THE ARES CAVITY FOR KEKB

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Abstract

The ARES (Accelerator Resonantly coupled with Energy Storage) structure is a normal conducting coupled cavity system operated in the π/2 mode designed for use under heavy beam loading environment of the KEK B meson factory (KEKB). Its accelerating cavity is coupled with an energy storage cavity via a resonant coupling cavity. The coupling cavity is equipped with a coaxial antenna damper in order to reduce the impedances of the parasitic 0 and π modes. The ARES structure has been demonstrated through a series of high-power RF tests and high-current beam experiments carried out with two prototype cavities named ARES95 and ARES96, where the former with Quadrupole Counter Mixing (QCM) choke method and the latter with Grooved Beam Pipe (GBP) one for Higher Order Mode (HOM) damping. This paper reports on the production model whose RF design is based on ARES96.

1 OVERVIEW

The RF cavity system ARES [1] has been developed as a countermeasure against the longitudinal coupled bunch instability driven by the accelerating mode. With a beam load, the resonant frequency of the accelerating mode has to be shifted toward the lower side of the RF frequency in order to compensate for the reactive component of the cavity voltage induced by the beam. The required frequency detuning for a conventional copper cavity employed in KEKB would exceed the revolution frequency, leading to the large excitation of a coupled-bunch synchrotron oscillation.

The ARES structure is a π/2-mode coupled cavity system as shown in Fig. 1, where its accelerating cavity is resonantly coupled with an energy storage cavity operated in a high-Q mode such as the TE_{013} mode via a coupling cavity. The energy storage cavity is employed in order to reduce the required frequency detuning, which is inversely proportional to the ratio of the electromagnetic stored energy over the reactive part of the beam-field interaction energy.

The π/2-mode operation with the coupling cavity enables the following key design features of the ARES:

- The π/2 mode is the most stable against tuning errors and heavy beam loading.
- The stored energy ratio U_s: U_a, where U_s is the stored energy in the storage cavity and U_a in the accelerating cavity, can be easily adjusted by changing the coupling factor ratio k_s : k_a, where k_s is the coupling factor between the storage and coupling cavities and k_a between the accelerating and coupling cavities.
- The parasitic 0 and π modes can be selectively damped by installing a coaxial antenna-type damper in the coupling cavity.
- The damped 0 and π modes are located nearly symmetrically with respect to the π/2 mode. Therefore, their impedance contributions to the beam instability cancel out each other.
- The coupling cavity functions as a filter to isolate the storage cavity from the HOM's of the accelerating cavity.

Needless to say, the accelerating cavity itself of the ARES system has to be a HOM-damped cavity. Two ARES prototypes with different HOM damping structures were developed: ARES95 [2] with Quadrupole Counter Mixing (QCM) choke method [3], and ARES96 [4] with Grooved Beam Pipe (GBP) one [5]. Both prototypes were successfully demonstrated through a series of high-power RF tests and high-current beam experiments carried out in the TRISTAN accumulation ring (AR) in 1996 [4], [6], [7].

2 DESIGN FEATURES

Figure 1 shows a schematic drawing of the ARES production model, whose RF design is based on ARES96. Severe high-power testing of ARES96 as the production prototype was further continued after the beam test in order to verify its long-term reliability. The basic RF parameters are listed in Table 1, together with the high-power test records.

As shown in Fig. 1, four straight rectangular waveguides are directly brazed to the upper and lower sides of the accelerating cavity in order to damp the monopole HOM's and also the dipole ones deflecting the beam in the vertical direction. The waveguide width was chosen 240 mm, which gives a cutoff frequency of 625 MHz for the dominant TE_{10} wave. An E-bend waveguide is attached to the end of each straight one to guide the extracted HOM RF power toward the load of two bullet-shape SiC absorbers. Each absorber, with dimensions of 55 mm in diameter and 400 mm in length including a tapered section, is directly water-cooled, and its power capability was verified up to 3.3 kW per bullet at a dedicated test bench with use of a L-band CW klystron.

The beam pipes attached to both end plates of the accelerating cavity are grooved as shown in Fig. 1 in order to damp the dipole HOM's deflecting the beam in the horizontal direction. The GBP (Grooved Beam Pips) method [5] is very effective for damping the dipole HOM's. The cutoff frequency of the TE_{11} wave, which couples with the cavity HEM_{11} modes, can be selectively lowered by grooving the inner wall of the beam pipe. The groove dimensions are chosen 30 mm in width and 95 mm in depth, which lowers the TE_{11} cutoff frequency below 650 MHz for the circular beam pipe with an inner diameter of 150 mm. As the GBP HOM load, eight SiC ceramic tiles in each groove are arranged in a line, and each tile is brazed to a water-cooled OFC (Oxygen Free Copper) plate with an OFC compliant layer. Its power capability is about 0.5 kW per groove, upgraded from 0.25 kW per groove for the prototype ARES96 with each tile attached with a bolt to a water-cooled SUS plate with a soft metal (gold) sheet sandwiched between. The high-power tests for the GBP HOM load were also carried out with use of the L-band CW klystron. The HOM loads for ARES96 were reported in detail in Ref. [8].

The coupling cavity, the keystone of the ARES as mentioned above, is directly brazed to the accelerating cavity, and is electromagnetically coupled through a rectangular aperture of 120 mm by 160 mm. Another half-cell coupling cavity is brazed at the opposite side for the $\pi/2$-mode termination.

A coaxial-type antenna coupler [9] is installed in the coupling cavity in order to damp the parasitic 0 and π modes down to loaded-Q values of about 100. The coupler is a coaxial waveguide (WX120D) complex with a cross stub support and a disk-type ceramic window, and the extracted RF power is guided through a tapered coaxial waveguide (WX120D-WX77D) to a water-cooled dummy load.

The energy storage cavity is a large cylindrical cavity with dimensions of 1070 mm in diameter and 1190 mm in axial length. Its major parts are a steel cylinder and two steel endplates, whose inner surfaces are copper-plated. About 90% of the electromagnetic energy of the $\pi/2$ accelerating mode is stored in this cavity operated in the TE_{013} mode, and its Q value achieved with the electro-plated copper surfaces is 1.65×10^5, including the reduction due to the coupling and port apertures, 83% of the theoretical value of 2.00×10^5. The degeneracy of the TM_{113} and the TE_{013} modes is resolved with a mode-shifting groove at each endplate's circumference. A movable tuning plunger with a diameter of 200 mm and a travel of 60 mm is installed in the central port of the upper endplate, while a fixed one in the central port of the lower endplate.

The storage and coupling cavities are coupled through a rectangular aperture of 120 mm by 180 mm, and are mechanically connected with rectangular flanges with bolts. The thin lips around both flanges are TIG-welded for vacuum sealing at the final installation phase in the KEKB tunnel. At a dedicated high-power test bench, a rubber gasket is temporarily used instead. That is because the storage and coupling cavities are separated for their installation after the high-power test completed. The performance of the rubber gasket was verified up to the maximum input power of 180 kW, limited by the radiation regulations applied to the test bench above the ground.

The RF power is fed to the ARES cavity system through an input coupler installed in one of three circular ports located at the middle level of the storage cavity. The RF power is transferred from the rectangular waveguide (WR1500) input, via a door-knob transition with a capacitive iris, to the coaxial waveguide (WX152D) with a disk-type ceramic window. The coaxial waveguide is tapered down (WX77D), and ends with a magnetic coupling loop. Two types with different window matching structures were developed [10]: the over- and under-cut type, and the choke one. Recently, both types were verified up to 950 kW [10], far above the design power capability of 400 kW.

3 PRODUCTION STATUS

The production of 24 ARES cavities for the first phase of KEKB operation has been started 1997. Eight ARES cavities have been constructed up to now and 7 out of them have been conditioned up to 180 kW at the dedicated high-power test bench. The first installation of 6 ARES cavities in the KEKB LER (Low Energy Ring) tunnel will be started immediately after this conference.

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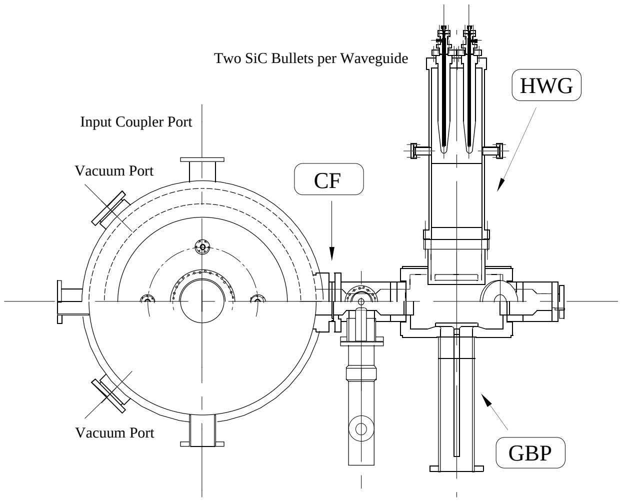

Table 1: RF design parameters of the ARES production model, and the high-power test records achieved with the production prototype ARES96.

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)

High-Power Performance

Maximum Continuous: Pc = 380 kW
Maximum for 20 minutues: Pc = 450 kW

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

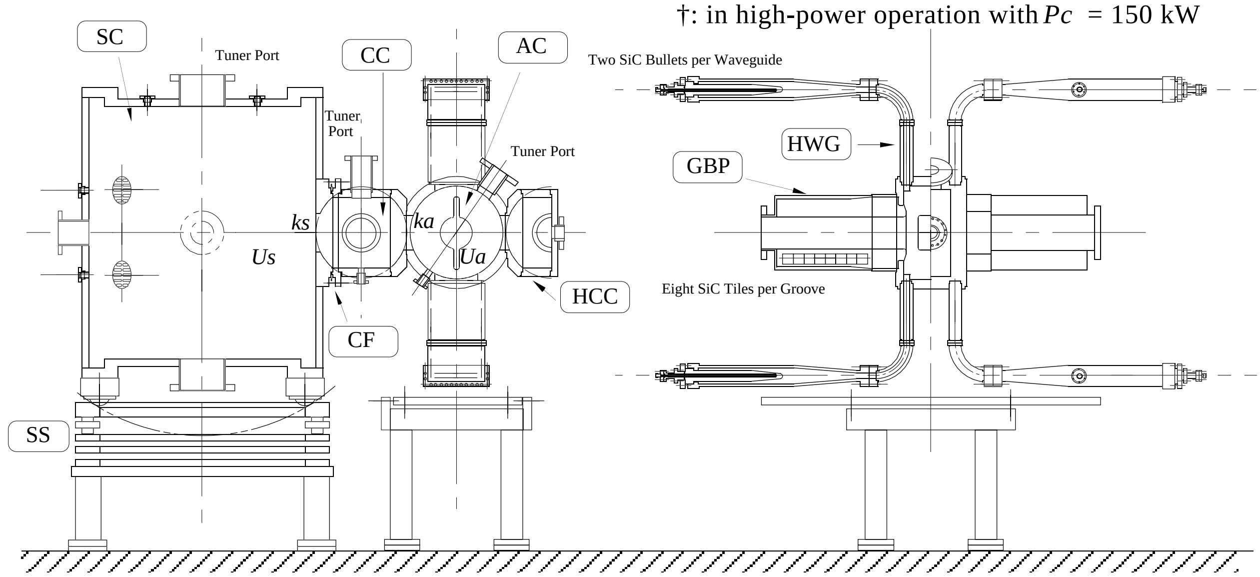

Figure 1: A schematic drawing of the ARES production model based on the prototype ARES96.

AC: Accelerating Cavity with four HOM rectangular waveguides (HWG's) for damping the monopole and the dipole-V HOM's, and with two Grooved Beam Pipes (GBP's) at both end plates for damping the dipole-H HOM's.

CC: Coupling Cavity functions as the keystone of the ARES structure, and is equipped with a Coupling Cavity Damper (CCD) to damp the parasitic 0 and π modes.

CCD: Coupling Cavity Damper for reducing the impedances of the parasitic 0 and π modes. Both 0 and π modes are damped about $Q_L \approx 100$.

CF: Connecting Flange
The Storage Cavity (SC) and the Coupling Cavity (CC) are mechanically connected at rectangular flanges with bolts, and its vacuum-seal is obtained by TIG-welding the lips around the flanges.

GBP: Grooved Beam Pipe selectively lowers the cutoff frequency of the TE11 traveling wave and damps the dipole HOM's in 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 (240 mm by 28 mm) for damping the monopole and dipole-V HOM's. Two bullet-shape sintered SiC ceramic absorbers are inserted from the end of each waveguides.

SC: Storage Cavity is a steel cylindrical 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) the x- and y-parallel motions in the horizontal plane, and the pitch-, roll- and yaw-motions with respect to the connecting flange (CF) direction.