DEVELOPMENT OF CYLINDRICAL-TYPE 1.2 MW HIGH POWER WATER-LOAD FOR SUPER KEKB*

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Abstract

We have developed and manufactured CW 1.2 MW high power water-load for the SuperKEKB, an electron-positron double-ring collider at KEK. As a water-tank of the load, a cylindrical type chooses to reduce a surface current and to shorten a length of the load. A tap water has been used to absorb the rf high power.

New water-loads will be installed at D4 and D5 in the high power rf stations of the main ring. The rf window and the water-tank were made of Al_2O_3 ceramics and SUS304. The operational frequency is 508.9 MHz. A proto-type model of water-load was fabricated in Sept. 2012, and tested in Oct. 2012 at D2-ET test station with a high power klystron (1.1 MW, YK1303). The design and the result of the high-power test will be reported in this paper.

INTRODUCTION

The SuperKEKB, an asymmetric electron-positron double-ring collider for B-factory at KEK, is under construction [1]. The design beam current is 2.6 A (HER) and 3.6 A (LER) respectively. In order to correspond to the large beam current and high beam power, reinforcement of the high-power rf systems to drive the ARES and the superconducting cavities is underway [2]. The maximum power supplied from a CW klystron (Toshiba, E3732, Operational frequency: 508.9 MHz) to the accelerating cavities in the operation will be ~1 MW. Therefore, a 1.2 MW high-power water-load is required to protect the klystron from a large reflected power when a rf trip happens at a cavity. The water-load will be mounted on the 3rd port of the circulator or 4th port of a magic-T depending on the number of driven cavity per klystron.

The new 1.2 MW high-power water-load with a cylindrical-type 1.5 m long water-tank (WDL-R06WC) has been developed from 2010 for the reinforcement of rf system. The features of design of new water-load are to reduce surface current around the rf window, to decrease pressure loss of cooling water, to improve cooling efficiency around the rf window and to shorten the length of the water-tank compared with the existing model. It is expected that the performance of the high-power water-load will improve more. The existing model of water-load at KEKB is the rectangular-type (WDL-R066D, fabricated by NKC in Japan) which was developed in 1998 [3]. Total twenty loads were fabricated until 2007, and the long time operation was also carried out without troubles.

In this paper, the rf design, flow analysis and high-power test result of the new water-load for the SuperKEKB will be reported. A comparison of the performance of the existing model also will be reported.

Table 1: Specifications of the New Water-Load

Item	Specifications
Operational frequency	508.9 ±5 MHz
Maximum power	>1.2 MW (CW) >2.2 MW (Pulse, <1 ms)
Input VSWR (20~60 °C)	<1.1 (508.9±2 MHz) <1.2 (508.9±5 MHz)
Cooling water (Absorber)	Tap water
Water flow	<700 l/min
Water pressure	<10 kgf/cm^2 (1 MPa)
Attenuation in water-tank	>12 dB
Temperature of inlet water	<30±5 °C
Temperature of outlet water	<70 °C
Power leakage	<40 dBμV/m (<1 mV/m)
Input waveguide	WR-1500

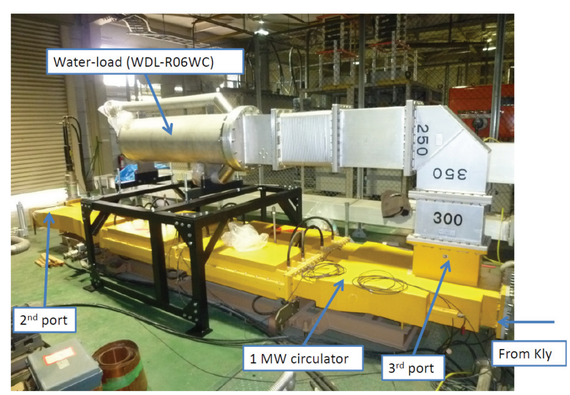

Figure 1: Picture of the cylindrical-type water-load mounted on the 3rd port of the 1 MW circulator.

SPECIFICATION AND RF DESIGN

The specification of the new water-load is shown in Table 1. A picture of the cylindrical-type water-load installed on the 3rd port of the 1 MW circulator is shown in Figure 1. The calculation model with electric-magnetic field is shown in Figure 2 a) and b). The load was composed of three parts which are the WR-1500 made of aluminium, the rf window made of Al_2O_3 ceramics and the water-tank made of stainless steel 304. The incident power is directly

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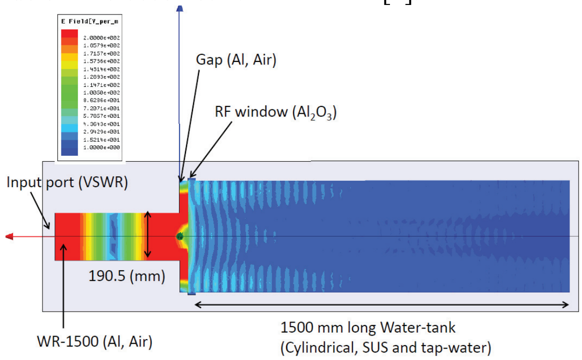
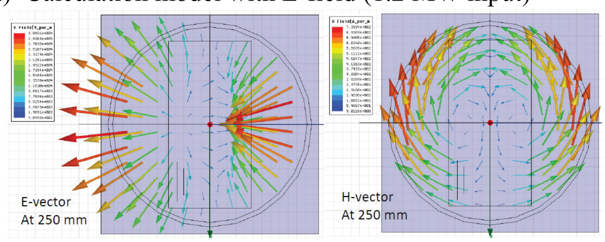
absorbed into the water. The total loss by absorption into the rf window and wall of water-tank is less than 1 %. The tap-water was chosen as the absorber, because temperature dependence of tanδ is small. The value of tanδ is varied as 0.04~0.046 at 20~70 °C. The dielectric constant is also varied 69~83. In case of the pure-water, the tanδ decreases dramatically with temperature rise. The value of tanδ becomes 0.015 at 60 °C [4].



a) Calculation model with E-field (1.2 MW input)



b) E-field (left) and H-field (right) distribution on the cross section at 250 mm away from the rf window.

Figure 2: Calculation model.

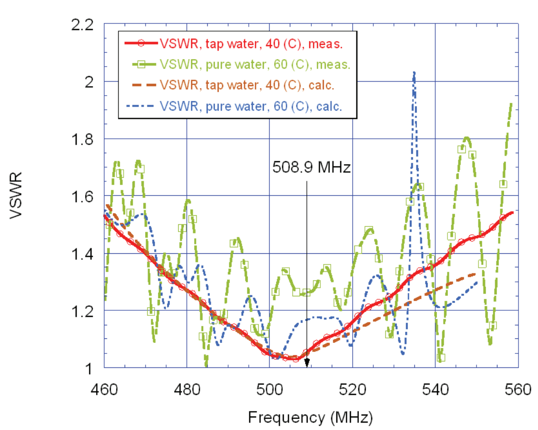


Figure 3: Broadband performance of the tap-water and pure water (measured and calculated value).

In the calculation, we assumed that the rectangular TE_{10} mode was excited from the input port. The VSWR and the field distribution in the load were estimated. According to result of the calculation, the penetration mode in water-tank was the circular TM_{11} mode. The mode was converted from TE mode to TM mode by the gap. The maximum surface current into load was 600 A/m at the input power of 1.2 MW and the location of the rf window. In the existing model, that was 2000 A/m at same location. The surface current was reduced to 1/3 by choosing the cylindrical shape.

Measurement and calculation results of VSWR of water-load with tap-water and pure-water are shown in Figure 3. In the measurement, the waveguide-to-coaxial adapter and the NWA (E8356A) were used. The minimum value of VSWR with the tap-water of 40 °C was 1.03 at 505.4 MHz. The VSWR at 508.9 MHz was 1.05. The variation of frequency of the minimum VSWR at 20~60 °C was 502.8~505.1 MHz. The bandwidth of VSWR less than 1.1 and 1.2 was ±10 and ±19 MHz from the frequency of the minimum VSWR. The measurement result was consistent compared with the calculation result. Therefore, the value of measurement was acceptable the specification at low-power. In the pure-water, a wave undulation was showed in the broadband response because of the tanδ of pure-water is small in compare with tap-water. To obtain a soothing response in case of the pure-water, the length of water-tank must change to long ~ 3 m.

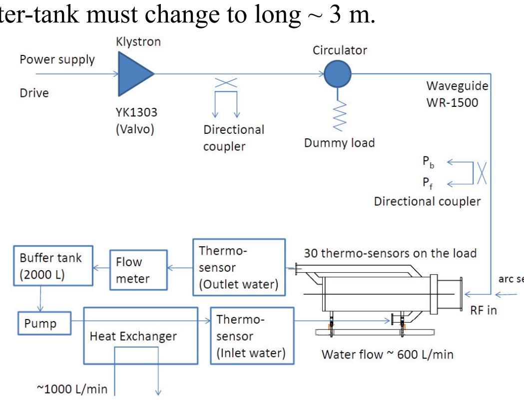


Figure 4: High-power test setup and arrangement.

HIGH POWER TEST

Setup of High Power Test

The high-power test of new water-load was carried out in Oct. 2012. Figure 4 shows the setup of the high-power test at D2-ET station. A high power klystron was used YK1303 (1.1 MW output power, made by Valvo at 1986). The flow rate of cooling water (absorber) to the load can changes from 400 to 600 l/min by the inverter motor drive of pump unit. The forward (P_f) and backward (P_b) power were monitored by the directional coupler and the power meter. The power absorbed into the water was also checked calorimetrically by measuring a temperature rise of cooling water. A number of the thermo-sensor attached on the load was 32 (the location shows in Figure 6). An arc-sensor was set to monitor an arc on the rf window, and a signal from arc-sensor was used for a rf interlock to protect the rf window. The rf power was gradually increased in about 50~100 kW step-up to 1 MW. At each power level, the rf process was carried out for 10~30 min.

Result of the High Power Test

The temperature rise of various locations on the surface of water-load for each power level is shown in Figure 5. At 1 MW with 604 l/min water-flow (Inlet: 31.3 °C), a maximum temperature was 65.2 °C at 400 mm away from the rf window. At the ceramic window, the temperature was 42~51 °C. The temperature of other locations was

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higher about 2 °C compared to the temperature of outlet water. In case of the existing model, the maximum surface temperature at 1 MW was 78 °C [3]. The temperature on the surface of new model was more than 10°C lower compared to the existing model. Figure 6 shows the response of all monitors at 1 MW input after holding 10 min. The VSWR during high-power test was changed 1.04 ~ 1.06 at each power level.

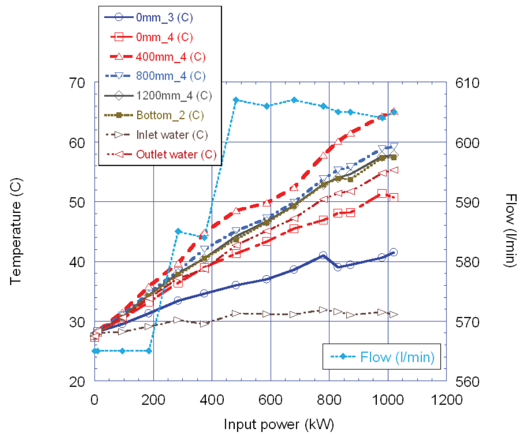

Figure 5: Surface temperature versus input power.

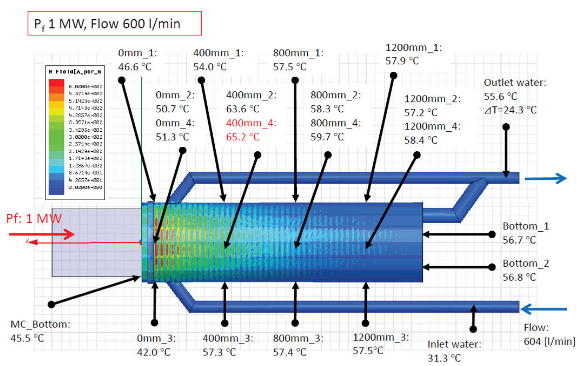

Figure 6: Thermo-sensors response at 1 MW input.

WATER-FLOW ANALYSIS

The state of the water-flow in the load is important to achieve absorption of the high-power without troubles. The 3D water-flow in the loads calculated using by the Solidworks Flow Simulation. And a mock-up made of acrylic was also made to check the water-flow by visual observation. In the calculation, the effect of gravity was applied, and the insulated wall was used for the structure. A heat load to the cooling water was set on the location of the rf window to optimise the structure of water-tank.

The calculation result of the velocity vector is shown in Figure 7. The state of the water-flow obtained by calculation was well reproduced visual observation. The loss of water pressure of new model was ΔP = 7400 Pa, and the existing model was ΔP = 13700 Pa. The loss of water pressure was decreased to half by changing the structure of the load. Figure 8 shows a temperature distribution in the cooling water with dummy heat load. The temperature of the edge around rf window and the both side near rf window was higher compared to other locations. By changing the structure around edge, the water-flow could be improved without degradation of the broadband response. That is under designing for the next version.

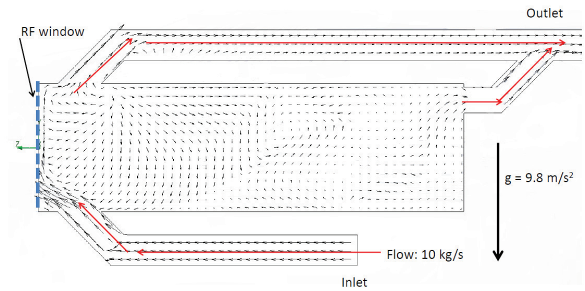

Figure 7: Velocity vector of water-flow.

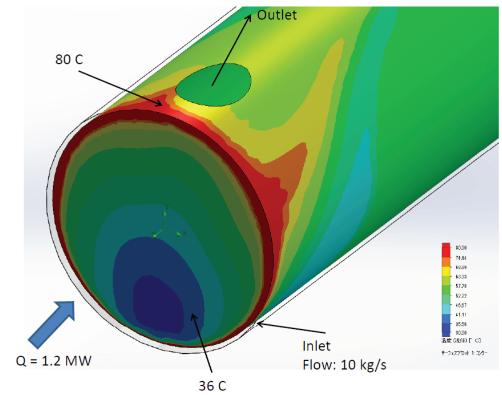

Figure 8: Temperature distribution in the load with dummy heat load (1.2 MW).

SUMMARY

- A new high-power water-load with a cylindrical water-tank has been developed for the SuperKEKB.
- The surface current was reduced to 1/3, and the loss of the water pressure was also decreased to half by changing the structure of load.
- The high-power test was carried out and acceptable without troubles. The maximum surface temperature at 1 MW was more than 10 °C lower compared to the existing model.
- Total 12 loads are under manufacturing until March 2014 for reinforced rf system. The design of the water-tank is under making for the next version to absorb more high-power.

REFERENCES

[1] SuperKEKB, URL: http://www-superkekb.kek.jp
[2] K. Akai, “RF system for SuperKEKB”, proceedings of the 7th Annual Meeting of Particle Accelerator Society of Japan, Himeji, Japan, Aug 2010, WESH05 (in Japanese).
[3] Y. Arisumi et al., “Development of 1.2 MW High Power Water Load”, proceedings of the 12th Sympisium on Accelerator Science and Technology, Wako, Japan, 1999.
[4] K. Ebihara et al., “RF High Power Water-Load for KEKB”, proceedings of the APAC01, Beijing China, 2001.