Commissioning of crab cavity system

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Factories08@BINP 2008/4/15
Crab crossing

• The highest luminosity in the world was achieved at KEKB even using finite angle collision scheme. (17.1/nb/s)

• To avoid the instability at high beam current operation, the crab crossing scheme was proposed.

• Dr. Ohmi showed the luminosity will be doubled by crab crossing scheme by the computer simulation.
Crabbing

- Time varying magnetic field is applied to bunches.
- The phase and voltage should be controlled.
How many crab cavities are required?

- Original scheme (4 cavities)
  - Head of bunches
  - Tail of bunches
  - 2 cavities for each rings

To adopt this scheme is very effective to reduce the cost.

1. The number of cavities can be reduce.
2. The installation site can be chosen freely. They was installed near by He refrigerator.
Install to KEKB

Crab cavities were installed near by superconducting acceleration cavities.
Baseline design of crab cavity

Basically Dr. Akai’s design was kept. Just liquid He supply port was moved.

Squashed Crab cavity for B-factories

Superconducting acceleration cavities use lowest mode in KEKB. But crabbing mode is not lowest mode. Cut off frequency of large beam pipe is about 750 MHz. To dump the parasitic modes below 750 MHz, coaxial coupler is needed. Dipole mode cut off frequency of small beam pipe (coaxial coupler) is about 610 MHz.

Why coaxial coupler is needed?

These modes should be dumped by coaxial coupler.
Schematic Drawing of Cryostat

Mechanical joints
Assembling the coaxial coupler

• Assembling the coaxial coupler was very difficult. We spent about 2 months to connect the mechanical joints.

• To connect them, an accurate installation tool should be made.
Set Up for Connection of Coaxial Structure

- Inner Conductor Nb 25.5 kg
- Inner Conductor 8.8 kg
- Notch Filter (~100kg)
- Vacuum Pumping Port 20.4 kg
- Inner Conductor 38 kg
- HOM Damper 55 kg

Could not connect!

- The Coaxial Structure is Heavy.
- Need Precise Alignment
- Position of Axis
- Direction Axis
- Insertion Tool
- Not Strong Support Structure
- No Precise Adjustment Knob
- Need Modification
Bunches has tilted

- The crab motion was observed directly using a streak camera.
Specific Luminosity

Crab crossing
• 49 sp. $\beta x^*=80, 84$ cm
• 49 sp. $\beta x^*=80$ cm, 24/24 nm
• 49 sp. $\beta x^*=150$ cm

3.06 bucket spacing
$\beta x^*=90$ cm (2007 Nov)

$\beta x^*=90$ cm (2008 Mar)

$\beta x^*=150$ cm

22 mrad crossing
HER

\[ y = 508.67 + 0.02205x \quad R = 0.99797 \]

LER

\[ y = 508.68 + 0.0206x \quad R = 0.99495 \]
Main tuner (Piezo)
Distribution of tuner phase

- The tuner phase for LER is unstable due to the bad fine tuner response.

\[ \text{RMS} = 0.6^\circ \]

\[ \text{RMS} = 9.5^\circ \]
Phase stability (histogram of phase detector signal)

The tuner phase instability was suppressed by low level RF control system.

Distribution of cavity phase (cavity feedback loops on)
Ice balls
Ice balls

(1) Boiled He gas return to refrigerator through isolation pipe. To cool down the coaxial coupler, Liquid He was taken from He vessel. That gas return to suction of compressor through the normal (not isolated) pipe, because the amount of He flow was expected very small.

(2) Some coaxial coupler quench was observed. Temperature of gas outlet rose at that time. After that gas flow was increased.

(3) Ice ball grew.
LER kick voltage limit

(1) Big quench was occurred on March 17, 2007.
(2) The reachable kick voltage of LER crab cavity decrease from 1.36MV to 0.98MV.
(3) To cure this trouble, aging was done. But the reachable kick voltage was not changed.
(4) Crab cavities were warmed up to 80K. After that, the reachable kick voltage was increased to 1.1MV.
(5) The reachable kick voltage was gradually increased to 1.14MV by steady aging effort.
Instability in high current operation

In the high-current crab-crossing operation, we encountered a large-amplitude oscillation of beams and the crabbing field caused by the beam loading on crab cavities together with the beam-beam force at the IP. We found that the oscillation can be avoided by shifting the crabbing phase, shifting the tuning offset angle, and adjusting the loop gain appropriately.
Comments

- 両リングの寿命が急落することがあり、LER 電圧変動と同期している。

Some times, beam life was suddenly dropped. LER Vcrab was also unstable at that time.

From KCG shift report (Jun 23, 2007)
Trip rate

2007 spring
HER 1.27 times/day
LER 1.57 times/day

2007 autumn
HER 3.34 times/day
LER 0.38 times/day

7 days moving average (HER)
7 days moving average (LER)
summary

- Two crab cavities were installed to KEKB.
- Crab cavity made kick voltage more than 1.8MV at KEKB.
- Bunches had been tilted.
- The luminosity was increased at low bunch current operation with crab cavity.
- The peak luminosity reach to 15.1/nb/sec with crab cavities. (17.1/nb/sec without crab cavity.)
- The tuner for LER crab cavity has big back rash. It is compensated by low level RF control system.
- At high current operation, RF instability was observed. It is suppressed by adjusting crabbing phase, tuning offset and feedback loop gain.
Fabrication Procedure of Crab Cavity

**Crab Cavity Cell**

- Nb Sheet (m m t RRR = 180)
- Half Cell Hydro-forming
- Mechanical Polishing & Trimming
- Electron Beam Welding
- Grinding of Welding Part
- Barrel Polishing (~ 100 μm)
- Electro-Polishing (EP 1 ~ 100 μm)
- High Pressure Water Rinsing
- Annealing (700 °C x 3 hr)
- Electro-Polishing (EP 2 ~ 5 μm)

**Beam Pipe & Flange**

- Nb Sheet
- Roll
- Electro-Polishing
- High Pressure Water Rinsing
- Assembling for Cold Test
- Cold Test in Vertical Cryo.

**Manufacturers**

- MHI
- Kobe
- KEK
- Tsukuba
- Nomura
- Plating Kanuma
- Kinzoku
- Giken Mito
- Tokyo Denkai
- Mito
- Kanuma
- Giken Mito
Electro Polishing & Annealing

Electro Polishing at Nomura Plating Ltd.

- EP 1 ~ 100 μm
- EP 2 ~ 5 μm

Annealing at 700°C for 3 hours at Kinzoku Giken Ltd.
Forming and Barrel Polishing

Forming of 4 Half-Cells for Crab Cavity for LER and HER

Feb. 14, 2005 at Mitsubishi Heavy Industries, LTD. Kobe

Barrel Polishing  
Polishing Time  312 Hr

Nov. 11, 2005 at KEK
High Pressure Rinsing and Assembling for RF Cold Test

Set Flanges of Beam Pipes and Ports in Class 100 Clean Room
High pressure rinsing

High Pressure Water Rinsing
by 80 bar Ultra-Pure water

Rotation & Up-Down Motion
Test Result  Crab Cavity for HER

HER Crab Cavity Vertical Test (2005/12/20)

$Q \times 10^{10}$

operation level

$10^9$

$10^8$

$E_{peak} [MV/m]$

21MV/m ($E_{peak}$) = 1.4MV (Kick voltage)
Test Result  Crab Cavity for LER

LER Crab Cavity Vertical Test History

$Q_0$ vs $E_{\text{peak}} [/\text{MV/m}]$

- Nov. 18 1st Test
- Nov. 29 2nd Test
- H.P.R.
- Jan. 13 Test
- Recovered!
High Power Test for Crab Cavity HER & LER

Crab Cavity HER

Second Horizontal Test for HER Crab Cavity at 4K

- Input Power: 120kW
- $V_{\text{kick}}$: 1.80MV
- Vacuum
- Temperature

Crab Cavity LER

First Horizontal Test for LER Crab Cavity at 4K

- Input Power: 55kW
- $V_{\text{kick}}$: 1.93MV
- Vacuum
- Temperature