OPERATION OF ARES CAVITIES FOR KEKB

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Abstract

The normal conducting RF system for the KEKB double-ring collider contains: 8 RF stations with 8 klystrons and 16 ARES (Accelerator Resonantly coupled with Energy Storage) cavities for the low-energy ring (LER); 5 RF stations with 5 klystrons and 10 ARES cavities for the high-energy ring (HER). The ARES cavity developed against difficulties associated with heavy beam loading conditions is a three-cavity system operated in the $\pi/2$ mode, in which an accelerating cavity is resonantly coupled with an energy storage cavity via a coupling cavity equipped with a parasitic mode damper on the 0 and π modes. On the whole, the ARES cavities have performed well to support the high current beams of both rings in spite of many troubles and accidents.

1 SYSTEM OVERVIEW

Figure 1 schematically shows the ARES cavity system. The design is based on a conceptual demonstrator named ARES96 [1] for a three-cavity system [2] proposed to solve difficulties associated with heavy beam loading conditions. Major RF parameters are listed in Table 1. The design cavity voltage of 0.5 MV is generated with a wall power dissipation of 150 kW in total, 60 kW and 90 kW inside the accelerating and storage cavities, respectively, where the stored energy ratio $U_a : U_s$ is 1 : 9.

The energy storage cavity operated in the TE_{013} mode is a large cylindrical steel structure with dimensions of 1070 mm in diameter and 1190 mm in axial length, whose inner surfaces are copper plated. The Q value of the TE_{013} mode is 1.65×10^5, which is 85% of theoretical assuming a copper electrical conductivity of 5.81×10^7 S/m. The circumferences of both end plates are grooved in order to resolve the degeneracy of the TE_{013} and TM_{113} modes. The RF power is fed through an input coupler [3] attached to one of the two drive ports at the middle level. The storage and coupling cavities are electromagnetically coupled through a rectangular aperture of 120 mm× 180 mm, and mechanically connected with rectangular flanges using bolts. Thin stainless-steel lips at the flange connection are to be welded for vacuum seal in a final stage. For high-power testing above the ground before installation or operation in early commissioning phases, a rubber gasket is to be temporarily used instead.

The accelerating cavity itself is a HOM-damped cavity with four rectangular waveguides at the upper and lower sides and with two grooved beam pipes [4] at both ends. The accelerating cell structure was designed as simple as possible from the viewpoint of structural stability in thermal deformation rather than increasing the shunt impedance. Details of the HOM-damped structure are found in a companion paper [5].

In the horizontal direction, the coupling cavity is brazed to one side of the accelerating cavity and coupled through a rectangular aperture of 120 mm× 160 mm. At the opposite side, another half-cell coupling cavity is brazed for the $\pi/2$-mode termination to restore the symmetry of the accelerating cavity with respect to the mid vertical plane. Furthermore, the coupling cavity is equipped with an antenna-type coupler [6] for damping the parasitic 0 and π modes. The extracted RF power is guided downward through a coaxial line toward a water-cooled dummy load.

2 OPERATIONAL STATUS

The commissioning of the HER was first started with 6 ARES cavities and 4 superconducting cavities in December 1998, and followed by the commissioning of the LER with 12 ARES cavities in January 1999. A typical operational RF voltage in the early stage was 0.4 MV per ARES cavity, 80% of the design voltage. In the summer of 1999, the number of ARES cavities in the LER was increased from 12 to 16, and in the HER from 6 to 10. Furthermore, every ARES cavity in the LER was vacuum-sealed by welding the thin metal lips at the flange connection after removing the rubber gasket. On the other hand, rubber gaskets are still used for the ARES cavities in the HER.

The real high luminosity operation was started in the fall of 1999. The beam currents of both rings were increased stepwise, overcoming many difficulties and improving the machine performance. As a whole, the ARES cavities have performed well in supporting the beam currents up to 950 mA in the LER and up to 780 mA in the HER in spite of many troubles and accidents stated later. In ordinary operation for the Belle experiment, the maximum cavity voltage was 0.43 MV, generating the total voltage of 6 MV for the LER with 14 cavities at 7 RF stations out of the 8 RF stations, one of which was not operated due to a cavity vacuum trouble. The maximum RF power transferred with one input coupler was about 260 kW at a beam current of 900 mA in the LER.

3 TROUBLES AND ACCIDENTS

Since the commissioning of KEKB, we have encountered many troubles and accidents with some ARES cavities and with some accessory devices. The problems can be roughly divided into two categories: infancy problems especially with accessory devices emerging in a long term operation, and cavity problems attributed to quality control issues usually incompatible with stringent cost goals in production phase.

Major troubles and accidents are given below in chronological order:

• A rubber gasket was burned due to RF power leakage at cavity No. 1 of the LER RF station D8C (LER-D8C#1 in abbreviation) in April 1999. The gasket was used for vacuum seal at the rectangular flange connection between the storage and coupling cavities. The power leakage was due to a machining defect on the contacting surface at the flange of the storage cavity. In the summer of 1999, the storage cavity was replaced with a new one and returned to the manufacturer for repair.

• An intermittent vacuum pressure rise occurred at LER-D8D#2 in October 1999. The trouble was due to a chemical solution for copper plating, which had been trapped in welding defects at some pumping ports of the storage cavity. Fortunately, the vacuum pressure was improved by baking the pumping ports with electric heaters. The station D8D recovered in January 2000.

• At LER-D7D#2, the doorknob-type transformer at the entrance of the input coupler was burned and partially melted in January 2000. The trouble was due to defective brazing between a thin copper dome part and a stiffener ring. Fortunately, the doorknob and other waveguide parts were replaced without breaking the vacuum and the cavity recovered in about 6 hours.

• In the fall of 2000, a thermal vacuum pressure rise phenomenon suddenly started up at LER-D7C#2 when the cavity was fed with an RF power of several ten kW. Finally, this vacuum trouble brought the station to a shutdown from November 2000 to July 2001. Recently, it was found that the trouble had been due to a piece of plastic stuff left in the accelerating cavity.

• At HER-D5C#2, the input coupler window was cracked due to arcing in November 2000. The cause of this accident was an arc sensor which had not been attached to a proper view port. The input coupler was replaced with a new one and the vacuum recovered in two days. However, the station was finally brought to a shutdown from November 2000 to July 2001 due to a leakage of cooling water to the air at the lower end plate of the storage cavity, which was found while dealing with the coupler accident and was difficult to repair in situ.

• A sudden vacuum pressure rise occurred at HER-D4C#2 in January 2001. A leak was located at a cooling water circuit for the ceramic window of the parasitic mode coupler. After the coupler was replaced with a new one, another leak was found and located again at a cooling water circuit for the input coupler window. Those leaks had been probably caused by erosion-corrosion of copper walls. Erosion-corrosion arises from a combination of chemical attack and the physical abrasion as a consequence of the fluid motion. Aggressive waters do not allow a protective film (oxides) to form inside the copper tube. Although the investigation is under way, the cooling water had been probably made aggressive by molybdenum oxide coming from molybdenum wires exposed to the cooling water with dissolved oxygen gas. Molybdenum wires are usually used as backup support when brazing a metal sleeve to a ceramic window. After the accident, an anticorrosive agent was added to the cooling water for the couplers.

• At LER-D7C#2, the parasitic mode coupler was burned in March 2001, although the station was not operated. The window was cracked due to thermal deformation. The accident was initiated from a cooling water leakage inside the 40-kW dummy load for the parasitic mode damper system. The water leakage led to the deterioration of the load performance, i.e. VSWR. Then, the beam-induced power extracted through the parasitic mode coupler was reflected at the load, and a standing wave was built up to heat the coupler. In order to avoid similar accidents, a directional coupler used to monitor the extracted power is going to be converted to a bi-directional type, which enables the real-time monitoring of the VSWR of the dummy load.

Fortunately, none of these troubles or accidents had limited the beam current in the LER or HER. Through the operation, we have improved the temperature monitor for the ARES cavity system, especially for some high-power accessory devices. For example, window arcing trips have been reduced by systematic maintenance based on the statistics obtained by monitoring the doorknob temperature for every input coupler.

4 CONCLUSION

On the whole, the ARES cavities have functioned well so far to support the high current beams for the LER and HER while we have encountered many troubles and accidents. With operational experience accumulated through those difficulties, we have made great progress and are confident of the performance and growth potential of the ARES cavity system toward high-luminosity frontiers beyond 4.49×10^{33} cm^{-2} s^{-1} explored with the KEKB collider.

ACKNOWLEDGMENT

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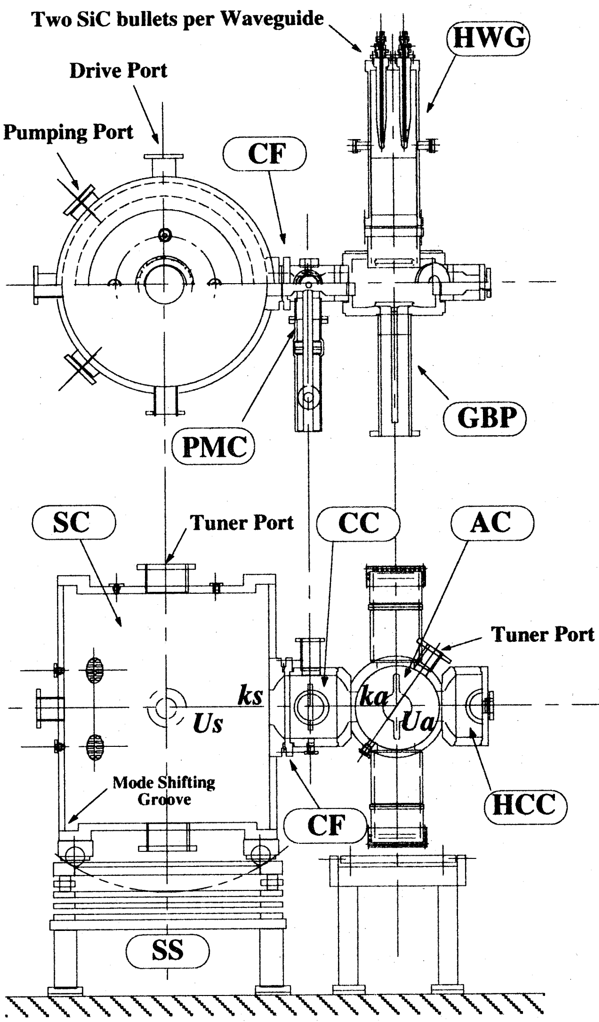
Table 1: Major RF parameters of the ARES cavity.

f_{RF}	=	508.887 MHz
$Ua : Us$	=	1 : 9
R / Q	=	15 Ω
Q	=	1.1×10^5 †

Pc = 150 kW per ARES Cavity generating Vc = 0.5 MV (KEKB Design)

†: in high-power operation with Pc = 150 kW



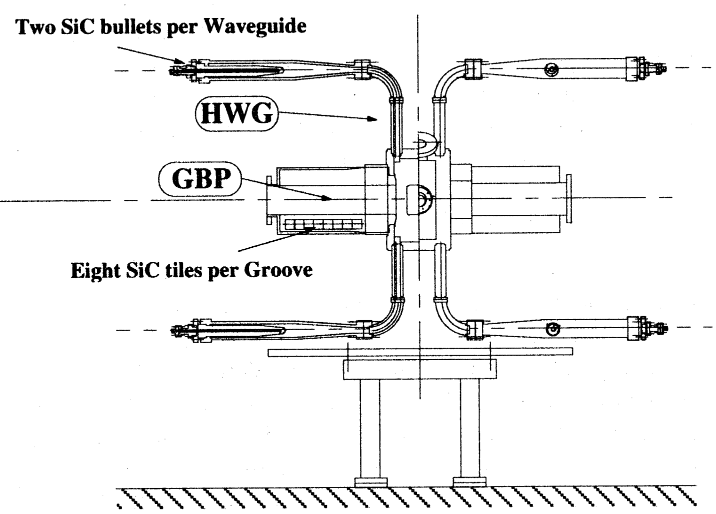


Figure 1: A schematic drawing of the ARES cavity system.

AC: Accelerating Cavity with four rectangular HOM waveguides (HWG's) for damping monopole HOM's and dipole HOM's deflecting the beam in the vertical direction, and with two Grooved Beam Pipes (GBP's) at both end plates for damping dipole HOM's deflecting the beam in the horizontal direction.

CC: Coupling Cavity functions as the keystone of the ARES cavity system, and is equipped with a Parasitic Mode Coupler (PMC) to damp the 0 and π modes.

PMC: Parasitic Mode Coupler for reducing the impedances of the parasitic 0 and π modes at both sides of the π/2 accelerating mode. Both modes are to be damped down to $Q_L \approx 100$.

CF: Connecting Flange
The Storage Cavity (SC) and the Coupling Cavity (CC) are mechanically connected with rectangular flanges using bolts. Thin stainless-steel lips at the flange connection are to be welded for vacuum seal.

GBP: Grooved Beam Pipe selectively lowers the cutoff frequency of the TE11 wave and damps dipole HOM's of the accelerating cavity. Each groove has 8 SiC ceramic tiles brazed to a water-cooled copper plate.

HCC: Half-cell Coupling Cavity restores the symmetry of the accelerating cavity (AC) with respect to the mid vertical plane including the beam axis.

HWG: HOM Waveguide is 240 mm wide and 28 mm high. Two bullet-shape sintered SiC ceramic absorbers are inserted from the end of each waveguide.

SC: Storage Cavity is a cylindrical steel cavity with electro-plated copper surfaces, and operated in the TE_{013} mode with $Q_0 = 165000$.

SS: Supporting Structure allows the storage cavity (SC) x- and y-parallel motions in the horizontal plane, and the pitch-, roll- and yaw-motions with respect to the connecting flange (CF) direction.