

DEVELOPMENT OF A 114.24MHz SUB-HARMONIC BUNCHER FOR THE KEKB INJECTOR LINAC

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Abstract

A 114.24-MHz sub-harmonic buncher cavity was newly developed to improve the single-bunch purity of the KEKB injector linac. The cavity was designed so as to have a high shunt impedance and a low maximum surface field at the acceleration gap. To reduce the probability of rf breakdown, the inner wall of the cavity was electrolytic-polished and a vacuum pump-out was put at the end wall of the cavity. Copper was selected as the structural material (it was copper-plated stainless steel for the old cavity) in order to improve the water-cooling capability and to reduce the resonant frequency shift by the gap-distance change when the input power increases. A cold test showed a shunt impedance of 1.2 MOhm, which is twice as large as that for the old cavity. The design, fabrication and results of low- and high-power tests and a beam-acceleration test are described.

1 INTRODUCTION

The upgraded KEKB injector linac (8.0-GeV e^- / 3.5-GeV e^+) is now at the stage of initial commissioning [1, 2]. The pre-injector of this linac has to provide single-bunch beams of 10nC in 10ps to produce intense positron beams. To satisfy this requirement, in this pre-injector, two sub-harmonic bunchers (SHB), i.e., SHB1 (114.24MHz) and SHB2 (571.2MHz) were introduced [3,4]. However, the bunch purity had not been sufficiently good; the percentage of the main-bunch current to the total current was only 80%. For this reason, we have developed a new SHB1 cavity having a large shunt impedance. Another problem of the old SHB1 cavity is low stability of the resonant frequency because of the gap-distance shift, due to poor cooling performance. Redesigns of the structural material and cooling-pipe configuration have been made.

2 DESIGN

According to the PARMELA simulation, it is possible to reduce the amount of the satellite bunch to less than 1% if the shunt impedance of the SHB cavity is increased by 1.7 times[4]. The dimensions of the new cavity was determined for this goal on the condition that the cavity can be install in the existing focusing coils ($\phi 200$ mm).

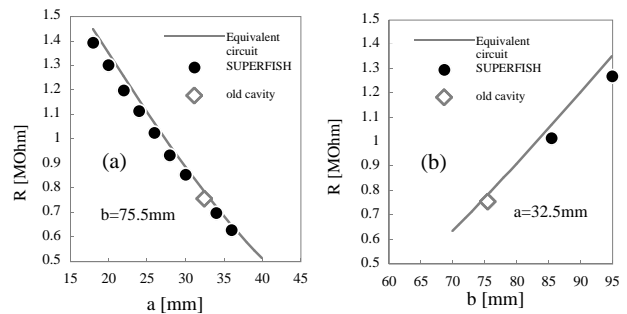


Figure 1: Dependence of shunt impedance on cavity dimensions; (a) inner radius, a ; (b) outer radius, b .

Figure 1 shows the dependence of the shunt impedance (R) on the inner radius (a) and the outer radius (b) of the cavity calculated by SUPERFISH and an equivalent-circuit model (quarter-wavelength-long short-circuited antiresonant transmission line). This figure shows that the required shunt impedance can be obtained when the values of a and b are selected as 30mm and 90 mm, respectively; these values were 32.5mm and 75.5 mm, respectively, for the old cavity.

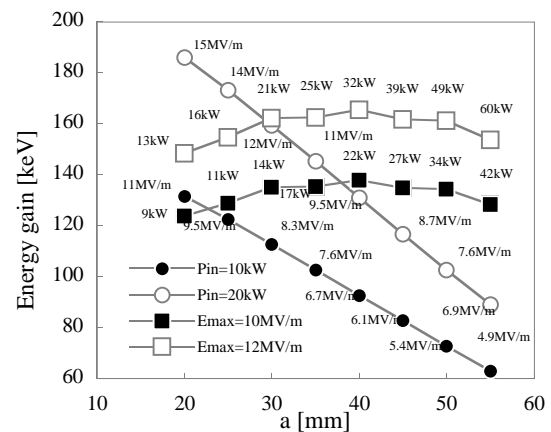


Figure 2: Relation between the energy gain and the inner radius (a). The numbers beside each mark show the maximum electric field for $P_{in} = \text{constant}$ or the required source power for $E_{max} = \text{constant}$.

Figure 2 shows the relation between the energy gain of SHB1 and the inner radius (a). When the input power is constant, the smaller is a , the larger is the energy gain. However, when the maximum surface field is constant,

the energy gain is maximum at $a = 40\text{mm}$. Finally we set the value of a at 30mm because the power source available at present is limited to 10kW and beam handling would be difficult if the value of a is too small.

The distance of the acceleration gap was determined as being 40mm (it was 18mm for the old cavity) because the longer is the gap distance, the lower is the maximum surface field. Though the shunt impedance also decreases for a wider gap distance, it is only a few percent (see Figure 3).

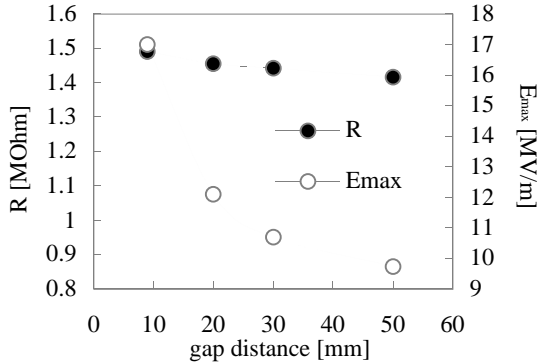


Figure 3: Shunt impedance, maximum electric field vs gap distance.

As the structural material, copper-plated stainless steel has been used for the old cavity. Also, only the outer conductor has been water-cooled. Consequently, the cooling performance is not good, which causes a change in the resonant frequency when the input power is changed. In the new cavity, copper (oxygen free copper) is selected as the structural material, and the inner conductor and both end plates are water-cooled.

The calculated value of the shunt impedance for the final dimensions (see Figure 4) is $1.28\text{M}\Omega$, which is 1.7-times that for the old cavity ($0.77\text{M}\Omega$).

As an rf input coupler, a loop antenna of coaxial waveguide (20D) has been selected instead of that of coaxial line, which is used in the old cavity, because it has a high possibility of rf breakdown. A copper rod ($\phi 24\text{mm}$) is used as the tuner. According to a MAFIA calculation, a frequency change of 200kHz can be obtained by a stroke of 40mm . The tuner is remote-controlled using an ultrasonic motor

An ion pump (10l/s) is put at the end plate (see Figure 4) to improve the vacuum level of the cavity. All inner

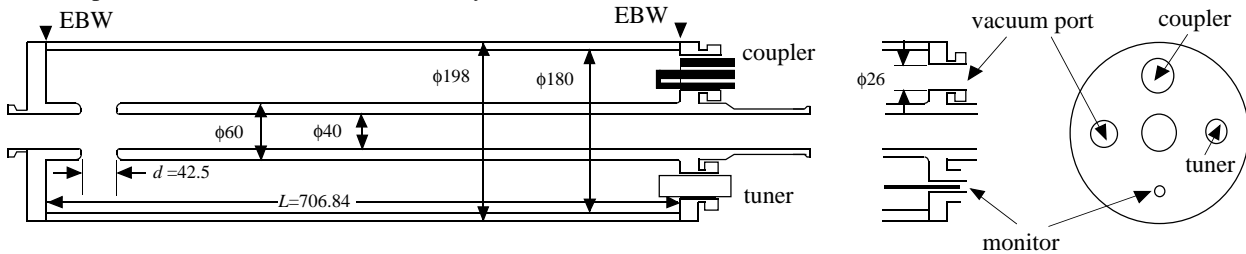


Figure 4: Cross-sectional view of the new Sub-harmonic buncher cavity.

parts of the cavity were electrolytic-polished ($20\mu\text{m}$).

3 LOW POWER TEST

The resonant frequency was tuned by adjusting the length of the short nose (d_L). The sensitivity of the dimensions on the resonant frequency is given in Table 1.

Table 1: Sensitivity of the dimensions on the resonant frequency. Units of kHz/mm .

	$\partial f/\partial L_R$	$\partial f/\partial L_L$	$\partial f/\partial d_R$	$\partial f/\partial d_L$
SUPERFISH	174.18	0	210.73	36.95
Measurement	-	-	200.0	36.3

The results of a low-power test are given in Table 2. The ratio of the measured Q_0 to the calculated Q_0 (Q_0^m/Q_0^c) has increased from 0.75 for the old cavity to 0.93. This may be due to an improvement in the electrical contact because end-plates were connected using bolts and nuts in the old cavity but are connected by electron-beam welding in the new cavity.

Table 2: Results of low-power tests.

SUPERFISH	measurement				
Q_0	Q_0	Q_c	Q_L	β	Q_0^m/Q_0^c
7523	6989	6741	3433	1.04	0.93

The shunt impedance was obtained from R/Q values measured by Slater's bead perturbation method [5]. Figure 5 shows the electric-field distribution on the beam axis near to the acceleration gap.

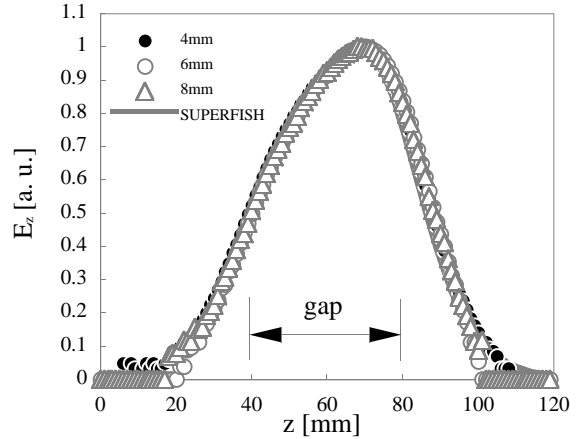


Figure 5: Distribution of the axial electric field measured by the bead-perturbation method.

Aluminum spheres of diameter 4, 6, and 8mm were used as perturbaters. When these values are extrapolated to the limit of zero volume, the value of shunt impedance of 1.15MOhm was obtained (see Figure 6).

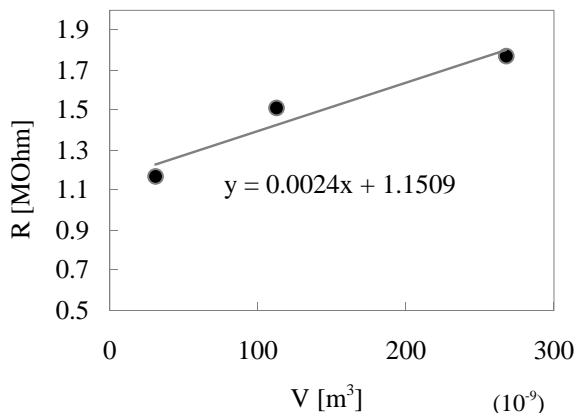


Figure 6: Relation between volume of bead and shunt impedance.

4 HIGH POWER TEST

Electric discharges by multipactoring have been observed during the initial stage of rf conditioning; it took ten days to reach an input power of 10kW without focusing coils and two days after the addition of coils. During rf conditioning, no change in the resonant frequency was observed. The pulse shapes for an input power of 10kW are shown in Figure 7. The time constant calculated from this pulse shape is about $10\mu s$. The theoretical value is $9.6\mu s$ ($= 2Q_L/\omega$).

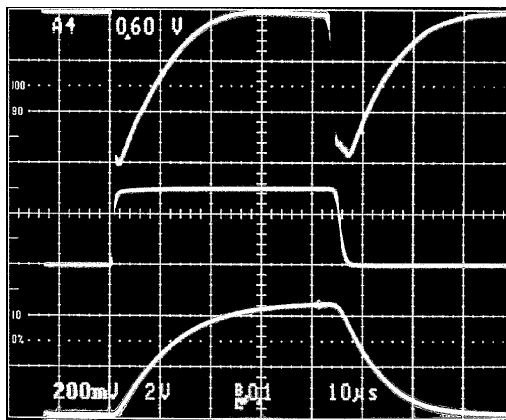


Figure 7: Photograph of rf pulses. Top trace, Reflection; Middle trace, Input; Bottom trace, Transmission. Input power, 10kW; $10\mu s$ per division.

5 BEAM ACCELERATION TEST

After installation of the SHB cavity on the beam line, a beam-acceleration test was performed. The beam charge was 12nC at the gun output. Figure 8 shows the bunch shape observed by a streak camera [6]. The bunch purity was improved from 80% to almost 100%.

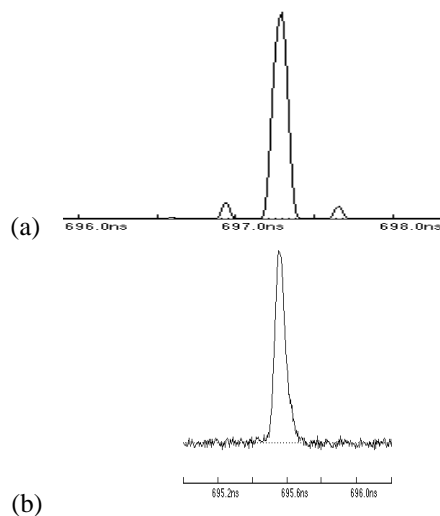


Figure 8: Shape of 12nC single bunch. (a) old SHB; (b) new SHB.

6 SUMMARY

In order to improve the bunch purity of the KEKB injector linac, a new 114.24MHz SHB cavity was designed, fabricated and tested. As a result, the shunt impedance was increased twice as large as that for the old cavity (70% came from the geometry and 20% from an increase of $Q_0(\text{measured})/Q_0(\text{theoretical})$), and a bunch purity of almost 100% was obtained for a 12nC single-bunch beam. Good stability of the resonant frequency was obtained by improving the cooling performance.

7 ACKNOWLEDGEMENTS

The authors wish to thank H. Hayano for his valuable comments on the design of the SHB cavity. They acknowledge Y. Morozumi for his help in fabricating the input coupler.

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