

OPERATION EXPERIENCE OF CRAB CAVITY

- ✓ **Brief history**
- ✓ **Crab cavity I/L system**
- ✓ **RF trip**
- ✓ **HOM load at HOM dampers**
- ✓ **Crab voltage scanning**
- ✓ **Piezo breakdown**
- ✓ **Voltage drop of LER crab cavity**
- ✓ **Lower temperature operation**
- ✓ **Oscillation at high beam current with “Crab ON”**
- ✓ **Achieved parameters during beam commissioning**
- ✓ **Summary**

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BRIEF HISTORY

month/year	comments
Jan/2007	Crab cavities were installed into KEKB.
Feb/2007	Beam commissioning started with “Crab ON”.
Mar/2007	Cavity voltage of LER Crab dropped suddenly.
Jun/2007	Piezo actuator of LER Crab broke down for the first time. Oscillation was observed at high beam current with crabbing collision.
Oct/2007	Physics run started with “Crab ON”.
May/2008	Cavity voltage of LER Crab was recovered slightly.
Oct/2008	Lower temperature operation was tried to recover cavity voltage of LER Crab.
Nov/2008	Beam study with “Crab ON” for LHC was tried.
Mar/2009	Lower temperature operation was retried.
Oct/2009	Oscillation was observed again, regardless of setting tuning phase offset and crab phase.
Dec/2009	Beam current with “Crab ON” achieved 1250mA for HER and 1700mA for LER. Beam study with “Crab ON” for LHC was tried again.

Crab cavities have been operated stably without any significant trouble for three years!

CRAB CAVITY I/L SYSTEM

Breakdown detector judges

whether P_{kly} , V_C and ϕ_{crab} (only V_C for LER) are normal, or not.

If not, Crab RF is switched off.

This is the most frequent cause of Crab RF trip.

Several pickup probes are attached for monitoring the transmit power and the RF output at coaxial beam pipe.

Breakdown detector

RF output from pickup probes

Vacuum

Temperature

Arc sensor

He pressure/level

Flow rate of cooling water

Crab RF Off

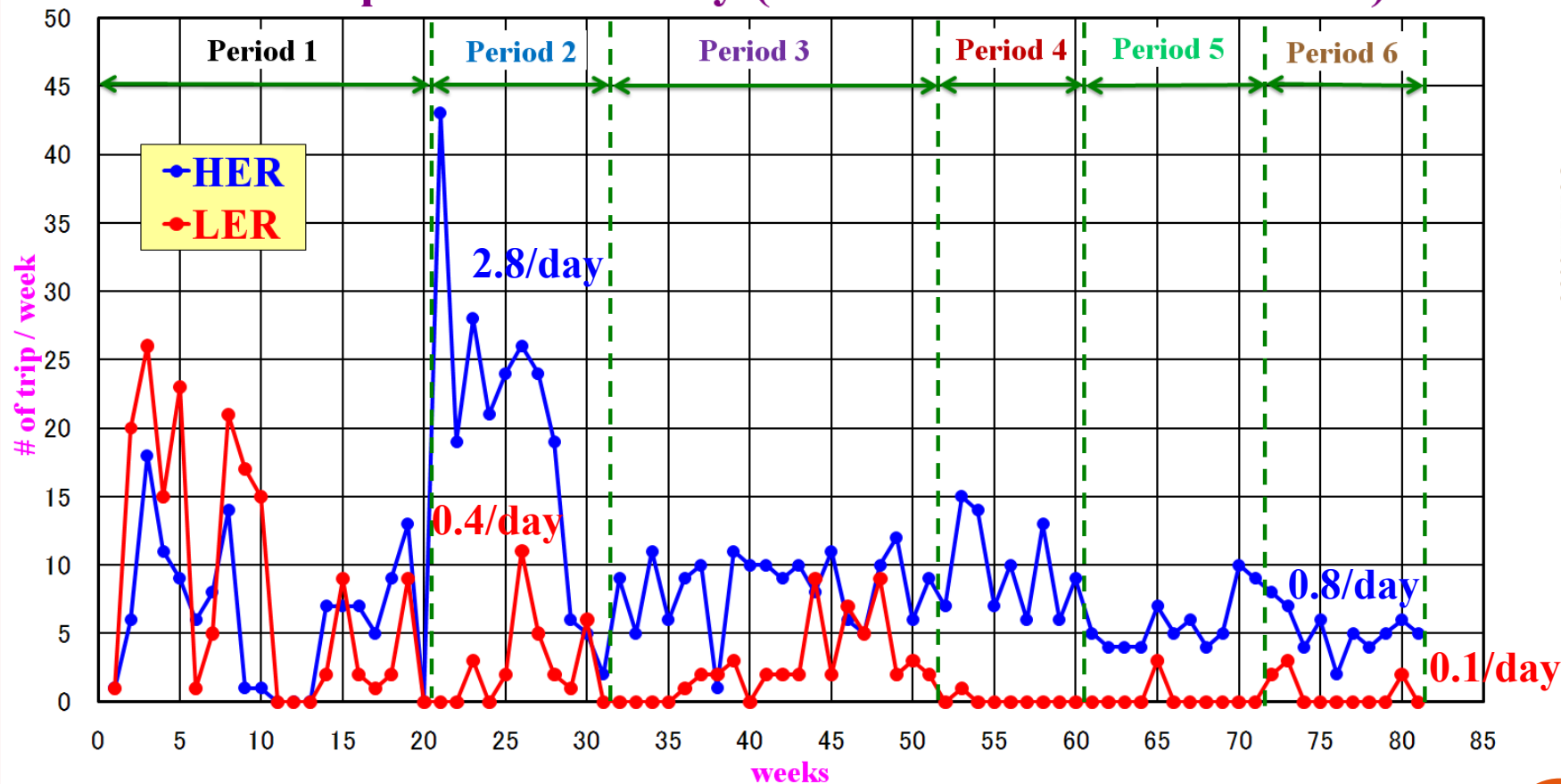
Beam abort

Whenever Crab RF is switched off, the beam is aborted coincidentally, because of safety.

RF TRIP OF CRAB CAVITY

Period 1 : Feb/2007~Jun/2007, Period 2 : Oct/2007~Dec/2007, Period 3 : Feb/2008~Jun/2008
 Period 4 : Oct/2008~Dec/2008, Period 5 : Apr/2009~Jun/2009, Period 6 : Oct/2009~Dec/2009

RF Trip of Crab Cavity (13/Feb/2007~24/Dec/2009)



← 558days →

Total average
 HER : 1.3/day
 LER : 0.5/day

RF trip of LER Crab was very small last year.

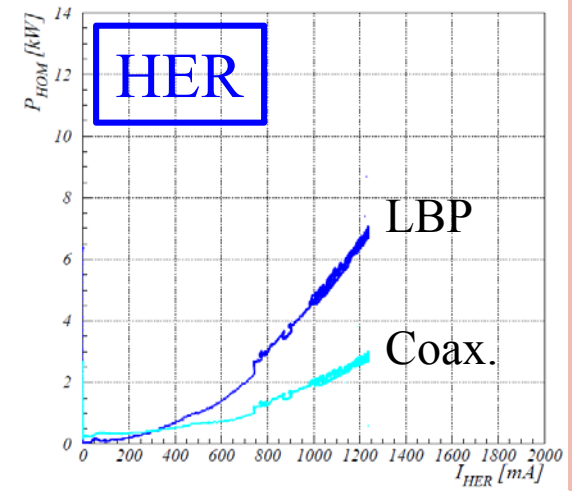
HOM LOAD AT HOM DAMPERS

- Crab cavity has two ferrite HOM dampers.
- There are two SiC dampers at downstream of LER Crab cavity.
 - They are also effective for damping HOM load generated in Crab cavity.
- SiC2 damper was introduced for reduction of HOM load absorbed at SiC1.

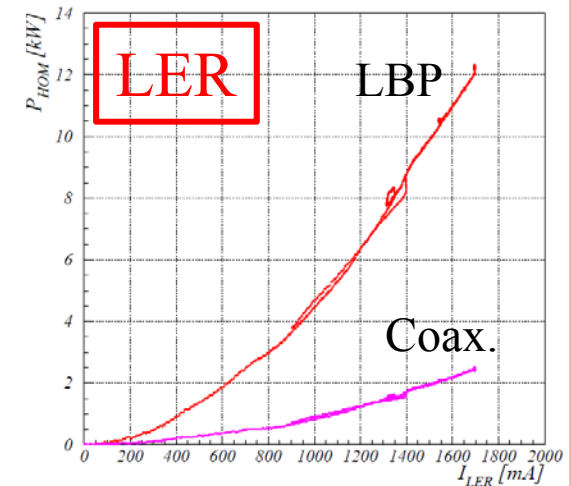


	Load (kW)	T _{max} (°C)	Flow (ℓ/min)	k (V/pC)
HER 1250 mA				
Coaxial	3.0	34.0	5.0	0.28
LBP	6.9	40.0	7.0	0.74
LER 1700 mA				
Coaxial	2.5	31.3	5.0	0.13
LBP	12.4	47.2	7.5	0.68
SiC1	13.0	39.1	13.0	0.72
SiC2	12.2	41.5	10.3	0.66

Commissioning for HER Crab Cavity ('09/12/16)



Commissioning for LER Crab Cavity ('09/12/16)



CRAB VOLTAGE SCANNING

Date	LER [MV]	HER [MV]
Feb/29/2008	0.83 → 0.88	1.37 → 1.41
Mar/4/2008	0.88 → 0.88	1.37 → 1.38
Apr/5/2008	0.83 → 0.84	1.38 → 1.39
Apr/15/2008	0.84 → 0.85	1.39 → 1.40
Apr/25/2008	0.83 → 0.83	–
Jun/4/2008	0.83 → 0.85	1.45 → 1.46
Jun/18/2008	0.83 → 0.83	–
Oct/26/2008	0.85 → 0.83	1.37 → 1.34
Nov/22/2008	0.83 → 0.81	1.50 → 1.48
Dec/18/2008	0.81 → 0.84	–
Apr/26/2009	0.85 → 0.83	1.35 → 1.32
May/20/2009	0.83 → 0.85	1.32 → 1.33
Jun/6/2009	0.85 → 0.86	1.33 → 1.37
Jun/18/2009	0.95 → 0.98	1.50 → 1.55
Nov/2/2009	0.87 → 0.90	1.29 → 1.34
Dec/12/2009	0.95 → 0.97	1.40 → 1.45

Voltage scanning is sometimes carried out as part of beam tuning for higher luminosity.

During this operation, RF trip of Crab cavity occurs frequently.

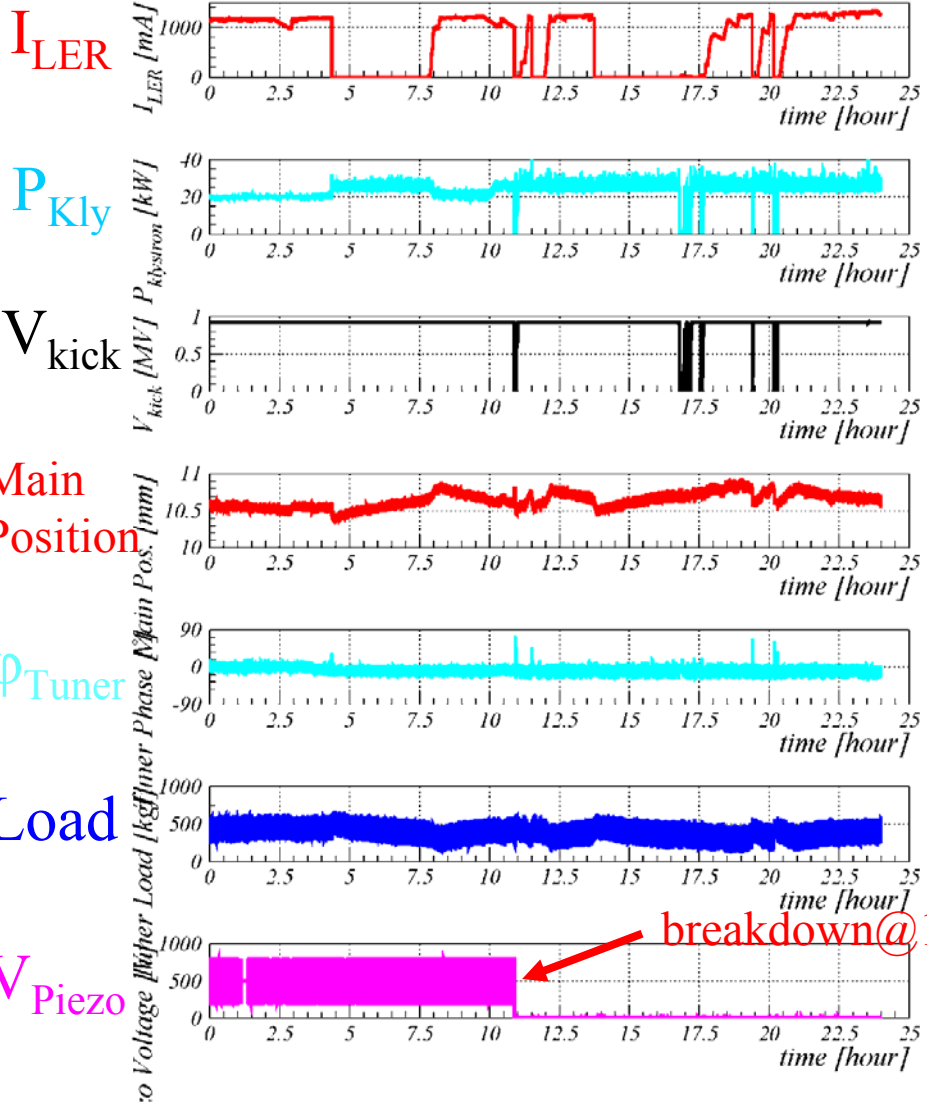
Very careful operation is necessary!

When Crab RF is switched off, RF conditioning is sometimes done at local control room.

← **Max. operation voltage**

PIEZO ACTUATOR BREAKDOWN

Commissioning for LER Crab Cavity (*07/6/23)



Date	Cavity	Comment
Jun/9/2007	LER	At RF recovery
Jun/23/2007	LER	At beam abort with RF trip
Oct/1/2007	HER	At RF recovery
Oct/4/2007	HER	At RF trip
Oct/16/2007	LER	At RF recovery
Oct/15/2008	HER	At RF trip
May/15/2009	LER	At beam abort with RF trip
Jun/11/2009	HER	At beam abort with RF trip
Oct/25/2009	LER	At beam abort with RF trip

Crab cavities have been operated without Piezo actuator during most of beam commissioning.

Not significant!

Low level feedback system can control Crab cavity without Piezo.

CAVITY VOLTAGE DROP OF LER CRAB

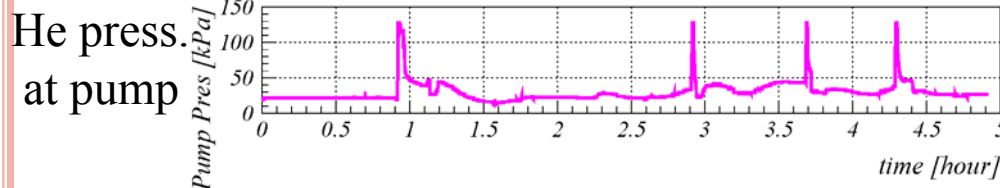
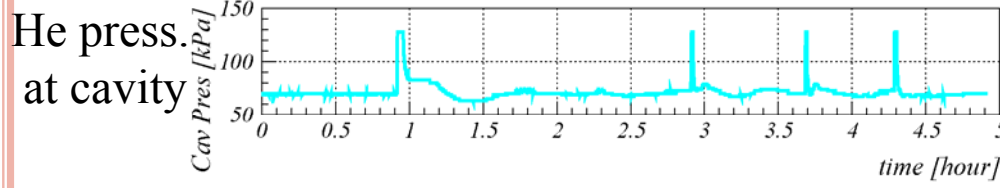
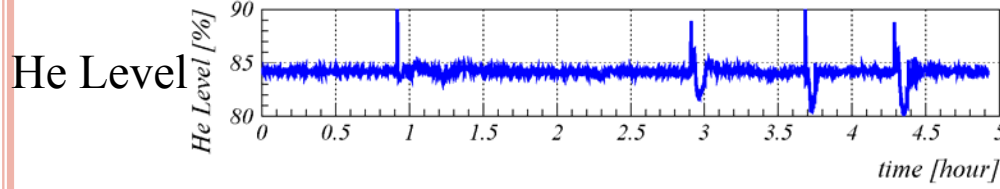
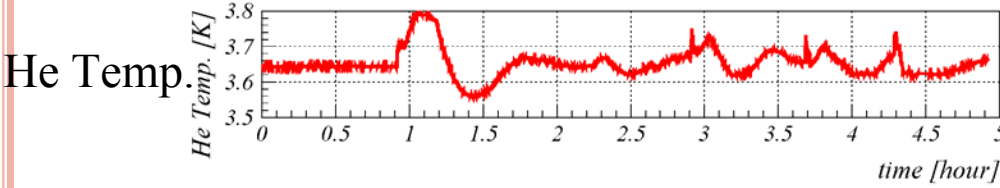
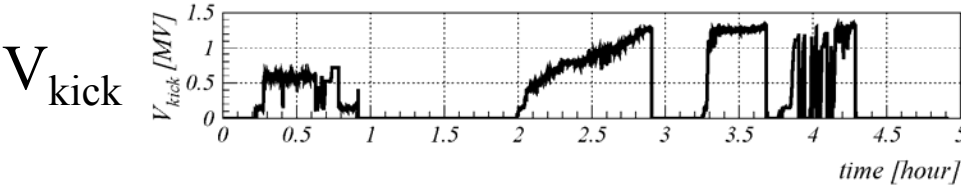
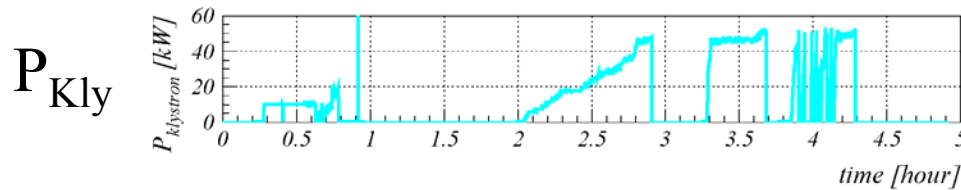
Cavity voltage of LER Crab was better than HER at horizontal test.
But, after installation to beam line, it dropped gradually.
And, it dropped suddenly from 1.3 to 1.0MV in Mar/17/2007.

Date	Cavity voltage [MV]	Comment
Dec/2006	1.9	horizontal test
Feb/19/2007	1.5	at beginning of beam commissioning
Feb/22/2007	1.3	maintenance day
black day Mar/17/2007	1.3 → 1.0	suddenly dropped
Mar/23/2007	1.1	after thermal cycle
May/22/2008	1.2	slightly recovered
Jun/30/2008	1.3	after pulse conditioning
Dec/18/2009	1.3	not more recovered

We hope cavity voltage of LER Crab is more recovered!
For example, at lower temperature, it can be operated?

LOWER TEMPERATURE OPERATION

Commissioning for LER Crab Cavity ('09/4/6)



Hosoyama-san's group tried lower temperature operation than 4.2K.

First trial was done in autumn/2008. It failed due to unexpected oil reduction of pumping system.

Second trial was done in spring/2009.

Lower temperature operation was successful!
The operation was stable around 3.6K.

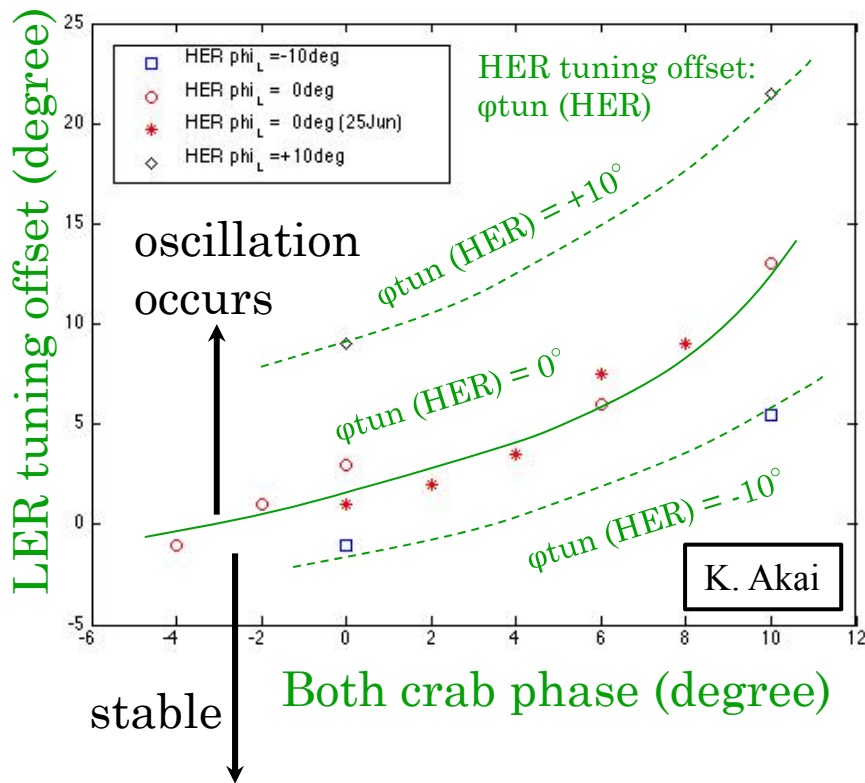
But, performance of LER Crab cavity was not recovered.

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REMEDY FOR OSCILLATION

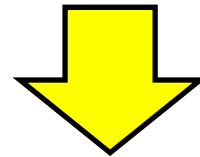
Oscillation phenomenon was observed at high beam current in beginning of beam commissioning in 2007.

Akai-san found remedy for suppression of this oscillation.



Tuning phase offset : $+5^\circ$ (HER)
 -8° (LER)

crab phase : $>+10^\circ$ (HER/LER)

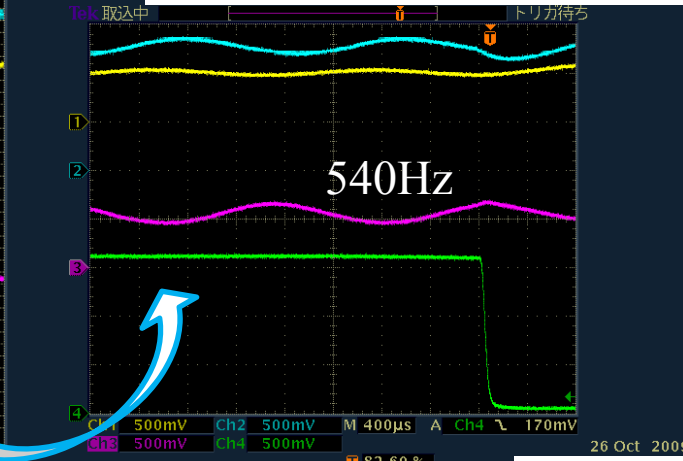
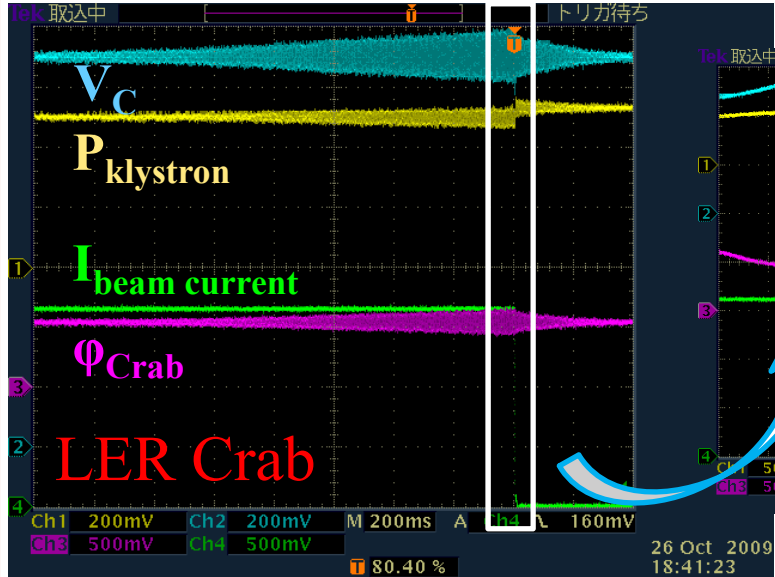


Oscillation is suppressed!

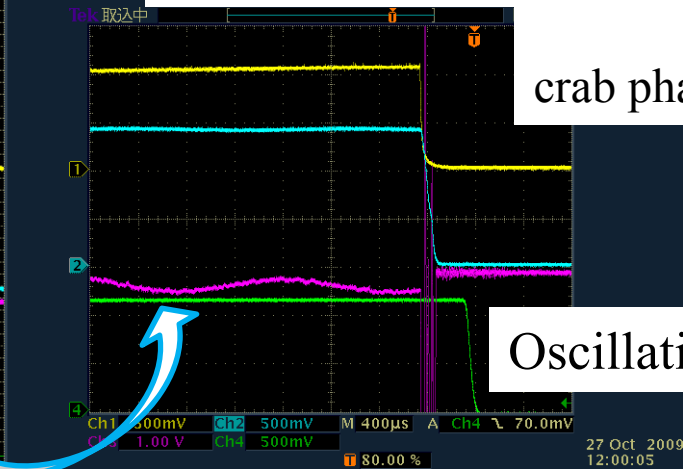
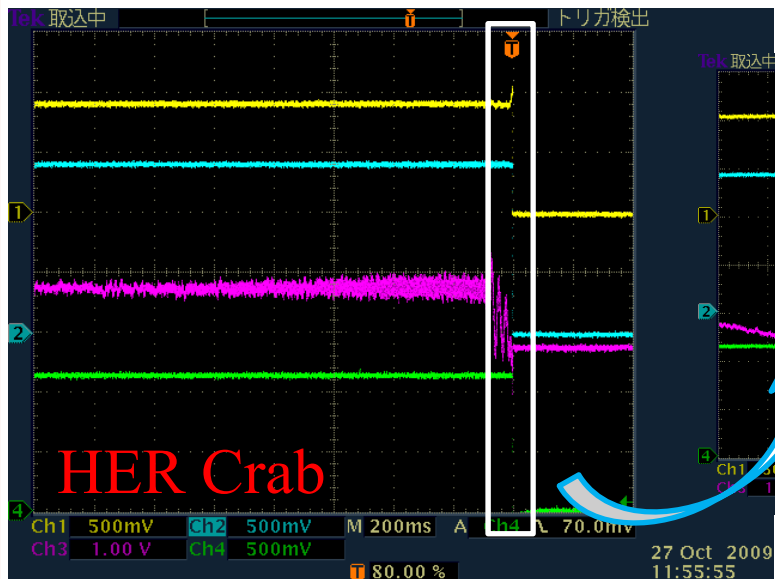
But...

OSCILLATION AT HIGH BEAM CURRENT WITH “CRAB ON”

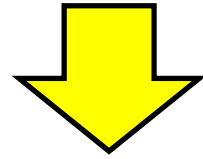
Oscillation occurred again in autumn/2009, regardless of setting same values as previous.



Tuning phase offset : $+15^\circ$ (HER)
 -10° (LER)



crab phase : $\sim +19^\circ$ (HER/LER)



Oscillation is suppressed again!

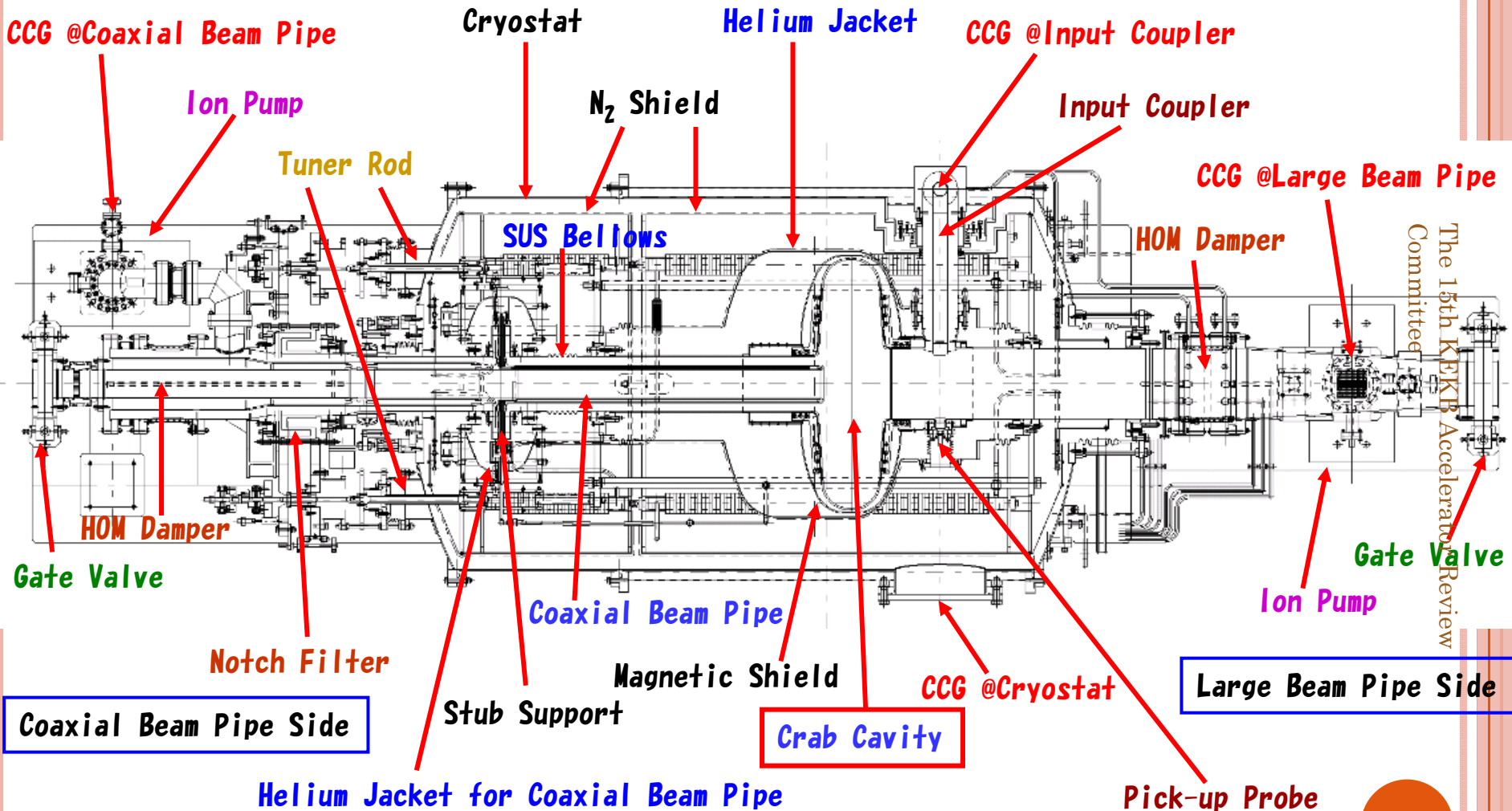
ACHIEVED PARAMETERS DURING BEAM COMMISSIONING

content	unit	LER	HER
Beam current (Crab ON)	mA	1700	1250
Crab voltage (operation)	MV	0.8~1.0	1.3~1.6
Crab voltage (Max.)		1.1~1.5	1.7~1.8
Max. HOM Power	kW	2.5(coax)+12.4(LBP)+13.0(SiC1) +12.2(SiC2)	3.0(coax)+6.9(LBP)
Water temp. @HOM	deg.	31(coax) / 47(LBP) / 39(SiC1) / 42(SiC2)	34(coax) / 40(LBP)
# of total RF trips	count	710	263
# of RF trip / day	count	0.5 (0.4 / 0.1)	1.3 (2.8 / 0.8)
# of Piezo breakdown	count	5	4
operation temperature	K	3.6~4.2	3.6~4.2

SUMMARY

- Crab cavities have been operated stably without any significant trouble.
- LER Crab cavity has small trip rate over one year.
- Trip rate of HER Crab cavity is decreasing.
- Lower temperature operation was tried and successful, but performance of LER Crab was not recovered.
- HOM dampers are used above designed HOM power.
- Piezo breaks down frequently, but it is not significant.
- Cause is unknown for oscillation reappearance.

VARIOUS COMPONENTS IN CRAB CAVITY



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Top View