Magnet Power Supplies for SuperKEKB Main Ring

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on behalf of the working group
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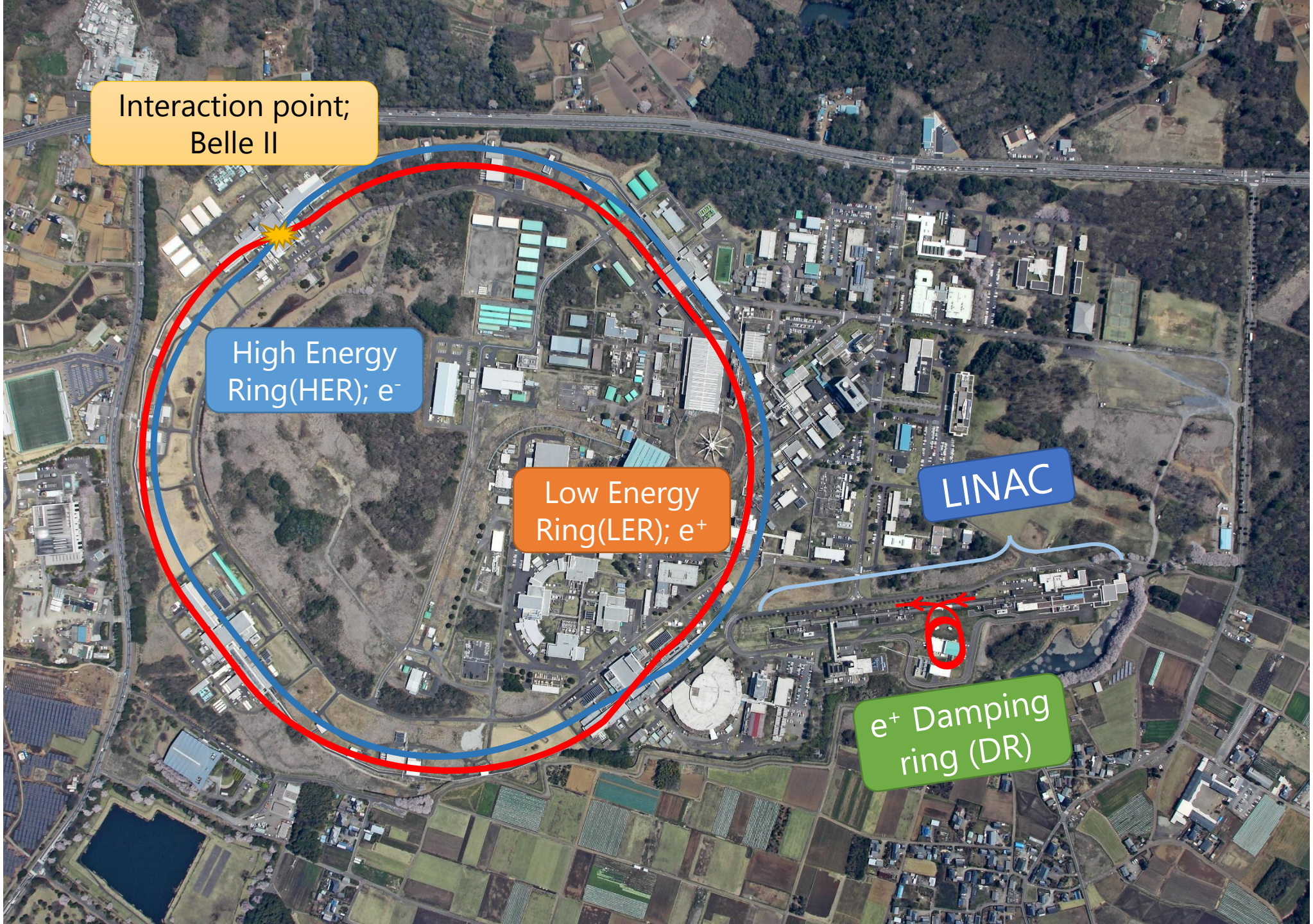

Interaction point;
Belle II
High Energy
Ring(HER); e-
Low Energy
Ring(LER); e+
LINAC
e+ Damping
ring (DR)

Machine Parameters

2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.20×10^{-4}	4.55×10^{-4}		
σ_δ	$7.92(7.53)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	():zero current
ν_s	-0.0245	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.76	2.43	MeV	
$\tau_{x,y}/\tau_s$	45.7/22.8	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

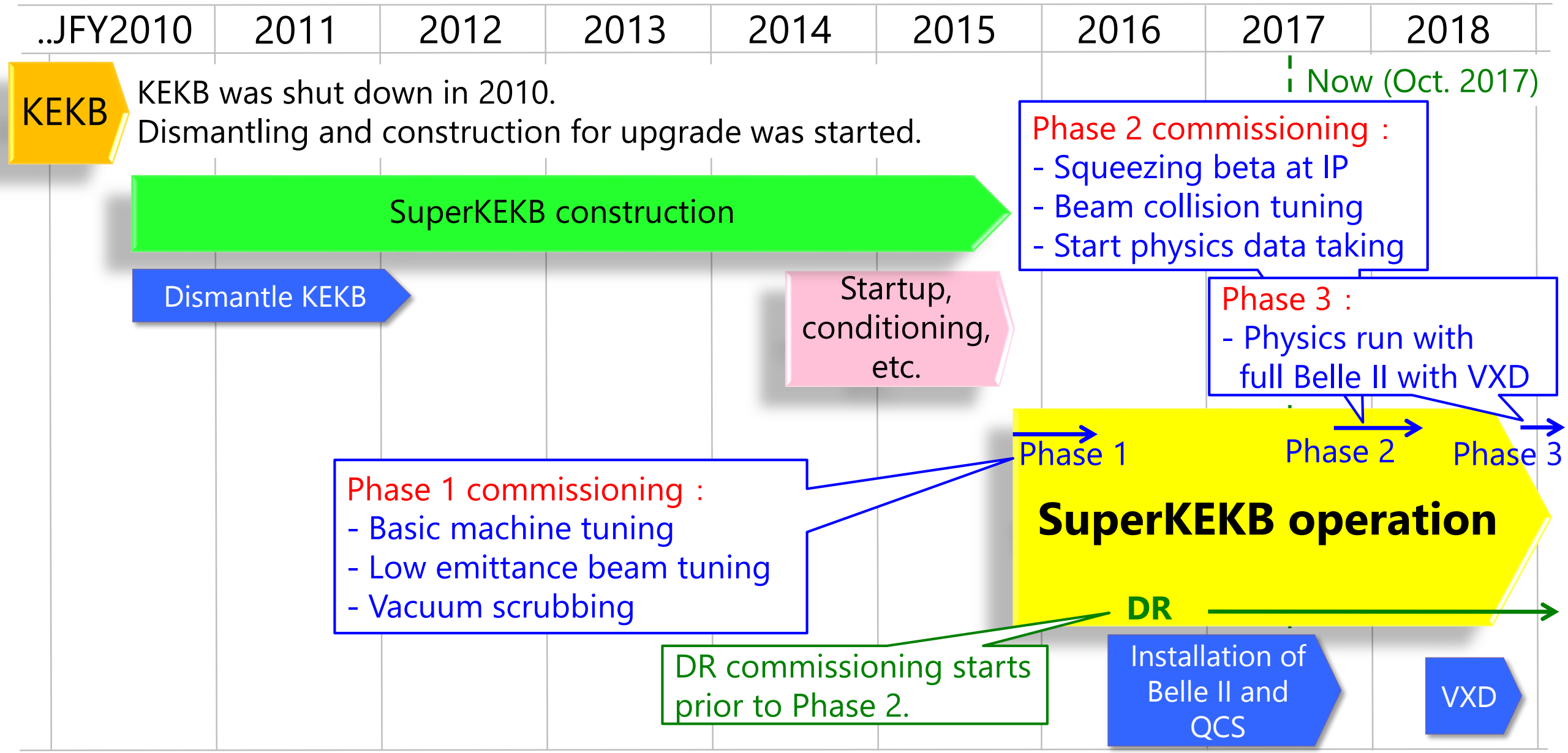
Beam current is
Two times larger than KEKB

×

Beam size at collision point is
20 times smaller than KEKB

Luminosity is
40 times higher than KEKB.

SuperKEKB master schedule



List of Magnet power supplies

- Newly fabricated or old power supplies for Main Ring

Output power	Newly fabricated PS	Reused PS (#overhauled)	
0.95 MW	2	0	Main dipoles
0.4-1 MW	9	0	Wigglers
0.1-0.5 MW	0	18#	Main quadrupoles
2-105 kW	92	335#	Bend./Quad./Sext.
0.3-2.4 kW	209+29	1493+α	Steering magnets/ corrector coils
Total	312+29	1846+α	2158+α

- Newly fabricated power supplies for final-focus superconducting magnets system(QCS)

2kA, 15V	8	0	QCS Main quads.
<500 A, 20 V	3	0	QCS Solenoids
±70A, ±10V	43+2	0	QCS correction coils

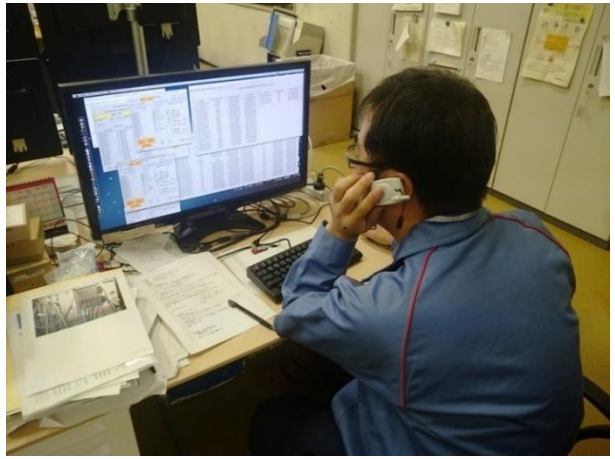
Large class PS (Wigglers)

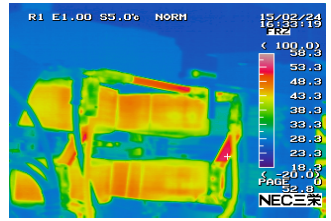
Medium class PS (Bend./Quad./Sext.)

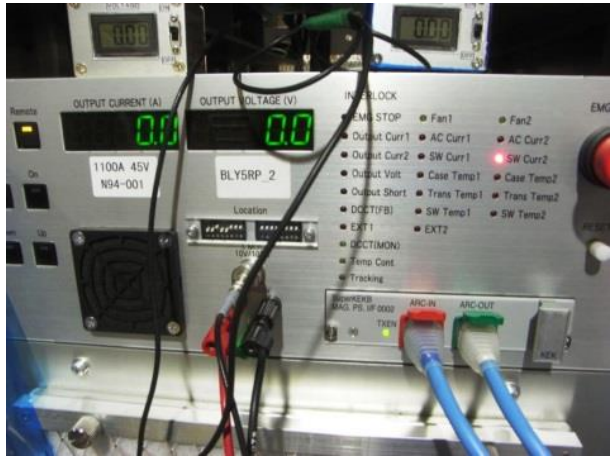
Small class PS (Steerings, auxiliary coils)

Start up: system check and full power load test (2015)

Full-scale start-up tasks such as network test, interlock system test, full power load test, cable connection check to avoid abnormal heating, polarity check, magnet standardization test and so on were completed before February 8(2016) beam injection to the MR.







First Commissioning in Phase 1 (2016.2.8 ~ 2016.6.28)

Magnet power supply system works well except for following failures.

Failures in Large class PS	# of event	comment
AC input over current	3	AC distortion (RF system crowbar work)
AC input over current	6	AC distortion (VAR system[#] work in line facility)
AC input Stop, CB Fault	2	Earthquake

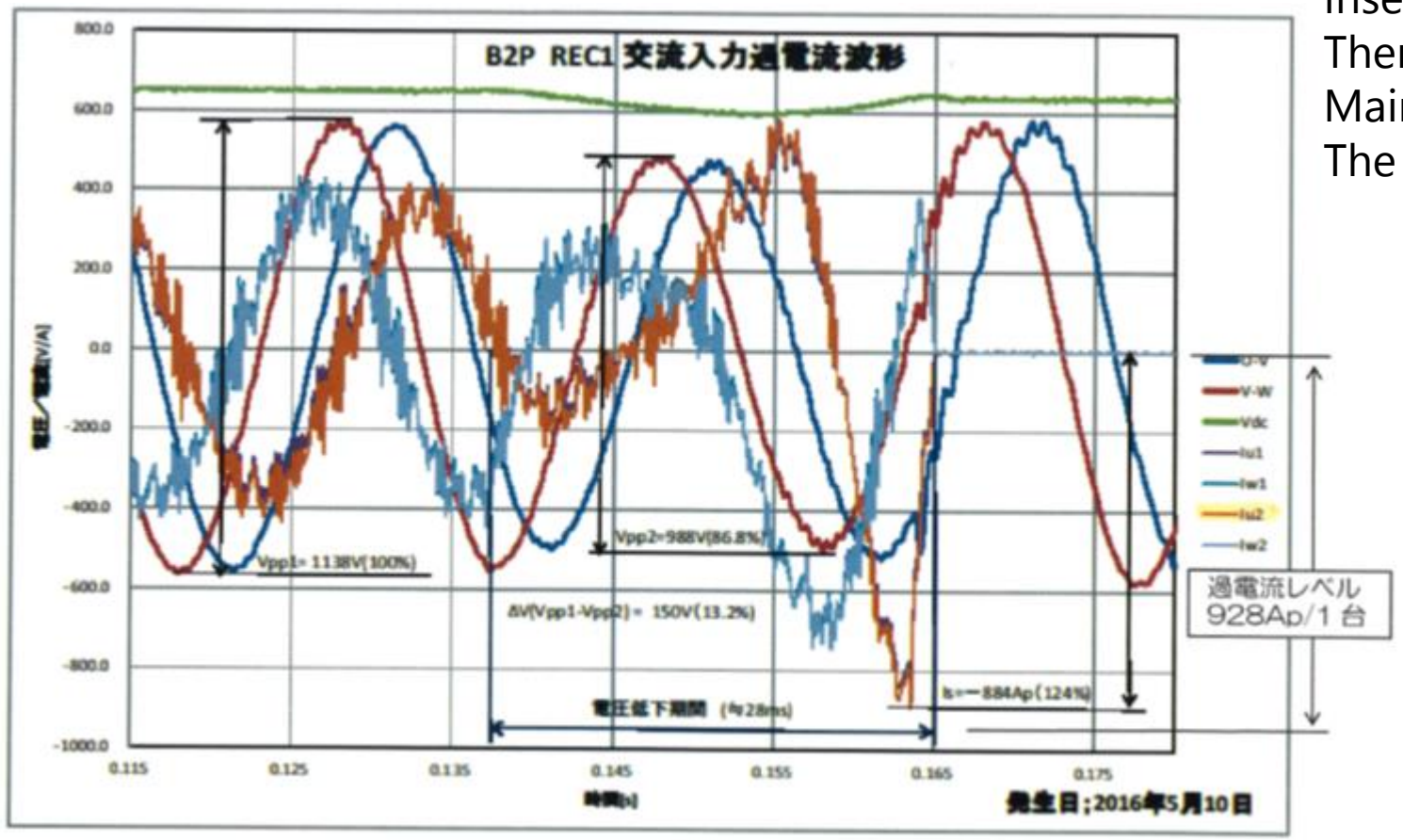
Failures in Medium class PS	# of event	comment
Thermostat	4	Thermal control equipment was repaired.
Over current (IGBT modules)	2	Modules were replaced. Repaired.
Cable GND fault	1	The fault cable was disconnected.
Tracking error	1	Fault in the polarity inversion circuit. Repaired.

Failures in small class PS	# of event	comment
DC-DC board failure Output over voltage etc.	17	Power supplies themselves were replaced.

[#]) Compensation system for a reactive power in the AC power distribution facility. AC line phase-advancing capacitor equipment was automatically controlled. However, unexpected operation occurred in early stage of Phase 1. Since capacitors has been manually operated, failures doesn't occur.

Preparations for Phase 2

AC input failure (Large class power supplies)



Insert additional AC inductors(ACL).
Then the peak height of the inrush current is reduced.
Main dipole magnet PSs are treated with the ACL.
The others are postponed due to a budget.

PS Control system

1. Remote control

   Setting output current, ON/OFF control, and reading various status of PS

   PSICM mounted in each Power Supply.

   (PSICM = Power Supply Interface Controller Module)

   Connected to the IOC through ARCNET.

   ARCNET = Attached Resource Computer NETwork

2. Current monitor

   Digital Voltmeter(KEITHLEY 2002 or 2001) with scanner(KEITHLEY 7001).

   Connected to the IOC through GPIB or Ethernet.

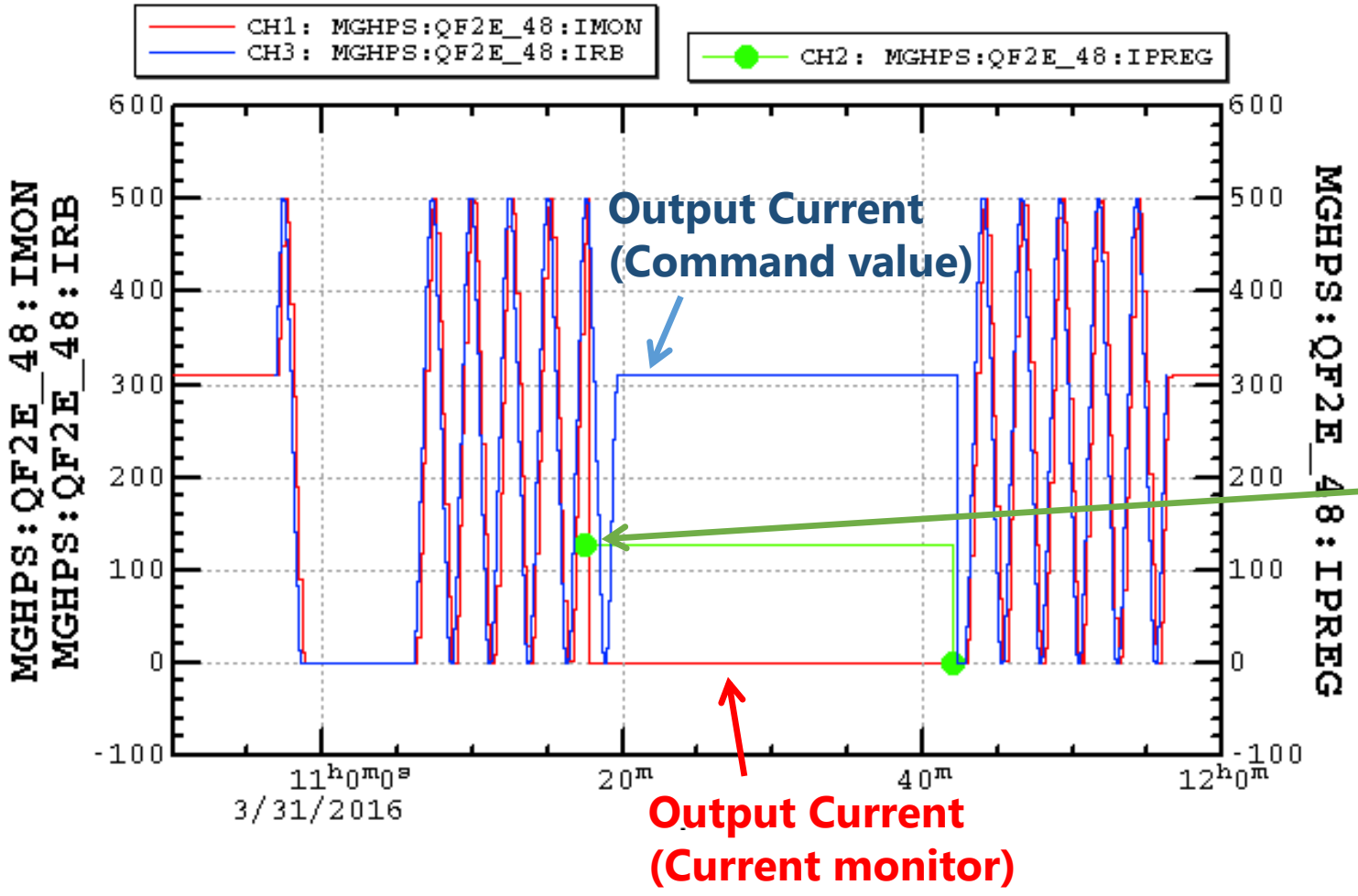
3. Interlock system to protect Magnets and Power supplies

   Standalone PLC system.

   The IOC is embedded in the PLC module(F3RP61).

They are controlled with EPICS(Experimental Physics and Industrial Control System).
KEKBlog system are logging channels of the EPICS records.

KEKBlog viewer

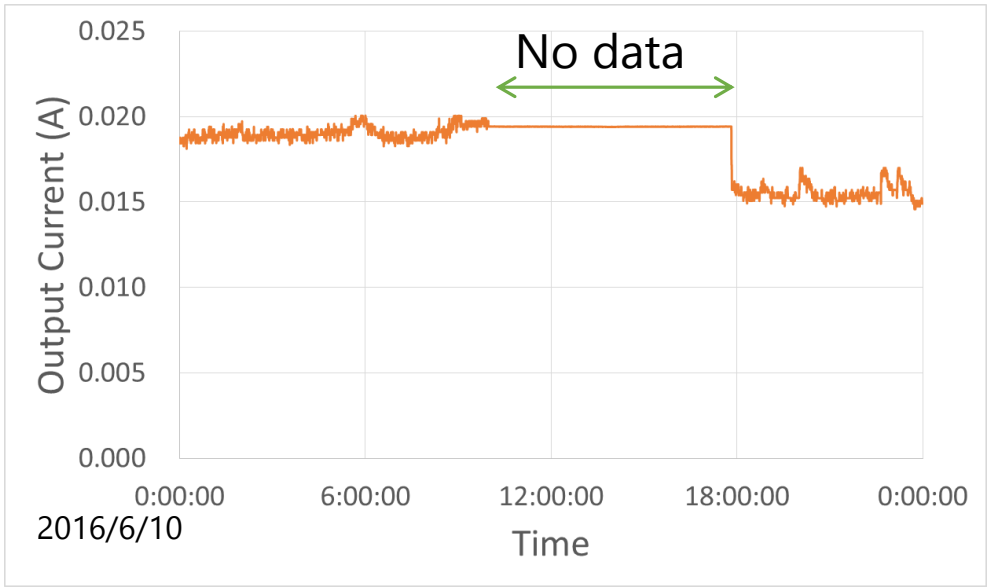


bit	Interlock
0	Output OC
1	Output OV
2	Thyristor Fuse
3	Case Temperature
4	Semicon. Failure
5	GND Fault
6	Emergency
7	External
8	DCCT Fault
9	-
10	Water Flow
11	-
12	-
13	Thermostat
14	Tracking
15	Fan

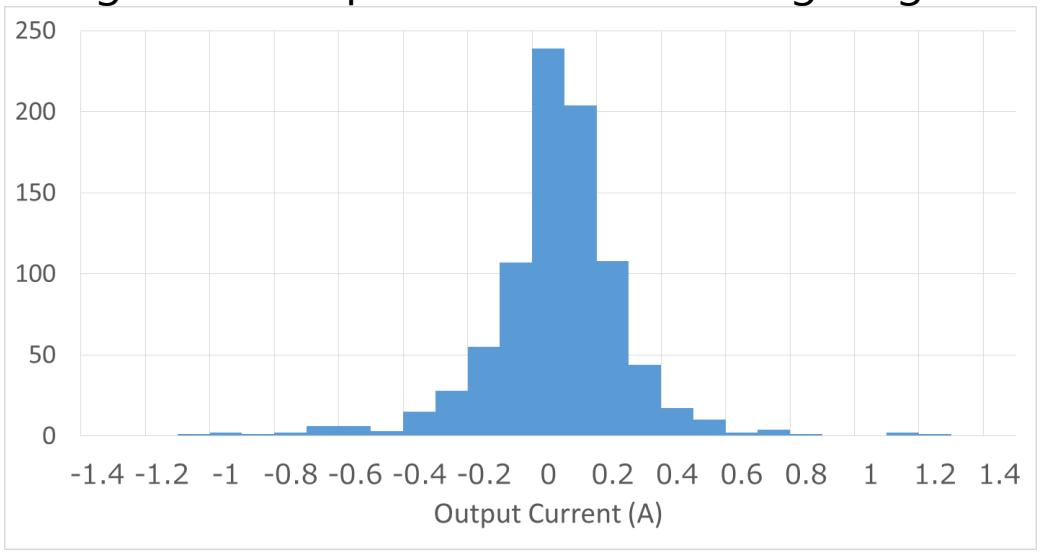
KEKBlog indicates 4W(who, when, what, where). We have to investigate remains(why, how).

Archived data

Time	record name	value
06/10/2016 00:00:36.48	MGLPS:ZVQD1P_1:IMON	1.843338e-02
06/10/2016 00:00:49.85	MGLPS:ZVQD1P_1:IMON	1.876372e-02
06/10/2016 00:01:26.15	MGLPS:ZVQD1P_1:IMON	1.875872e-02
06/10/2016 00:01:39.35	MGLPS:ZVQD1P_1:IMON	1.843839e-02
06/10/2016 00:01:55.85	MGLPS:ZVQD1P_1:IMON	1.843338e-02
06/10/2016 00:02:18.95	MGLPS:ZVQD1P_1:IMON	1.844840e-02
06/10/2016 00:02:45.35	MGLPS:ZVQD1P_1:IMON	1.844339e-02
06/10/2016 00:03:11.75	MGLPS:ZVQD1P_1:IMON	1.843338e-02
06/10/2016 00:03:38.15	MGLPS:ZVQD1P_1:IMON	1.843839e-02
06/10/2016 00:04:04.55	MGLPS:ZVQD1P_1:IMON	1.844339e-02
06/10/2016 00:04:30.95	MGLPS:ZVQD1P_1:IMON	1.844840e-02
06/10/2016 00:04:44.15	MGLPS:ZVQD1P_1:IMON	1.844339e-02
06/10/2016 00:04:57.35	MGLPS:ZVQD1P_1:IMON	1.843839e-02
06/10/2016 00:05:10.55	MGLPS:ZVQD1P_1:IMON	1.843338e-02
06/10/2016 00:05:23.75	MGLPS:ZVQD1P_1:IMON	1.844840e-02
...		



Histogram of output current of steering magnet PSs

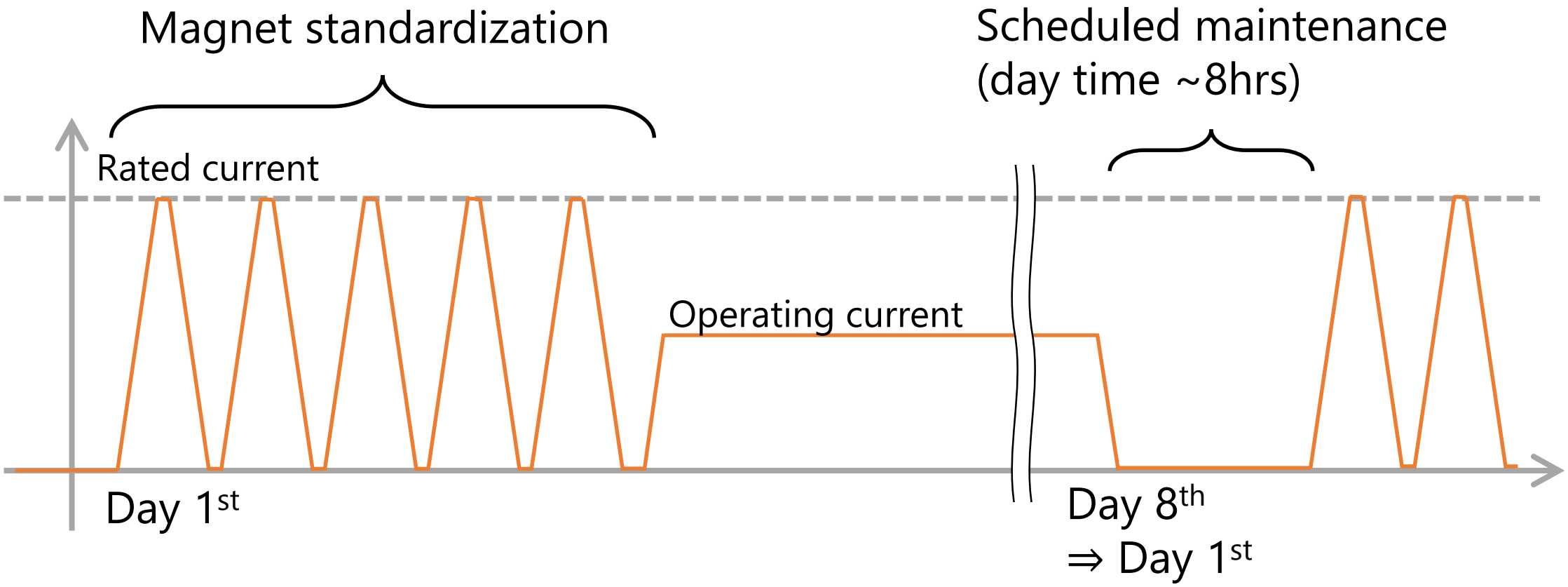


Summary

- SuperKEKB have started.
  - ✓ Large class power supplies were fabricated. Medium class power supplies were overhauled. Small class power supplies were swept clean.
  - ✓ Magnet power supply system has been worked well during Phase 1 commissioning except for several failures.
  - ✓ Unexpected spike noise caused AC input failures. Old components, which were not replaced, made troubles.

- PS status is recorded and archived with KEKBlog.
  - ✓ We have many information on the PS status.
  - ✓ Postprocess to get useful date is under construction.
  - ✓ Near future, I hope to forecast which power supply seems to break down.

Typical operation cycle of the power supplies

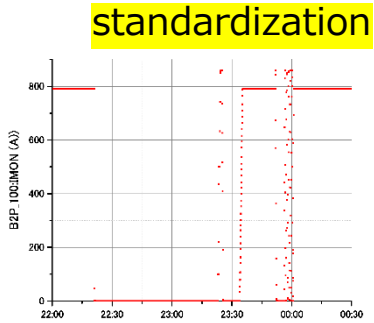


Magnet standardization: the magnet currents are increased to the maximum current of each power supply and then decreased to 0 A. This cycle is repeated several times, and then the current is set at the desired value determined by the machine optics. This cycle cancel out a relict magnetic field and assure us of repeatability of the magnetic field.

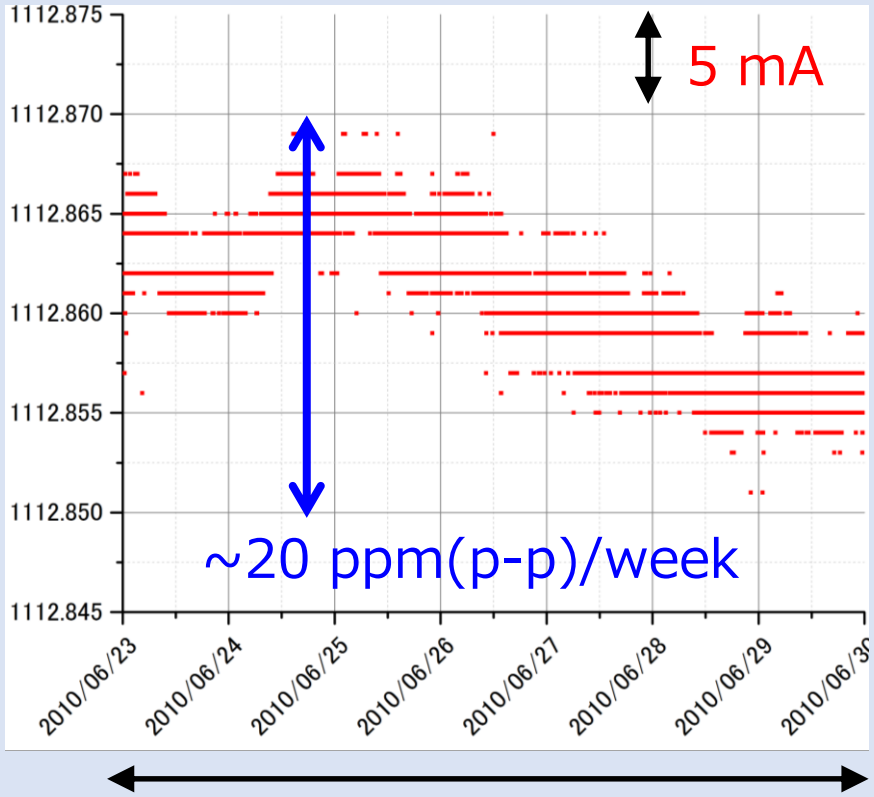
Scheduled maintenance:

First Commissioning in Phase 1

- How the system works well? Current stability of Main dipole magnet power supply is compared with one of KEKB.

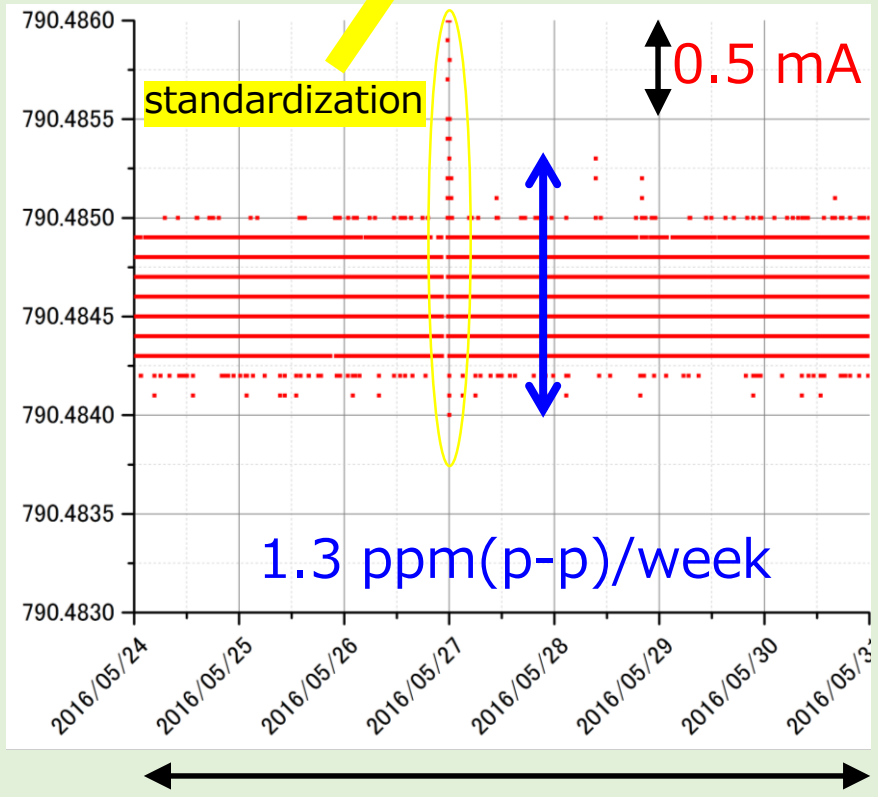


KEKB (1250 A, 770 V)



1 week

SuperKEKB (860 A, 1100 V)



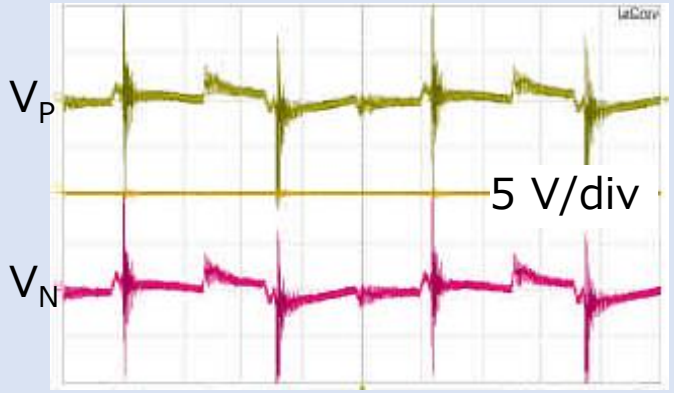
1 week

Test example 1/2 —switching noise

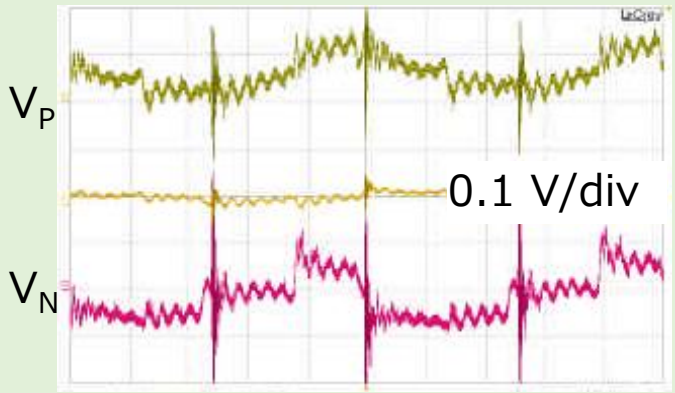
- Old medium-class power supplies were overhauled. Replacement of chemical capacitors, AC-DC converters, circuit breakers and IGBTs was performed.
- In order to reduce switching noise, ceramic capacitors are added at the output terminal. Switching noise is reduced to 1/20.

Ceramic capacitors

W/O capacitor



W/ 1 µF capacitor



Test example 2/2 —ripples

- Newly fabricated medium class power supplies were designed to be lower current ripples. Histograms of current ripples are compared with the results of old (overhauled) power supply.