FUNDAMENTAL MODE CHARACTERISTICS OF ARES CAVITY UNDER BEAM ENVIRONMENT

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Abstract

Two types of ARES cavities were tested in the TRISTAN accumulation ring in KEK. In this paper, results relating to the fundamental mode in the accelerating cavity are reported. The status of the cavity, including the detuning frequency under beam loading and the output power from the coupling cavity damper, was measured at different beam current and with various bunch patterns. Its behavior agrees well with the calculation based on a coupled resonator model.

1 INTRODUCTION

The ARES cavity was developed to suppress multi-bunch instabilities induced by both fundamental and higher order modes (HOM) in KEKB [1]. It consists of three cavities: accelerating (a-), coupling (c-) and storage (s-) cavity. As a consequence of their coupling, the accelerating $\pi/2$-mode and parasitic 0- and π-modes are formed. The characteristics of ARES is:

1. The a-cavity is a damped cavity. The instability due to HOMs in the a-cavity is suppressed.
2. The R/Q of the accelerating mode is about 10 times lower than that of the a-cavity alone so that the resonant frequency of the accelerating mode do not cross integral multiples of the revolution frequency during the current build-up.

Table1 Parameters of the accelerating mode of ARESs.

	ARES95	ARES96	
Shunt Impedance R_{sh}	1.66	1.91	M Ω
Q_0	1.12×10^5	1.17×10^5	
R_{sh}/Q_0	14.8	16.3	Ω

Table2 Machine parameters of AR high current experiment.

Beam Energy	2.5	GeV
Radiation Loss	0.15	MeV/Turn
Momentum Compaction	0.0129	
Long. Damping Time	21.6	ms
Trans. Damping Time	43.1	ms
RF Frequency	508.58	MHz
Harmonic Number	640	

Two types of ARES cavity have been fabricated and tested under high RF power. They adopt different scheme of HOM damping for their a-cavity. The chokemode cavity [2] is used for the first ARES cavity (ARES95) [3]. The second ARES cavity (ARES96) is equipped with four rectangular waveguides and grooved beam pipes [4]. The parameters of their accelerating mode are listed in Table1.

These two ARES cavities were installed in the TRISTAN Accumulation Ring (AR) for preliminary testing under the electron beam current up to 570 mA. Main parameters of AR is listed in Table2. Principal aims of the test are:

1. Confirm its basic function and performance.
2. Study effects of HOMs on the beam.
3. Establish the cavity control method.

In this paper, the result of the first and third subjects above are reported. Effects of HOMs is reported elsewhere[5].

2 OPERATING ENVIRONMENT

2.1 Power Feed

The two ARES cavities were installed at one straight section in the TRISTAN AR ring. At another straight section, a superconducting cavity (SCC) and a choke mode cavity (CMC) were also installed. Only one ARES cavity was operated at a time while the other is detuned in order not to affect the beam stability.

The input RF power is fed to the s-cavity through the input coupler with a disk-type ceramic window [6]. The cooling water flow is 400l/sec for each ARES cavity.

2.2 Tuning of the A- and S-Cavities

The frequencies of the a- and s-cavities were controlled automatically with movable tuners independently [7]. The tuner for s-cavity controlled the relative phase between the input RF field and the field inside s-cavity so that the input impedance be purely resistive as usual. On the other hand, the frequency of the a-cavity is controlled so that the phase between the a- and c-cavity is $\pi/2$. The field in the c-cavity is excited as a consequence of energy flow from the s-cavity to the a-cavity.

0-7803-4376-X/98/$10.00

3 RESULTS

Mostly the study was concentrated on ARES96, which has been adopted as the normal conducting cavity for KEKB. It was operated for about 20 days while ARES95 was about 2 days. The following results are about ARES96 except 3.4.

3.1 Heavy Beam Loading

The maximum current while the cavity is operating is 500mA. No anomalous behavior was observed.

In the case of KEKB LER, the ratio of the power consumed by the beam to that by the cavity wall will be

$$\frac{P_b}{P_c} = \frac{200\,\mathrm{kW}}{150\,\mathrm{kW}} = 1.33.$$

In order to simulate the operation under a large beam loading, P_c is lowered to 85kW (V_c=0.4MV) and the relative phase between ARES and CMC was shifted to increase P_b in ARES. At the beam current of 300mA, the ratio was

$$\frac{P_b}{P_c} = \frac{75\,\mathrm{kW}}{85\,\mathrm{kW}} = 0.9,$$

and there was no anomalous behavior in the cavity control.

3.2 Frequency Detuning

The frequency detuning due to beam loading is expressed as

$$\Delta f = -\frac{f_{rf}}{2}\left(\frac{R_{sh}}{Q}\right)\frac{I_b}{V_c}\sin\phi, \qquad (1)$$

where R_{sh} and Q are the shunt impedance and Q value of the mode, and f_{rf}, I_b, V_c and ϕ are the RF frequency, beam current, cavity voltage and synchronous phase, respectively. In the scheme of ARES, the amount of frequency shift of the a-cavity is the same as in the case without the c- and s-cavities. However, the resonant frequency of the accelerating π/2-mode changes by

$$\Delta f_{\pi/2} = \frac{U_a \Delta f_a + U_s \Delta f_s}{U_a + U_s},$$

where Δf_n and U_n are the frequency shift and stored energy of the *n*-cavity. The detuning of the π/2-mode is $\Delta f_a/10$ since Δf_s is zero and U_a:U_s=1:9. Thus in KEKB LER, the largest detuning frequency will be about 30kHz, which is well below the revolution frequency of 99kHz.

The frequency detuning of the accelerating mode under beam loading could not be measured directly. It was estimated from the tuner positions of the a- and s-cavities. The frequency shift of the a-cavity is plotted as a function of the beam current in Fig.1. The total V_c was 1MV, which was the sum of 0.5MV of ARES96 and 0.5MV of CMC. The straight line in the figure is calculated from Eq.(1) with the a-cavity parameters R_{sh}=4.8MΩ and Q_0=3(10^4. The measurement agrees well with the calculation. On the other hand, the frequency of the s-cavity changed only slightly when the beam current changes. There was no frequency shift observed beyond random fluctuation when the beam current was kept constant.

The above measurement of the tuner positions indicates that the frequency detuning of the accelerating π/2-mode is in good agreement with the theory.

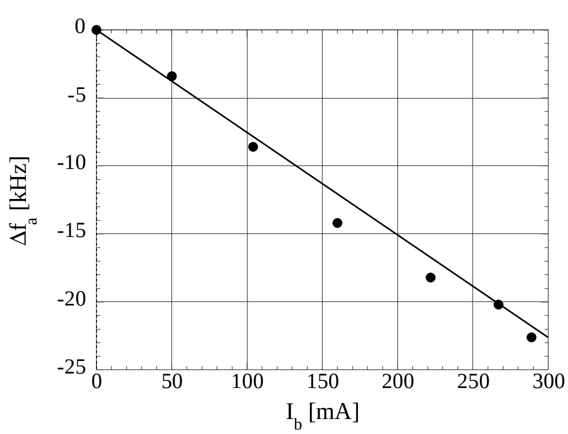


Fig.1 Frequency detuning of the a-cavity as a function of the beam current. The dots are measured value and the straight line is the expected value.

3.3 Power Output from the C-Cavity Damper

A coaxial waveguide is attached at the center of the c-cavity to damp the parasitic 0- and π-modes. A water load is connected on the other end of the waveguide with a ceramic window [8] between them. Only a small output power (measured 180W and expected 150W at V_c=0.5MV) flows out through the waveguide with no beam current. The output was observed with a peak power analyzer (HP8991A).

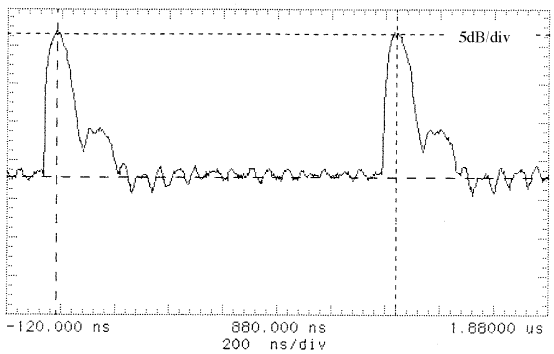
3.3.1 Single Bunch

Figure2(a) shows the output waveform with a current of 100mA single bunch. The distance between the two large peaks is the revolution time of 1.26μs. The time difference between a large peak and the following small peak is about 150ns, which corresponds to the beat frequency of the 0- and π-modes separated by 6.6MHz. The computer simulation based on a coupled resonator model [7] is shown in Fig.2(b), which reproduces the measured waveform pretty well. Although their absolute value cannot be compared precisely due to possible errors in the calibration of the measurement system, their difference is within a factor of 2.

3.3.2 Multiple Bunches

*With equally spaced 64 bunches, there was no prominent feature e*xcept small noises as expected.

(a)



(b)

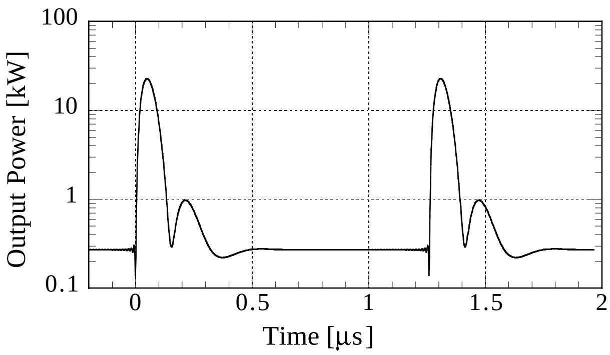
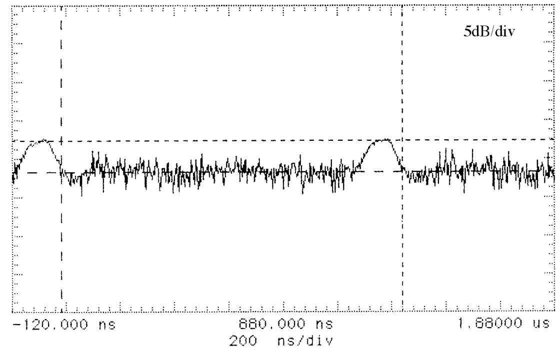


Fig.2 Output of the c-cavity with a current of 100mA single bunch. (a) is the measurement and (b) is the simulation.

3.3.3 Multiple Bunches with a Gap

When 8 consecutive bunches were removed from the equally spaced 64 bunches, a small hill emerges at the missing bunches (Fig.3(a)). Similar situation is expected in KEKB in order to avoid the instability due to ion trapping. The measured waveform is reproduced well by computer simulation as in the single bunch case.

(a)



(b)

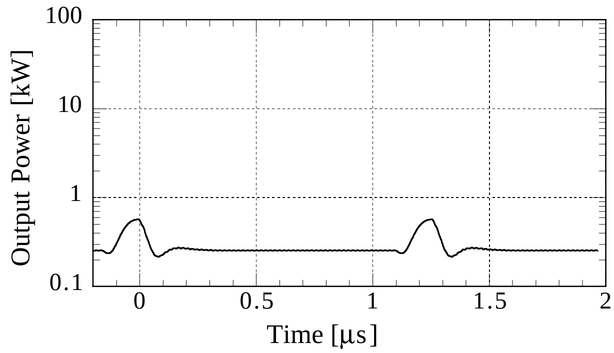


Fig.3 Output of the c-cavity when consecutive 56 buckets are filled out of equally spaced 64 buckets. The current was 164mA. (a) is the measurement and (b) is the simulation.

3.4 Cavity Start-up with a Circulating Current

In KEKB, accelerating cavity may have to start up with its full circulating current. This is because the refilling of the beam would take much time.

ARES95 was used for the start-up test. SCC provided the accelerating voltage while the input RF power was not fed into ARES95. Below 300mA, ARES95 started up without losing the beam. In some cases above 300mA, the beam was lost during the cavity startup. The beam loss occurred when the feedback changed from controlling the klystron output to controlling the cavity field. Although the effect of the start-up is smaller in KEKB because of the larger number of operating cavities, more sophisticated means of smooth feedback changing or a direct RF feedback system will be desirable.

3.5 Absorbed Power into the HOM dampers

There are several HOM dampers of SiC in ARES [9]. The maximum total power absorbed in one ARES was about 7kW. This value is not enough as a high power test for KEKB. They will be tested using a klystron up to higher power level.

4 SUMMARY

Two ARES cavities were tested under beam environment in TRISTAN AR. Their behavior agreed well with the prediction based on a coupled resonator model.

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