SKIP - A PULSE COMPRESSOR FOR SUPERKEKB

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Abstract

A C-band RF pulse compressor "SKIP", which stand for SuperKEKB Injector Pulse compressor, has been developed for the SuperKEKB project aiming luminosity upgrade of the present KEK-B factory. The design of the compressor using $TE_{0,3,8}$ mode cylindrical cavity is based on the "LIPS" used in the LEP injector S-band linac. Detailed dimensions of the cavity have been optimized for C-band (5712 MHz) with low power models. In the high power test of the pulse compressor, a peak output power of 200 MW is achieved with the input RF power of 43MW in 2 μsec duration.

INTRODUCTION

KEKB attained the highest luminosity ($1.3\times10^{34}cm^{-2}s^{-1}$) in the world. SuperKEKB, an upgrade of KEKB whose target luminosity is 1-5 $\times10^{35}$ $cm^{-2}s^{-1}$ is under consideration [1]. In the SuperKEKB project, energy exchange of beams has an important role. In order to escape the influence of electron clouds, the energy of an electron beam is lowered to 3.5 GeV from 8 GeV, and the energy of a positron beam is raised from 3.5 GeV to 8 GeV. Although it is easy to lower the energy of an electronic beam, it is not easy to raise the energy of a positron beam. A positron is a secondary particle, and after generating it, the space in which a positron beam is accelerated is restricted. One of solutions is to double an acceleration field. Thus the C-band accelerator module which has double acceleration field has been developed [2]. In the summer of 2003, an accelerating structure was installed into the beam line and beam acceleration has been performed since. The acceleration gain with the accelerating structure is 40 MeV/m, feeding power from a klystron into one 1m-long structure. In the complete composition of accelerator module, one klystron feeds two 2m-long structures. Since peak power runs short with the present 50 MW class klystron in such a case, an RF pulse compressor is essential.

Modified RF pulse compressors of SLED are used in the sections of S-band [3]. The half-scale model of S-band structure was adopted in the design of an accelerating structure [4]. In the design of a pulse compressor, when the scale down model of S-band is considered, sufficient Q factor is not acquired. Then, another design plan is needed. We considered using the cavity in the $TE_{0,3,8}$ mode adopted in the LIPS cavities [5]. The Q factor of about 150,000 is expected in $TE_{0,3,8}$-mode cavity. Thereby, an energy multiplication factor of the same as SLED for S-band can be obtained.

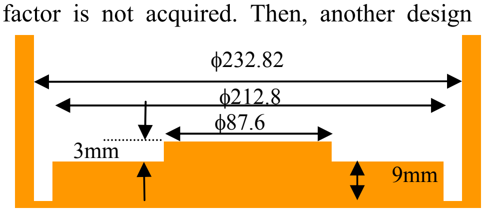

Figure 1: Sectional view of the groove

DESIGN

As already stated, the cavity in the $TE_{0,3,8}$ mode was adopted. Considering a simple cylindrical cavity, there are two adjustable parameters such as diameter and height. For the first step, a scale down model of LIPS cavity is considered. The diameter of 232.82 mm is as almost same as the present S-Band SLED type pulse compressor in KEKB injector linac. It is necessary to investigate the resonance modes of a cylindrical cavity with such form. The mode which should be most careful of is the $TM_{1,3,8}$ mode which is degenerating with the $TE_{0,3,8}$ mode. It is also necessary to take care about the $TE_{12,1,1}$ mode. In order to detune these modes, there is a groove on the base plate as shown in a Fig1. In the numerical computation by MAFIA, these modes are detuned, as shown in the Table1.

Table 1: Frequency shift by groove

Mode	**F_0(MHz)**	**ΔF from $TE_{0,3,8}$ (MHz)**
$TM_{1,3,8}$	5684.525	-12.723
$TE_{12,1,1}$	5708.321	11.073
$TE_{0,3,8}$	5697.248	0

An energy multiplication factor M is given by [6]

$$M = \gamma e^{-T_a/T_c}\left[1-(1-g)^{1+\nu}\right]\left[g(1+\nu)\right]^{-1} - (\alpha - 1),$$

where T_a is the filling time of the accelerating structure, T_c is the filling time of the cavity, $\alpha=2\beta/(1+\beta)$ and $\nu=T_a/T_c[ln(1-g)]$. The group velocity vg varies linearly with the position z according to $v_g(z)= v_{g0}(1-gz/L)$, where v_{g0} is a group velocity at position $z=0$, L is the length of the accelerating structure and g is the quantity about the gradient of a group velocity v_g variation along the structure. For the case of C-band accelerator, characteristic parameters of RF are given in Table 2. Using these values, relation between coupling factor β and energy multiplication factor is represented in Fig. 2.

Table 2: Main RF parameter

Frequency	5712 MHz
Q_0	130000
T_a	350 nsec
g	0.6
L	1.924
Full RF pulse width	2.00 μsec
Pulse width before phase inversion	1.65 μsec

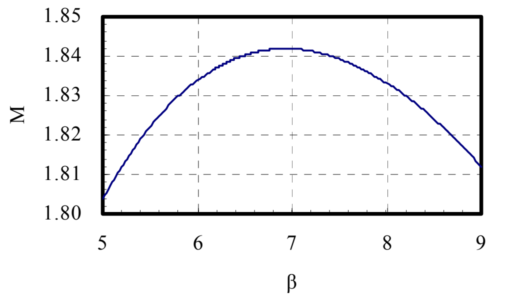

Figure 2: Energy multiplication factor as a function of coupling factor β.

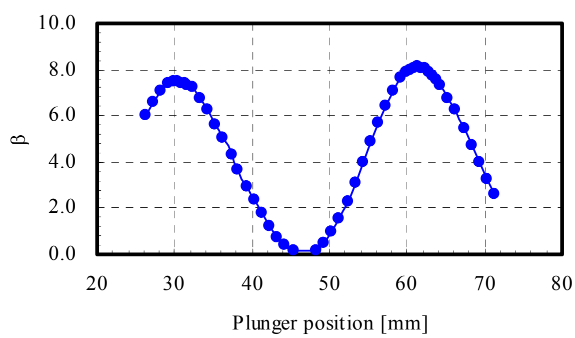

Figure 3: Measured coupling factor β as a function of position of short plane when the diameter of hole is 18.8 mm.

COLD MODEL

In order to determine the dimensions of the compressor, a cold model was manufactured and RF measurement was performed. Using the cold model, cavity length was determined so that the resonant frequency becomes 5712 MHz. +1mm of cavity length is equivalent to -8.7 MHz on frequency.

The cavity is coupled to the waveguide through two holes on the sidewall of waveguide. They are half wave length away from each other. Figure 3 shows a relation between β and position of short plane. The position of a short plane is optimized in order to maximize β and is about 3/4 wave length, which corresponds to the plunger position of 61.3 mm, off the one of coupling holes.

Figure 4 shows relations between β and Diameter of coupling hole computed by MAFIA. Three coupling plate with different thickness were prepared based on the relations, and each β and Q factor was measured with changing a diameter of the holes. Figure 5 shows a relation between the length of coupling hole and β. Although the tendency of an actual measurement result suited the calculation result, some absolute values had shifted. The diameter and length were determined by cold-model measurements to be 18.8mm and 6mm, respectively. Under these conditions, unloaded Q factor is 148000. Figure 6 shows that there are 8 resonances near 5712 MHz. By bead perturbation measurement of a field inside the cavity in the radial and longitudinal directions, it turns out that the number of nodes of the resonance "e" is consistent with the $TE_{0,3,8}$ mode as expected.

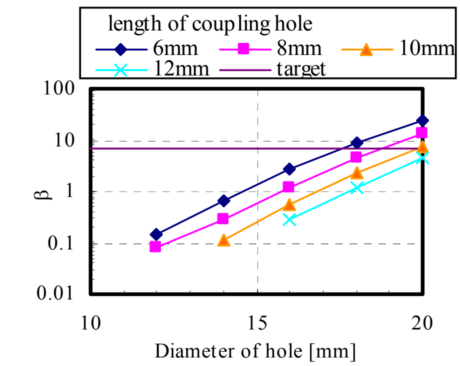

Figure 4: Calculated coupling factor β as a function of diameter of coupling hole.

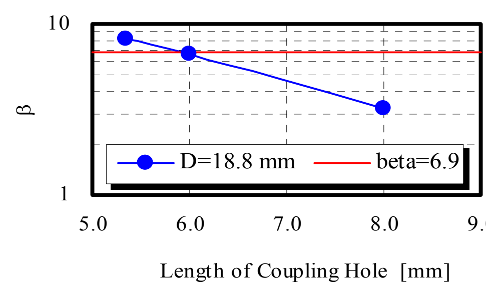

Figure 5: Measured coupling factor β as a function of length of coupling hole when the diameter of hole is 18.8 mm.

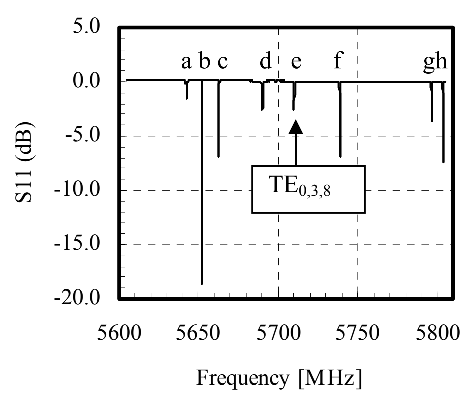

Figure 6: Reflection from the cavity (S_{11}). There are 8 resonances near 5712 MHz.

HOT VERSION

The first product is manufactured based on the dimensions determined with the cold model. However, unloaded Q value and β were smaller than those of the cold model. It is expected to come from the difference in the processing method of a coupling plate. Although coupling plate of the cold model was processed with a lathe, the plate of the hot version was processed with a milling cutter. As a result, the roughness of the surface of a coupling plate differed, and unloaded Q value and β fell. Therefore, the length of holes was reduced to 5.35 mm from 6 mm in order to achieve sufficient β.

Results of RF measurement for hot version of cavities are listed in Table 3. A 3dB-hybrid coupler is attached to two cavities and it is completed. Figure 7 shows a whole view of the RF pulse compressor. Figure 8 shows the 3dB-hybrid coupler for the pulse compressor.

Table 3: Measured parameter of Cavities (30 centigrade, N_2 gas)

	Q_0	β
Cavity A	136000	6.71
Cavity B	137000	6.79
Cavity A,B with 3dB coupler	133000	6.59

After an RF processing of about 170 hours, the peak output power attained 200 MW at a repetition rate of 50 pps with the pulse duration of 2 μsec. Figure 9 shows some forms of RF pulses. RF power at the exit of a klystron and the exit of the pulse compressor was measured, and it turns out that the ratio of the peak output power to input power is 4.7.

This RF pulse compressor is named "SKIP" (SuperKEKB Injector Pulse compressor). SKIP is now installed into the RF system of C-band accelerator module of injector linac for KEKB, PF (Photon Factory) and PF-AR (Advanced Ring). It will be tested for a year under the real operation. The energy multiplication factor M will be measured in the beam acceleration test.

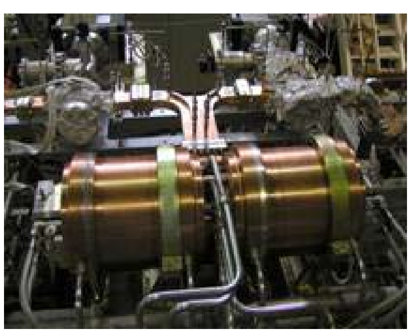

Figure 7: Whole view of the pulse compressor "SKIP" at test stand.

SUMMARY

A C-band pulse compressor SKIP with $TE_{0,3,8}$-mode cylindrical cavities is developed. It achieves a peak output power of 200 MW with the input RF power of 43 MW and the repetition rate of 50 pps.

Figure 8: Whole view of 3dB-hybrid coupler (left) and waveguide for low power RF measurement (right).

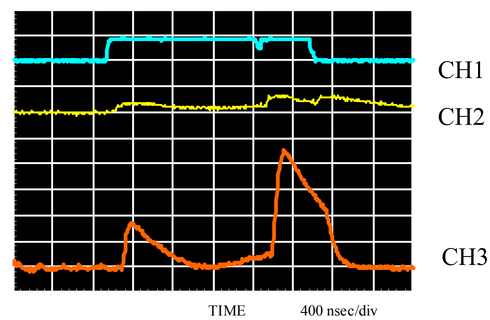

Figure 9: Form of input signal (CH1), VSWR (CH2) and output signal of SKIP (CH3). They are plotted in arbitral units in vertical axis. The peak of CH3 exceeds 200 MW.

ACKNOWLEDGEMENT

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