

# High Current

(Feb.25 11:55-12:15 K.Akai)

# *High Current Issues of KEKB*

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**K. Akai (KEK)  
Machine Advisory Committee  
Feb. 25, 2002**

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  - IR vacuum components
- **Other hardware components**
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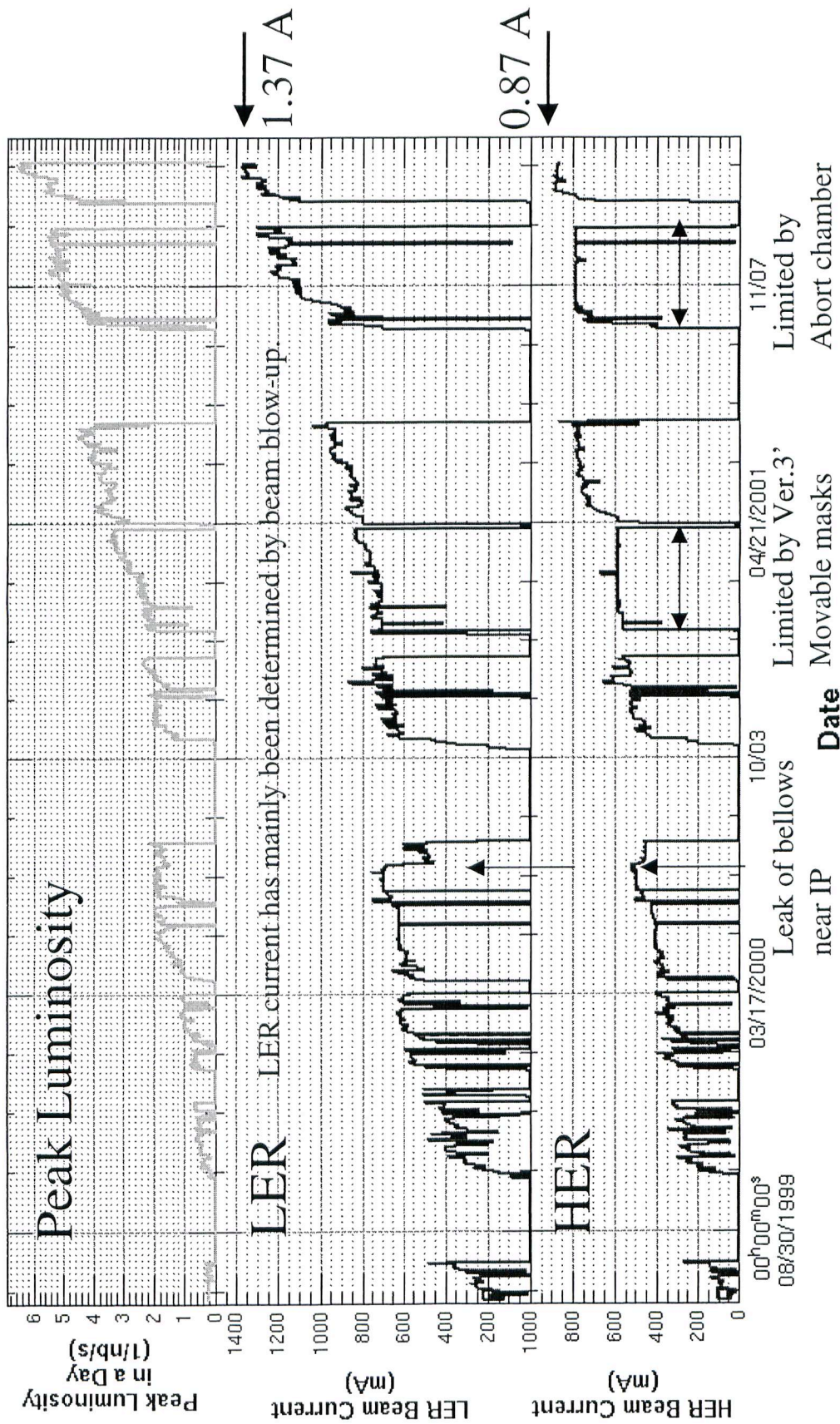
# *Beam current 2000 ~ 2002*

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- **LER**
  - Most of the time beam current has been set to optimize luminosity, rather than hardware problems. As the beam blow-up is reduced by solenoid windings, the current has been increased.
- **HER**
  - Sometimes beam current was limited by hardware problems. However, the current has been increased by improving the hardware.

# Luminosity and Beam Current of KEKB July 1999 – Feb. 2002



# *RF power to beam*

- Number of cavities and RF stations
- Beam current

|                         | LER     | HER    |       |
|-------------------------|---------|--------|-------|
|                         | ARES    | ARES   | SCC   |
| Dec. 1998~              | 12 (6)  | 6 (3)  | 4 (4) |
| Oct. 1999~              | 16 (8)  | 10 (5) | 4 (4) |
| Oct. 2000~              | 16 (8)  | 10 (5) | 8 (8) |
| Sep. 2002~<br>(=Design) | 20 (10) | 12 (6) | 8 (8) |

( ): number of RF stations

|                                      | LER<br>(mA) | HER<br>(mA) |
|--------------------------------------|-------------|-------------|
| Max. current stored so far           | 1370        | 870         |
| Present RF can support               | 2000        | 1000        |
| with 6 more ARES's added (Sep. 2002) | 2600        | 1100        |

# *Achieved RF parameters*

| Ring   | LER         |            | HER        |     |
|--|-------------|------------|------------|-----|
|  | ARES        | ARES       | ARES       | SCC |
| Beam current (mA)                                | 1370 (2600) | 870 (1100) |            |     |
| Operating RF Voltage (MV)                        | 6.5 (5~10)  | 12 (8~16)  |            |     |
| No. of cavities                                  | 16 (20)     | 10 (12)    | 8 (8)      |     |
| Operating Voltage / cav. (MV)                    | 0.41 (0.5)  | 0.29 (0.5) | 1.14 (1.5) |     |
| Conditioned up to (MV)                           | 0.5 (0.5)   | 0.45 (0.5) | >2.0 (1.5) |     |
| Total beam power (MW)                            | 2.5 (4.5)   | 3.1 (4.0)  |            |     |
| Beam power / cav. (kW)                           | ~150 (225)  | ~130 (170) | 380 (250)  |     |
| Beam power / cav. (kW)<br>(by shifting RF phase) | ~230 (225)  | ~200 (170) |            |     |
| HOM power / cav. (kW)                            | ~3          |            | ~8 (5)     |     |

Numbers in ( ) are design values.

# *Cavity performance*

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- RF voltage
  - Relatively low operating RF voltage has been chosen because:
    - Lower synchrotron tune is preferred.
    - To reduce HOM heating of vacuum components.
  - ARES has been conditioned up to the design value and SCC more than 2 MV/cavity. Thus they have enough margin.
- Beam power
  - Beam power delivered by ARES and SCC has achieved or exceed the design value.
- HOM damping
  - HOM dampers have been working well.
  - No sign of coupled-bunch instabilities caused by HOM's of the cavities has been observed.



# *Major troubles of cavities '00~'02*

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- The RF system has been operating with good stability and reliability.
- Major troubles of cavities occurred in two years are:
  - Input couplers
    - Discharge (SC D10-D) → detuned Oct.'00~Jul.'01.
    - Leak due to arching (Nov.'00 ARES D5-C#2) → replaced.
      - Arc sensor did not work since the window was accidentally blocked.
    - Leak due to arching (Oct.'01 ARES D7-B#1) → replaced.
      - Arc sensor worked. But beam-induced power caused damage.
      - After this trouble, beam abort is triggered by any arc signal.
  - Helium leak at indium seal of SCC
    - D10-A → lined off Jan.'01 and reinstalled Aug.'01.
    - D11-C → lined off Oct.'01 and reinstalled Jan.'02.

## *Major troubles of cavities (cont'd)*

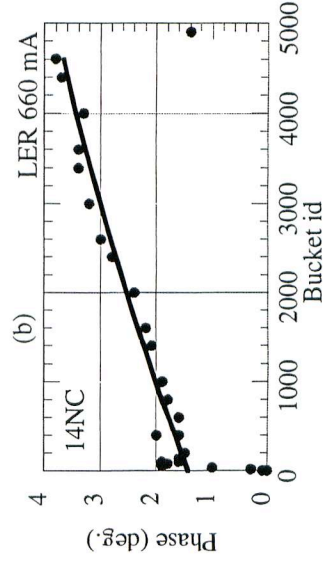
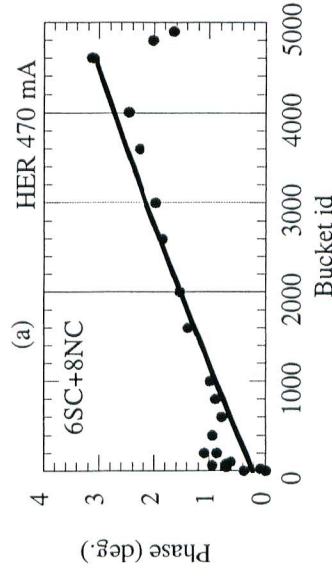
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- Other troubles
  - Gas burst (ARES D7-C#2) → detuned Nov.'00~Jul.'01.
    - » Plastic nozzle of air spray was found in the cavity.
  - Leak of cooling water on air side (ARES D5-C#2) → detuned Nov.'00~Jul.'01.
  
- While the trouble cavities are lined-off or detuned, necessary voltage and beam current was supported by other cavities.

# *Bunch-gap transient*

- Beam phase modulation due to abort gap is small, owing to large stored energy of cavities.
- Recently, gap length was reduced from 10% to 5%.
- No compensation is required.
- Measured and calculated phase modulation for 10% gap (T. Ieiri et al.)



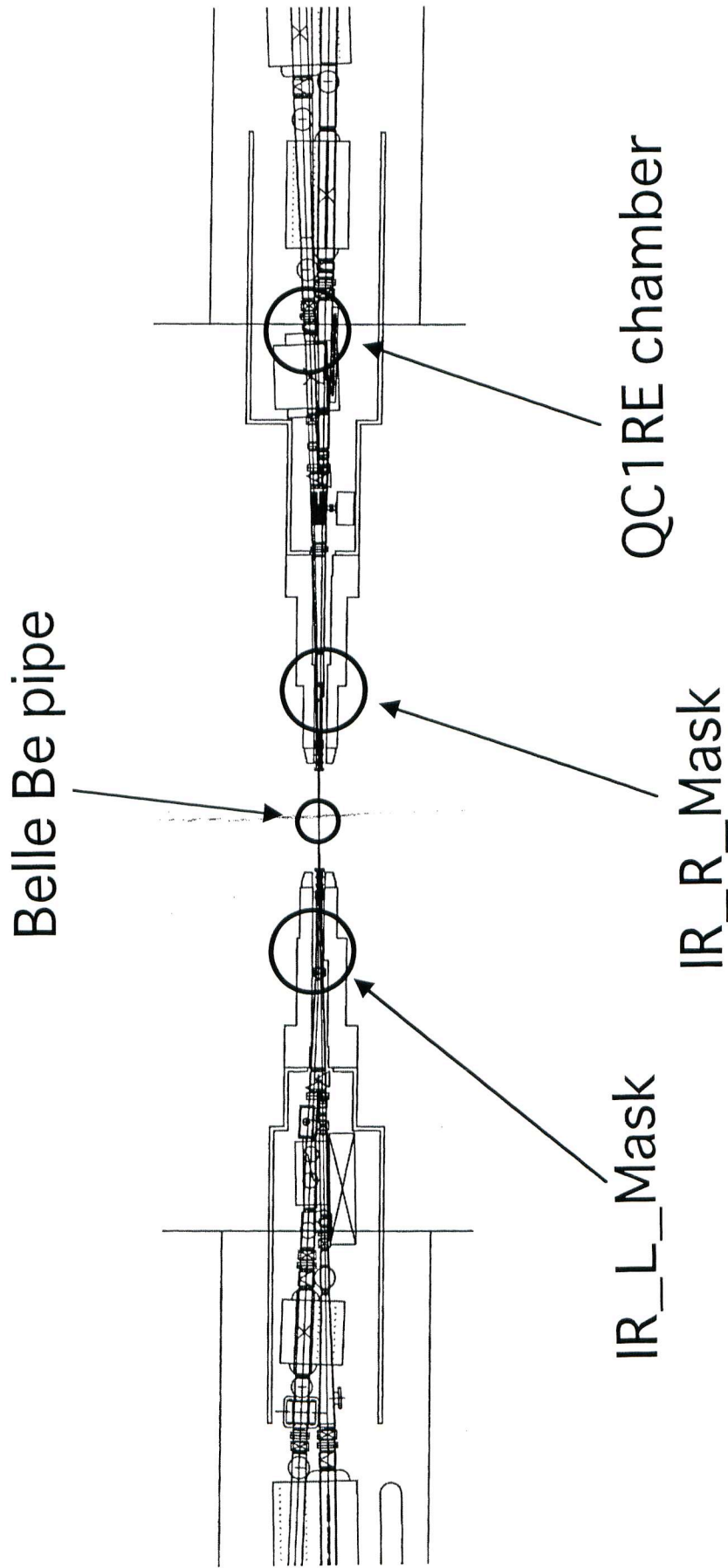
# *Heating of vacuum components*

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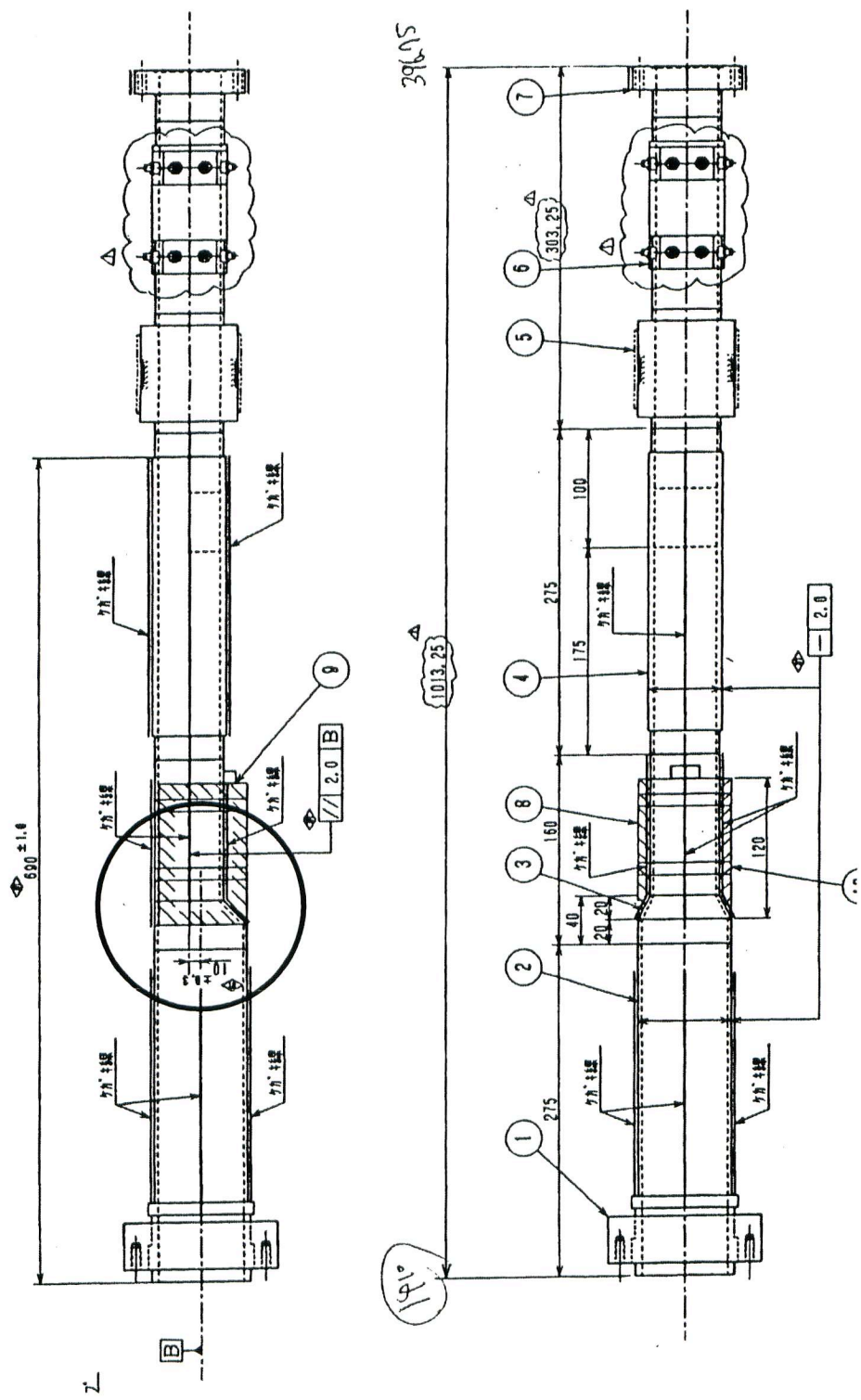
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- **IR vacuum components**
  - **Bellows near IP (HOM)**
    - Water cooling was reinforced in summer '00. It is moderate now.
  - **Beryllium beam pipe of Belle detector (HOM)**
    - Abnormal heating due to resonant build-up with 5 bucket spacing pattern. Since then this kind of pattern has been forbidden.
    - Broadband HOM seems OK up to the design current.
  - **Chambers downstream of HER (SR)**
    - Water cooling was reinforced.
    - Reduced by orbit change (QC1RE) and/or realignment of the chamber (QC2RE). It is moderate now.
  - **Masks for SR at QCS chamber (SR+HOM)**
    - No cooling now.  $\sim 110^{\circ}\text{C}$ . Water cooling is planned this summer.

*Temperature rise around IR vacuum chambers*



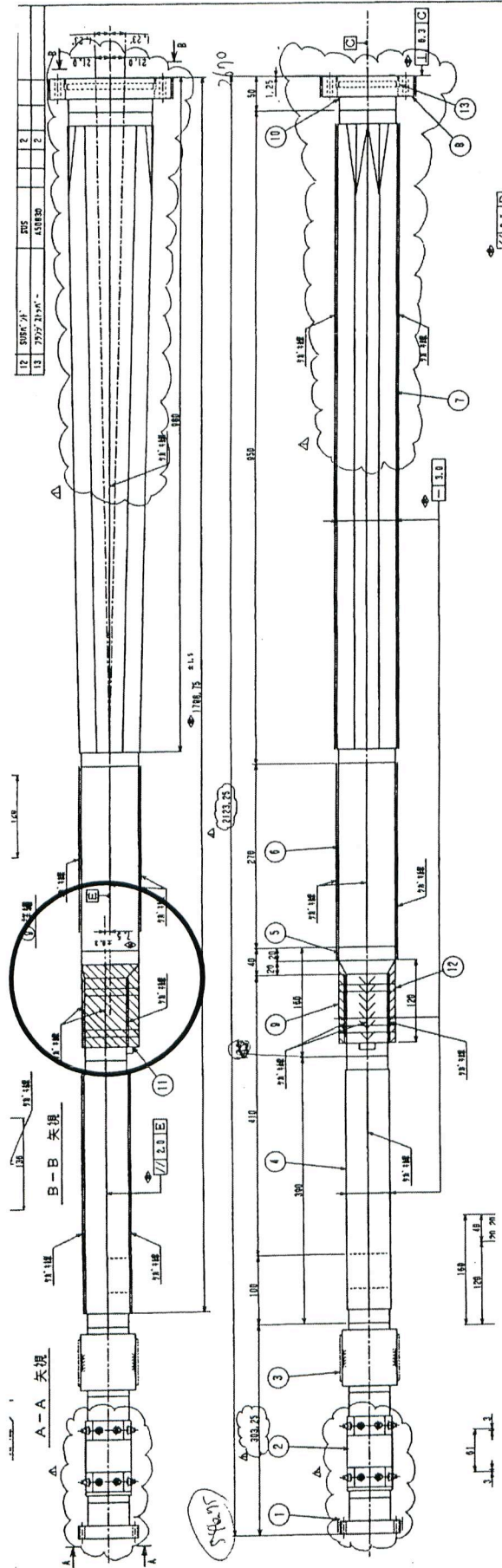
# QCS\_L Chamber



Feb. 25, 2002

High Current by K. Akai

# QCS\_R Chamber

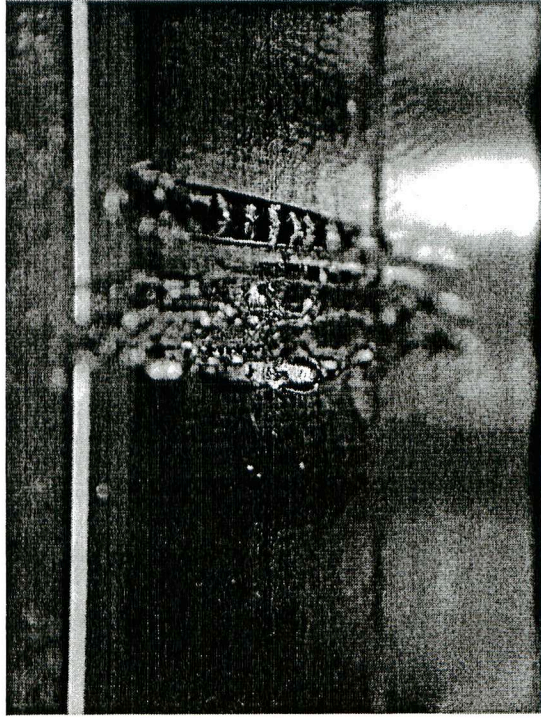


# *Movable masks damaged by beam abort*

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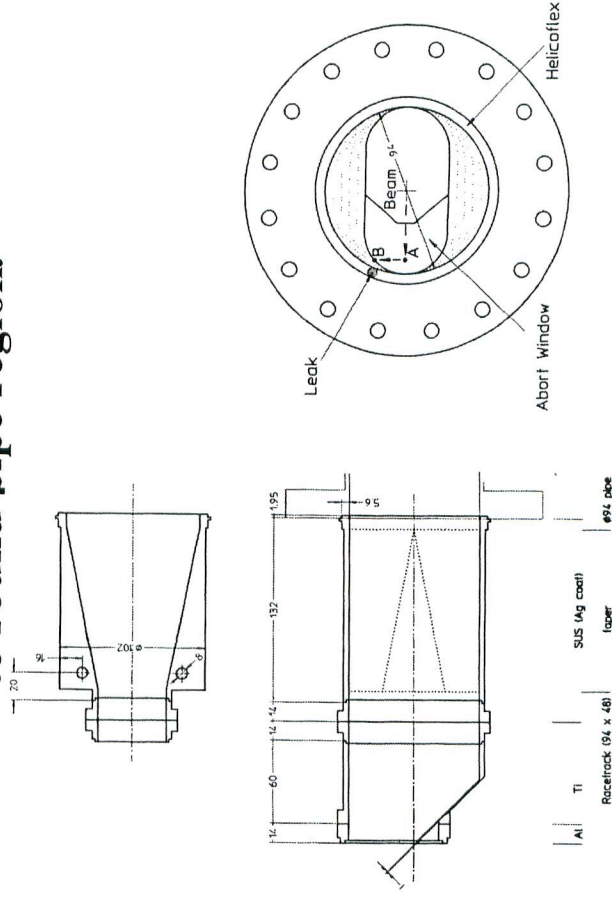
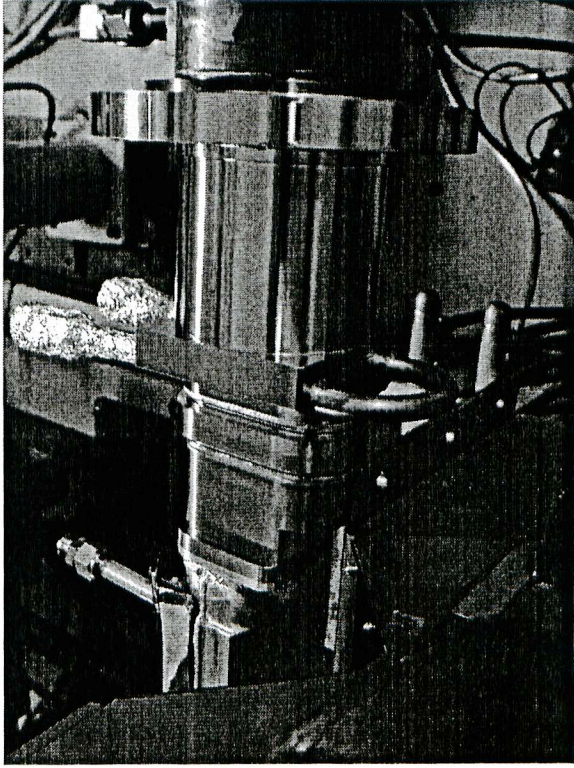
- Mask heads were damaged by beam aborts.
- Suspected cause:
  - RF trip → beam energy shift → abnormal orbit when abort kicker fires.
- Cures:
  - Abort as fast as possible
    - BPA (Beam Phase Abort) + Loss monitor abort.
    - After the threshold of BPA was set to 1 degree (Dec.'01), no damage has been observed.
    - Additional protection is being installed.
  - Various material tested for mask head.
    - Ti seems promising.





# Troubles of abort chambers

- Leaked at flange connection.
  - Replaced with new one with no flange or bellows attached.
  - However, the new one also leaked at SUS-Ti transition.
- Suspected cause:
    - aborted beam runs too close.
  - Cures:
    - The transition will be moved to round pipe region.



# *Other hardware components*

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- Feedback kickers
  - Feedthrough connectors were damaged (Jun. 2001).
    - Connection to rod electrode was improved.
- Ceramic chambers of kickers
  - Temperature is about 50 ~ 60°C.
    - Water cooling + air blowers helps.
- Heating due to HOM at movable masks
  - Bellows at masks are about 50~70°C.
    - Avoid resonance by changing length of bellows.
  - Pressure rise due to heating of NEG pumps.
    - RF shield will be inserted at flanges for NEG pumps.
- SR monitors
  - Temperature and pressure rise.

# *Beam abort \_ Problems and cures*

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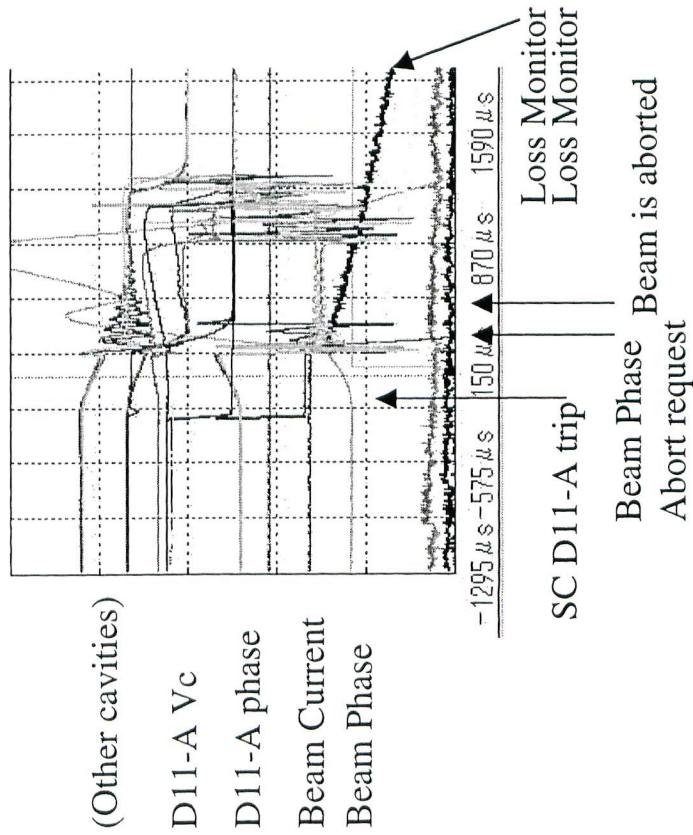
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- **Damage on hardware caused by aborts and/or RF trips**
  - A large amount of radiation hit Belle (5 kRad worst case!).
  - Mask heads were damaged. (HER injection and beam life deteriorated.)
    - Cause suspected: RF trip → beam energy shift → abnormal orbit when abort kicker fires or even the bunch slips out of RF bucket.
- **Measures taken (abort faster and more reliably)**
  - Beam Phase Abort (When beam phase is shifted, abort is requested.)
  - Loss Monitor Abort (Fast loss monitors using PIN diodes)
- **Results of the improvements**
  - Very few radiation hit Belle of more than 100 Rad recently.
  - No damage of masks observed since Dec. 2001 (1 degree set BPA).

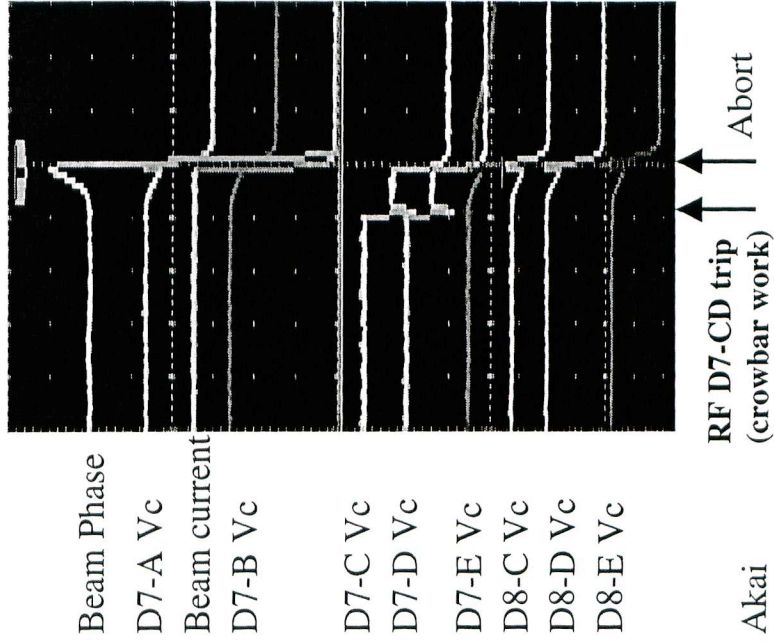
# Beam abort \_ Analysis

Every beam abort is monitored and analyzed to find the cause so that measures can be taken quickly. (Akai, Furuya, Ikeda, Stanic)

- HER abort monitor



- LER abort monitor



# *Beam abort \_ Statistics*

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- From Feb. to Jun. 2001
  - HER and LER
  - Manual abortions are included.
  - Beam loss without abort is included.
- From Nov. 2001 to Jan. 2002
  - HER only
  - Manual abortions are included.

|                         | caused by RF | all abortions |
|-------------------------|--------------|---------------|
| Feb. 2001               | 26           | 86            |
| Mar.                    | 32           | 98            |
| Apr.                    | 21           | 104           |
| May                     | 30           | 84            |
| Jun. (until 25)         | 21           | 98            |
| <b>Total (140 days)</b> | <b>130</b>   | <b>470</b>    |

|                        | caused by RF | all abortions |
|------------------------|--------------|---------------|
| Nov. 2001              | 38           | 154           |
| Dec. 2001              | 23           | 126           |
| Jan. 2002              | 15           | 80            |
| <b>Total (70 days)</b> | <b>76</b>    | <b>360</b>    |

# *Instabilities*

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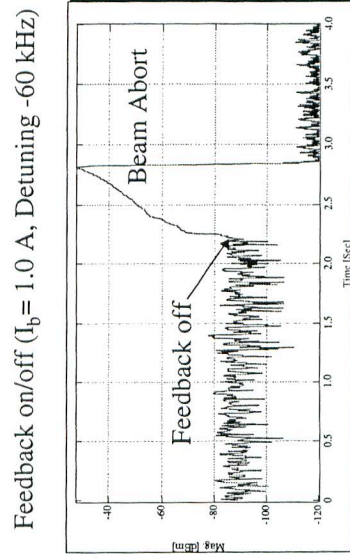
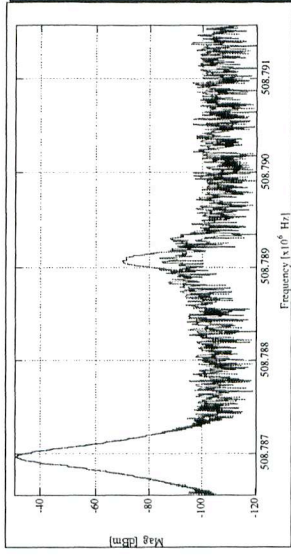
- Longitudinal instability
  - -1 mode due to large detuning of cavities
    - Even with ARES or SCC, growth rate is marginal at high current.
    - -1 mode feedback is successfully operating to suppress it.
  - 0 mode stabilization
    - Oscillation due to random noise was reduced by zero-mode damper (from  $\pm 1$  degree to  $\pm 0.1 \sim 0.3$  degree).
    - Higher RF voltage is preferred for higher beam current.
      - Once instability was excited at 1A in LER. Cured by increasing RF voltage to 6.5 MV and tuning RF feedback.
  - No sign of instability due to HOM's
    - So far longitudinal bunch-by-bunch feedback is not needed.
      - Once instability was excited by old type of movable masks (Jan'00). Cured by replacing them with new type with absorbers.

# RF feedback for the -1 mode

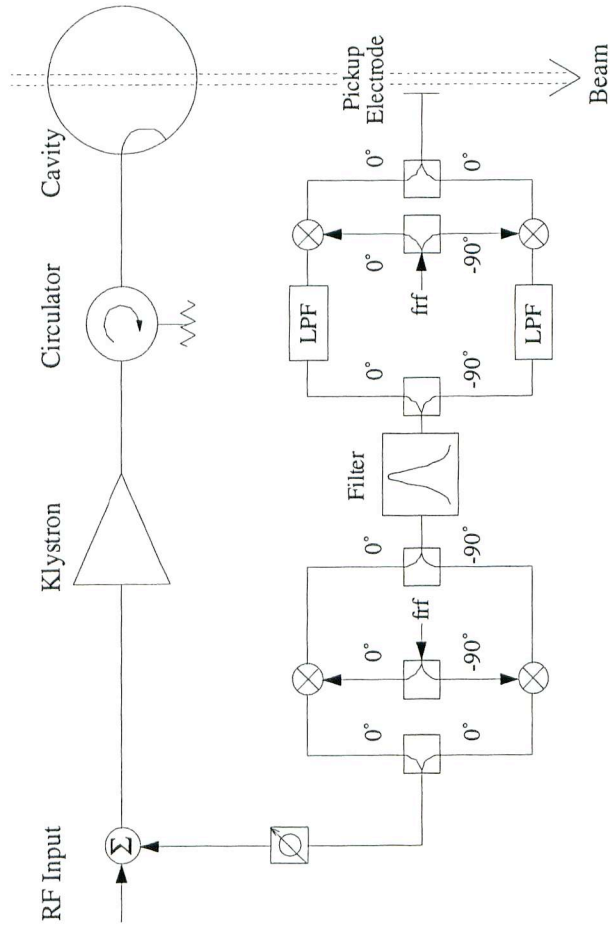
- Successfully operating in KEKB.

(S. Yoshimoto)

Feedback on/off ( $I_b = 890$  mA, Detuning -60 kHz)  
 BW = 1 kHz, Gain = 15 dB



Block diagram of the -1 Mode Damping System



# *Instabilities (cont'd)*

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- **Transverse instability**
  - So far well cured by bunch-by-bunch feedback.
- **LER beam blow-up due to photo-electron instability**
  - Talk by Fukuma-san.



# *Possible current limit near future*

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- Heating of SR masks at IR → LER ~ 1.6A, HER ~ 1.1A
  - Water cooling is planned this summer.
- SR monitor → LER ~ 1.5A?
  - Vacuum pressure rise with beam  $>10^{-5}$  Pa.
  - Temperature rise at extraction window  $> 250^{\circ}\text{C}$ .
  - A new type with HOM absorbers is being developed.
- HOM absorbers of SCC → HER ~ 1.0A?
  - Already beyond the design power. No troubles so far.
  - Keep watching and increase HER current carefully.
- e+ beam blow-up at higher current? (LER)

# *Summary*

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- As the e+ beam blow-up is reduced by more and more solenoid windings, LER beam current has been increased up to 1.37 A.
- By solving hardware problems that limited the current, HER beam current has been increased and reached 0.87 A.
- Until this summer beam current will be limited up to around 1.5 A (LER) and 1.0 A (HER) due to some hardware issues.
- To increase beam current more, cures for present or potential limitations will be made in the summer shutdown.
- Efforts have been made successfully to reduce beam aborts and damage on hardware components caused by aborts.