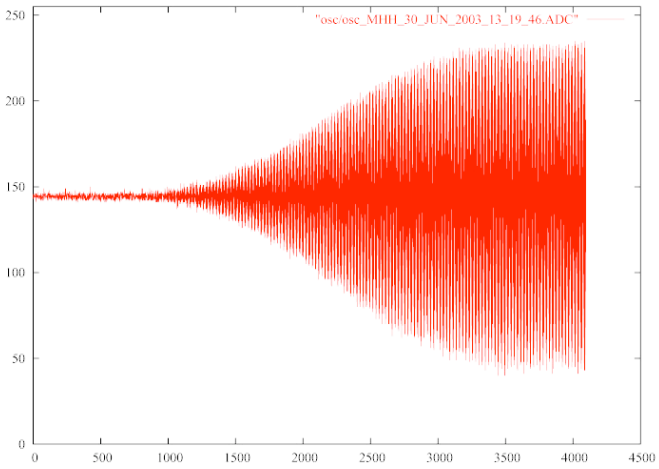
Coupled Bunch Instability in HER

[from H.Fukuma]

- CBI has been observed in HER
- Simulation suggests that the horizontal oscillation is caused by CO^{+} ion
- Amplitude grows along train and saturate
- Peak is about 10^{th} revolution harmonics in mode spectrum
- Growth rate is about 10 ms^{-1} at 700 mA
- Suppressed by a bunch by bunch feedback



Oscillation amplitude along a train
(four trains in HER)



Time evolution of oscillation

Summary

- We have experienced various problems in high currents operation at KEKB and learned lots of things.
- Some problems could be avoided by more delicate consideration in design of components and more careful installation of them.
- But others were revealed for the first time under high current and are indications of problems that will appear in higher current operation.
- The important thing is to study and understand the problems accurately, which makes them valuable lessons for us toward future high intensity machines.
- Struggling against high currents will continue for higher luminosity.