Status of High-power rf system for MR and DR

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Introduction (1)

The high-power rf system in MR and DR has the role of supplying rf power to the accelerating cavities, to compensate an enormous synchrotron radiation loss of electron / positron beams.

The operating frequency is 508.9 MHz and the required maximum rf power from one klystron is ~700 kW, it is a dependent on the cavity system.

Many equipments that build high-power rf systems used in SuperKEKB are still many manufactured at TRISTAN where construction was done in the early 1980s. There have been used for more than 30 years since manufacturing, and are used while continuing maintenance.



*Total 31 stations are used for Phase 2.



Introduction (2)

Max RF output 1.2MW (CW) Efficiency: ~65 % (at saturation) Vapor cooling (for cooling collector)

Cathode Voltage (Vk): 45-90 kV Anode Voltage (Va): 0-65 kV Beam current: ~20 A x 2, Max 40 A for 2 klystron

* Waveguide system: WR-1500 (Circulator, Waveguide, Water and Dummy loads)

High-power rf stations

* Photo of the high-power components in power supply building.

D5-F (1:1)





<u>Future plan</u>

RF Cavities for SuperKEKB



When the commissioning advances, then more rf power is necessary,

- : OHO (D4,D5): Add Two klystrons and one KPS <- First
- : Fuji(D7, D8): Add Two klystrons, and update one KPS <- It is dependent on the

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progress of commissioning.

Summay of operation at Phase1 (1)

Many of the troubles that occurred during phase1 operation (about 2900 hours) were failure and breakdown of equipments due to aging. The beam abort occurred by trouble of high-power components was <u>total 13 times</u>.

KPS: Crowbar work happened without notice for particular KPSs. D7-AB (4), D7-CD (4) and D5-FE(2) : <u>total 10 times (it happens on from KEKB)</u> It occurred between PM 19:00 to AM 9:00. It did not occurred during the day time. -> Why ?



Thermo-sensor trouble in cooling channel of klystron (D11-A): <u>1</u>



Failure of water supply system for the collector of klystron (D5-E, D8-A): 2

Summay of operation at Phase1 (2)

Cooling system for klystron (Vapor cooling) * Water leaks were happened from cooling systems for the collector of klystron. The components were broken due to aging. * Connection point of fin-tube in AFC (Air fin cooler) was also happened water leak at D7 (1 of 6).

These water leaks were repaired on the maintenance day.



Sight glass (10 of 66)

Summay of operation at Phase1 (3)

High-power components

The WR-1500 waveguide, the high-power dummy and water loads : There was no big trouble causing the beam abort during operation.

1 MW UHF circulator

: Total 30 circulator were used for RF stations. 22 of 30 circulators, these are fabricated at 1984-1987. 11 of 22, these circulator were done the overhaul for repair the water leak from cooling channel.

: Small water leakage was detected from <u>five circulators</u> before starting operation. <- it can operates while supplying water to reserve tank of cooling system (1-4 weeks).

: <u>Two more water leak</u> were happened at D7-C (March 23, small) and D7-D (May 18, serious). <u>At D7-D, the water leak rate grew to inoperable</u> <u>amount in a few days. It was **disconnected** form <u>the operation (May 24).</u></u>





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<u>Current situation of high-power system (1)</u>

Current situation

Construction of DR for Phase2:

A high-power rf system of DR was constructed using by many spare parts of MR. Required rf power is 450 kW (150 kW/ cavity) at three cavity scheme. The conditioning of DR cavity was started from May 2017.

Klystron moved from D11-E

KPS moved from D4-C



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Current situation of high-power system (2)

Klystron

: Water leak was happened on the cooling pipe for two klystrons at Feb and Mar 2018. Now, the klystrons changed to spare.-> Now, planning repair in house.

: Fabrication of one klystron using new ceramic for RF window in output coupler (Manufacturers have changed) is planning at 2019-2020 or later. Currently used klystrons are of two types, Toshiba E3786 and E3732 (late-model). If the E3786 is broken, repair it to the E3732 specification.

The E3732 specification achieves high stability and long life expectancy.





KEKB review

Operating time of Toshiba Klystrons before SuperKEKB Phase2



Operating time (hours) x 10^5

Operation time (E3786) since TRISTAN Average : 5.6 x 10^5 hours Maximum: 11 x 10^5 hours (since 1986)

Operation time (E3732) since 2003. Average: 1.8 x 10^5 hours Maximum: 7 x 10^5 hours

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Current situation of high-power system (3)

KPS (DC power supply) : The control cabinet, the communication system of crowbarcircuit and the smoothing capacitor were already updated.

The concern at this time is the failure of <u>the rectifier on high</u> <u>voltage section</u>. In the analysis of insulating oil in rectifier, no abnormality is found in electrical characteristics, but ethane, which is one of the items showing aged deterioration, is increasing.

<u>Frequent inspection for the high</u> <u>voltage section is necessary to check</u> <u>the inside rectifier.</u>



12 phase full-wave rectifier

<u>Current situation of high-power system (4)</u>

Cooling system

: Updating the equipment and piping that caused problems as a result of aging advanced considerably. We were able <u>to replenish spare parts sufficiently this fiscal year</u>, so we are ready to respond promptly when trouble happen.

High-power components

Waveguide: We are updating waveguide manufactured at the early stage of construction of TRISTAN. Currently there are only a few remaining in the Fuji area (D7 and D8).

"Circulator

: As time goes on, the number of cooling water channel that cause leakage of circulator which have not overhauled is increasing due to corrosion by aging.

For repair, there is a limit on the cuttable range of cooling water channel. So, new production is desired.



Current situation of high-power system (5)

Dummy load

: All of the dummy loads made at TRISTAN were broken, so they were discarded. All dummy loads were updated from direct water cooling type to the indirect water cooling type for SuperKEKB.

Water load

: The water leakage due to corrosion of seal material was detected for all Rectangular-type water loads after the end of KEKB. The cause of corrosion is that tap water (~ 360 μ S/cm) was used as a microwave absorber. For the long operation without corrosion, "Water quality changes to mixed water (~ 20 μ S/cm) and controls the conductivity in water. " Gold coated on the surface of metal seal for improving sealing performance and corrosion resistance.





Water-loads Top: Cylindrical-type Bottom: Rectangular-type



Water leak due to corrosion of metal seal

<u>Summary</u>

In order to survive more than 10 years from now, (For half century-long to work),

Klystron

- : Need fabrication and test for klystron with new ceramics (Manufacturers have changed)
- : Repair work to E3732 if previous model is broken.

KPS

: Breakdown of high-voltage equipment is the primary concern. It is exhaustive to do frequent inspections.

High-power components

- : Waveguide -> No problem
- : Water load -> No problem
- : Dummy Load -> No problem
- : Circulator -> Need fabrication new one and continue repair work for aging material.

Back-up slides

Number of each components for high-power rf system

* Number of high-power rf components for SuperKEKB MR, DR and test stations.

	Туре	Number	Other
Klystron	Toshiba E3786 E3732 (late-model) (* 1.2MW CW 508 MHz)	22 19	1986-2002: 22 2003-2014: 19 (10) (E3876 -> repaired to E3732)
KPS	Type-A (for two klystrons) Type-B (for one klystron)	15 8	1983-1986: 13 <i>,</i> 2010-2013: 2 1983-1986: 8
Wave guide	WR-1500		1983-1989: Many components "It is divert to SuperKEKB 2010-2016: Manufactured the Shortfall
Circulator	UHF 1MW 4-ports-type	38	1984-1987: 30 (Repaired: 11) 2004-2012: 8
Dummy Loads	 1.2 MW water-load 400 kW water-load 20-50 kW Dummy-load 	31 9 42	1998-2002: 19, 2012-2014: 12 2005-2010: 9 2008-2017: 42

* All of the dummy loads made at TRISTAN were broken, so they were discarded.

<u>Klystron</u>

operation period

<u>Project</u>	Number of Stations	Date N	<u> Maximum RF power</u>
TRISTAN	36	1986 ~ 1995	~ 900 kW
КЕКВ	29	1999 ~ 2010	~ 600 kW
SKEKB Phase	1 30	2016 Feb. ~ Ju	ne ~ 500 kW
SKEKB Phase	2 31	2018 Feb. ~ Jul	y ~ 700 kW

Reasons for klystron failures from TRIATAN (Total time: 11 x 10⁵ hours). Failure (cause of repair, disposal) occurred at 34 of 80 deliveries.

Reasons for klystron failures	TRISTAN	KEKB	SKEKB	incidence rate (%)
Power variation *1	9	5	0	17.5
Vacuum leak *2	7	5	0	15.0
Bad electrical strength of DC gun		4	0	7.5
Hysteresis of RF output		0	0	1.25
Breaking of heater wire in DC g	un 1	0	0	1.25

- *1: Operating time < 6 x 10⁵ hours (only E3786), like as surge
- *2: Cooling water channel in output coupler -> 6 Collector : 3 Bazing point: 1 Melting ceramic window: 1 Unknown: 1

• Power variation: It does not occur in the E3732 specification.

- There is a possibility of occurrence of unreformed E3786 type.
- Vacuum leak : Significant decrease due to initial improvement Those with a long operation time are expected to occur.
- Bad electrical strength of DC gun : Greatly improved with E3732 specification
 In future it is expected to occur in proportion to the driving time.

• Hysteresis of AB output : It has not occurred since the initial improvementew The E3732 specification achieves high stability and long life expectancy. Operating time of Toshiba Klystrons after SuperKEKB Phase1





Operating time (hours) x 10⁵

Average operation time (E3786) : 5.6 x 10^5 hours Maximum operating time: about 11 x 10^5 hours

Average operation time (E3732) : 1.8×10^{5} hours Maximum operating time: about 7×10^{5} hours

Klystron Power Supply (KPS)



Broadband performance of the circulator

1MW UHF circulator (SPC)
 Frequency: 508±5 MHz
 Input: 1.0 MW (CW) Through

 600 kW (CW) Reflection
 Loss: < -0.2 dB
 At 1.0MW input, Loss is <46 kW.
 Isolation: > -25 dB





<u>Circulator (1)</u>

Magic-T

"1MW UHF circulator

Troubles

* Water-leak from cooling water channel in phase shifter

* Clack on the ferrite

The circulator continues to use it by repairing the cooling channel. However, the cuttable range of the cooling water channel has become low, some overhauling has come up.











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3dB coupler

<u>Circulator (2)</u>

Repair of the cooling water channel is done by machining and then subjecting the surface to alodine treatment.

As a current situation, the circulators are repairing (overhaul) at two pace per year using two spare parts.

At present, there are 6 of 31 units with small water leakage detected. We are trying to control water pressure, water temperature and keep it to the minimum.

We are planning to repair for two circulator, and to production new for one circulator.



The surface current distribution in water-load



Rectangular-tank

Max surface current (at 1.2 MW input) : 600 A/m on water tank.

Max surface current (at 1.2 MW input) : 1500 A/m on water tank.

: 2200 A/m on RF window.

Tank material is stainless steel (SUS 304) $Rs = 0.038 [\Omega]$ at room temperature and 508.9 MHz. $Walk koss = 15 \, kW$ **KEKB** review

Water-load

- 1.2 MW water-load (Two type)
- : Rectangular-waveguide type x 19 (1998-2010)
- : Cylindrical-waveguide type x 12 (2012-2014)

Rectangular-waveguide type has been used from 1998 to 2010 at Fuji and Nikko. For the SuperKEKB, Cylindrical-waveguide type was fabricated for update and reinforce at Oho.

The water leakage due to corrosion of seal material was detected for all Rectangular-type water loads after the end of KEKB. It is caused by using Tap water as microwave absorber. But, Tap water is good microwave absorber compared to pure water. Because of, the dielectric loss tangent of Tap water dose not decrease even at high-temperature. However, it turned out not to be suitable when considering to use for long-term.





Water-load

Water quality of water was changed from tap water (~ 360 μ S/cm) to mixed water (~ 20 μ S/cm) in SuperKEKB considering prevention of corrosion and VSRW performance.

Regarding the surface of the metal seal used for the load, a conventional one plated is adopted for the purpose of improving sealing performance and corrosion resistance.

From now on, I will pursue aged deterioration.



Pure water (7 years) 2018/3/15



KEKB review

SWR









Rectangular-type water load





KEKB review

Corrosion of the metal seal compare with tap-water and pure-water

D10-A Operating time: 13 years (tap-water) D11-F Operating time: 7 years, pure-water









タール面まで浸食していた箇所があり、そこ 角とE面の外皮が剥がれた。H面は剥がれ から微量の水漏れあり。緑青のみ。孔食には る割含が少ない。緑青の他に孔食あり。 KEKB re 空っていない。 30