RF SYSTEMS FOR JHF SYNCHROTRONS

C. Ohmori, M. Fujieda[1], Y. Hashimoto, Y. Mori, H. Nakayama, K. Saito[2], Y. Sato[3], M. Souda[4], Y. Tanabe[4], T. Uesugi[5], M. Yamamoto[6], KEK-TANASHI, 3-2-1 Midori-cho, Tanashi, Tokyo 188-8501, Japan,
E. Ezura, A. Takagi, M. Toda, T. Yan[7] and M. Yoshii, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305-0801, Japan

Abstract

Based on the measurements of the magnetic cores and R&D works, MA(Magnetic Alloy)-loaded cavity will be adopted for the RF cavity of JHF 50 GeV Main Ring and 3 GeV Booster. Because of high stability at large RF amplitude, high gradient of acceleration voltage (>50 kV/m) is available. By a test cavity, 2.5 kV/core has been already achieved in the CW operation using one MA core of 2.5 cm thickness. For the pulse operation, 5.5 kV/core has been obtained. Another advantage is that the system does not require the tuning system because of the cavity band width is wide enough to cover the RF frequency. A stability analysis shows that the RF system without the tuning loop has wider stable region than high Q cavity system with the loop. A multi-particle simulation shows that the RF system is also stable for the periodic transient and the RF bucket distortion. However, the distortion should be corrected when the Q value of the cavity is low (Q<2).

1 INTRODUCTION

JHF accelerator complex[1,2] consists of a 200 MeV Linac, 3 GeV Booster Synchrotron and 50 GeV Main Ring[3]. In this paper, the RF systems using the MA[4]-loaded cavity for both synchrotrons will be described. The Requirements for the RF systems are summarized in the Table 1. Both rings require very high RF voltage for the acceleration. Since the space available for RF cavity is limited, the RF cavity should deliver sufficiently high voltage and should be compact.

The intensities of both rings are very large and the beam loading is very severe for both rings. Because the harmonic numbers are 17 and 4 for the Main Ring and the Booster, respectively, the coupled bunch instability may have a fast growth rate. For the cavity and RF system design, it should be considered to reduce the growth rate of the instability.

In the Main Ring, the periodic transient is exist during injection and acceleration. At the injection, the transient beam loading is maximum when eight bunches are injected. During acceleration, one empty bucket is still existing for the rise time of the kicker magnet to extract the beam. In the Booster, the injection transient is exist during 400 µs for the charge exchange injection. Around the injection and extraction, the beam loading will be maximum in the Booster because the required RF voltage is very low and the relative loading parameter becomes about 2 (Max.) at the extraction.

The longitudinal emittance of the Main Ring beam is three times larger than that of the Booster beam in order to suppress some instabilities. It is planed to use the controlled emittance growth during the injection. The MA-loaded cavity[5,6] is also suitable for the beam gymnastics like a barrier bucket injection because of the wide band width.

The repetition of the Booster is 25 Hz and it will be increase up to 50 Hz in future. The RF system of the Booster should be durable for the fast frequency sweep.

Table 1. Main Parameters

	Main Ring	Booster
Harmonic Number	17	4
Number of Bunches	16	4
RF frequency	3.4-3.5 MHz	2-3.4 MHz
Emittance	3 eVs	1eVs
Intensity	6.6-6.8 A	4-7A
Acceleration Time	1.9 s	20 ms
Total RF voltage	280 kV	414 kV
Max ϕs	30 deg.	51.4 deg.

2 RF CAVITY DESIGN

The High Gradient (HG) cavity[7] will be adopted for the RF cavity of the Main Ring. In the ferrite-loaded cavity, accelerating voltage is limited by the RF voltage dependence of the core impedance and it is usually less

[1] also Kyoto University.
[2] also Hitachi. Co. Ltd.
[3] also JSW Co. Ltd.
[4] also Toshiba Co. Ltd.
[5] also University of Tokyo.
[6] also Osaka University
[7] also the Bureau of Basic Science of Academic China.

than 700 V/core. The MA cores show a very interesting characteristic that the shunt impedance is very stable at high RF field of 2,000 Gauss[8]. A test cavity, in which only core was installed, could deliver 2.5 kV at the gap in the CW operation and 5.5 kV for short pulse operation as shown in Fig. 1. The duration of pulse was limited by the maximum current (5A DC) of the power supply. In the cavity, the core was installed in the water tank and cooled by the water directly.

A HG cavity was assembled as shown in Fig. 2. The length of the cavity is 40 cm. The cavity has a single gap and two water tanks surrounded by the stainless steel and FRP. Each water tank is $\lambda/4$ cell and three cores can be installed in the chamber. The cavity will be driven by a push-pull amplifier of 200 kW class. Parameters of RF cavity and amplifier are tabulated in Table 2. The cavity impedance has been measured by network analyzers and no parasitic resonance was observed as shown in Fig. 3.

For the RF system of the JHF Main Ring, the HG cavity will be adopted. Because of the high gradient acceleration voltage and compact cavity size, the HG cavity is also very attractive for the Booster cavity. The design parameters for the JHF Main Ring and Booster are tabulated in Table 3. In this table, only parameters for the HG cavity are listed. Because of the low cavity impedance, the total power to drive the cavity is larger than that for the ferrite-loaded cavity. However, we should note that the biasing circuit which consumes a lot of power to tune the ferrite-loaded cavity is not necessary for the MA-loaded cavity.

Table 2. Parameters of RF cavity and amplifier.

Size of Cavity	80cm (O.D)X40 cm
Size of Core	67cm(O.D)X32cm(I.D)X2.5cm
Volume of Core	6800 cc
Number of Core	6 (4)
Gap Voltage	20 kV (Goal)
Impedance	600 (400) Ω @3MHz
Core	FINEMET FT3M
Tube	4CW150,000E X 2
Operation	Class AB, Push-pull
Anode Impedance	about 1kΩ

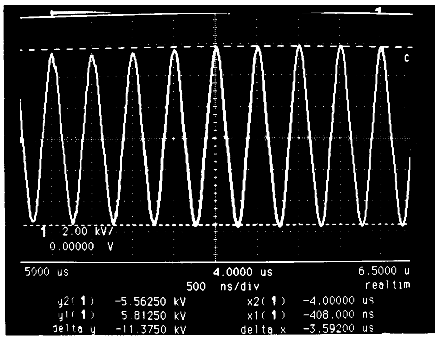

Figure: 1 Obtained RF voltage by a test cavity in which one FINEMET core was installed.

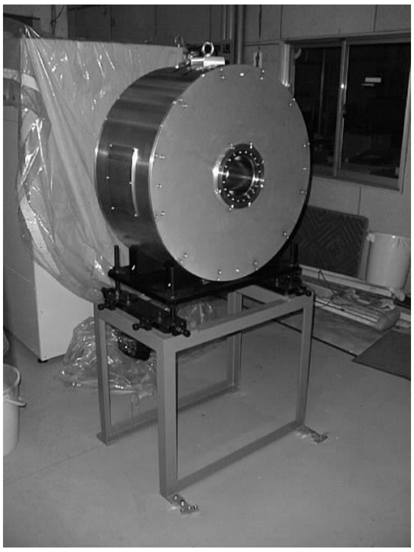

Figure: 2 High Gradient RF cavity. A 200 kW class push pull amplifier will be located under the cavity.

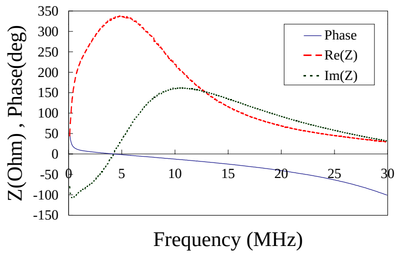

Figure 3: Impedance of the HG cavity.

Table 3. Parameters of both RF system

	Main Ring	Booster
Number of cavities	18	25
Voltage per cavity	16 kV	16 kV
Cavity Impedance	500 Ω	500 Ω
Beam Impedance	330 Ω	330 Ω
Relative Loading, Y	0.3	0.3
Power dissipation	256 kW	256 kW
Max. Beam Power	56 kW	67 kW
Total RF Power	2.8 MW	<4 MW
Total Anode loss	1.4 MW	<2 MW
Total Power	4.2 MW	<6 MW

3 RF CONTROLE SYSTEM

3.1 variable Q value of core

The Q-value of the cavity can be changed from 0.7 to 5 by adjusting the radial gaps of the cut core. Besides, other amorphous core also has the Q value of about 4[9] and the perpendicular biasing technique can also increase the Q value[10]. However, the shunt impedance of core is almost constant. The R/Q per gap of the cavity will be changed from 80 to 700 Ω. For the Main Ring, the tuning system is not necessary if the Q-value is less than about 10 because the frequency change is small (3%).

For the Booster, the tuning system will be required if Q-value is large than 2. The growth rate of the coupled bunch instability was calculated for several different Q-values[2]. An analytic calculation[11] shows that the growth rate is less than 30 Hz if the tuning circuit is not adopted. In this paper, we assume that the tuning system is not used for both rings.

3.2 Basic RF Control System

The basic RF control system consists of phase, radial and amplitude loops. The total RF system has wider stable region than the usual RF system using the ferrite-loaded cavity with the tuning loop[12] because the characteristic equation to analyze the total RF system without the tuning loop is simpler than that with the tuning loop although it can not be solved analytically. Another reason is that the phase control lag by the tuning error is small because of low Q value. For the whole Main Ring cycle, the relative loading parameter, Y, is about 0.3 through the whole Main Ring cycle. For the Booster, however, the relative loading parameter will become about 2 around the extraction because the RF voltage is low, then. The usual counter phasing to reduce the loading parameter or compensation techniques will be applied.

3.3 Bucket Distortion by Higher Harmonics

The bunching factor will become very small around the extraction for both rings. For the Main Ring, it will become 0.038 around the flat top. Because the short bunch has a rich frequency spectrum and MA-loaded cavity may have a broad band impedance, the distortion of the RF bucket will be large. However the distortions are relatively small at the injection and beginning of the acceleration for both accelerators. The distortion will be increased as an adiabatic process. Independent two approaches show that the beam bunch will be lengthened but the momentum spread will not become large[13] and the longitudinal emittance will be conserved[14]. Both results suggest that this distortion may not cause the beam loss by the emittance growth although the bunch length will be long. We should note that the AVC loop may work to damp the quadrupole motion which is observed in the simulation[14]. In order to make a short bunch which may be required for some high energy experiments, there are two possibility, that is, to increase the Q-value of the cavity to 3-5 and to apply the compensation techniques for the higher harmonics[13]. For the Booster, Q-value of 2 may be enough because the bunching factor is not very small.

3.4 Periodic Transient

The periodic transient beam loading is usually evaluated by the R/Q value of a cavity. However, the transient effects will be the worst when the Q-value is about 10 which is the typical value of the loaded Q of the ferrite-loaded cavity[14]. If the Q-value of HG cavity is low, whatever the R/Q value is large however the transient effects become very small because the effects become the single bunch phenomenon. There are two possibility to manage the transient effects; to reduce the Q-value of the cavity less than about 3 or to apply the feedback and/or feed forward techniques for the many revolution harmonics.

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