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RF SYSTEMS OF SYNCHROTRONS FOR JAPANESE HADRON PROJECT

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Abstract

Conceptual designs of the RF systems for both 3 GeV and 50 GeV proton synchrotrons are described. The RF systems provide an accelerating voltage per station of 40 kV because of a high accelerating rate, and also the systems are required to be stable for the heavy beam loading to accommodate high intense proton beam acceleration. In order to reduce enormous beam loading, a low plate-resistance tetrode and a fast feedback technique are considered to use.

I. Introduction

Accelerator complex for the JHP is located in the KEK site and consists of four accelerators: pre-injector, 200 MeV linac, 3 GeV booster and 50 GeV main ring synchrotrons[1].

The booster is a rapid-cycling proton synchrotron and will be constructed in the present KEK-PS tunnel. The booster magnet is excited by using a resonant network [2]. The repetition rate of the booster is 25 Hz, in future 50 Hz operation is scheduled. A circulating average beam current in the booster is designed to 200 μA. The beam is supplied to the adjacent 3 experimental facilities[1] as well as injected into the 50 GeV main ring. Because of a high repetitive operation, a sweep-rate of rf-frequency and an accelerating voltage needs to be high. The RF harmonic numbers of both rings are 4 and 34, respectively. Thirty-two bunches from the booster are injected into the main ring.

The main ring synchrotron is located on the northern part of the KEK site. The size of ring is about four times larger than that of the booster ring. The main ring synchrotron operates in a cycle of 6 seconds; the accelerating period is 2.5 seconds. The main ring synchrotron is also a high current beam accelerator. Proton beams of 4 x 10^{14} ppp (particles per pulse) is designed to be accelerated. The circulation beam current in the main ring is about twice larger than that in the booster, the beam loading effects in the main ring acceleration become more serious than in the booster.

In both the synchrotrons, for stable accelerations of high current beams, the reductions of heavy beam loading effects must be dispensable.

The main parameters of both the rings summarized in Table 1.

II. RF System for The Booster

A. Cavity and RF-station

The requirements for the high intensity and rapid cycling synchrotron determine many parameters on the RF system. In the case of the booster, a fast time-response for tuning a cavity and to minimize a heat power loss in the cavity should be required.

The rf-frequency range is from 2. to 3.4 MHz, at the request of experimental users. For this frequency range, a ferrite-loaded re-entrant cavity is practical. The number of the rf-stations is 10 and the length of the station is 3 m. One rf-station consists of four quarter-wave coaxial lines, there is two accelerating gaps to obtain the required acceleration voltage .

Under the conditions of maximum acceleration rate of 220 GeV/sec and an intensity of 5 x 10^{13} ppp, the beam consumes a maximum peak power of 180 kW per rf-station. An accelerating voltage of 40 kV per station must be required at a synchronous phase angle of 45 degrees.

The design of cavity strongly depends on the choice of ferrite materials. A μQf-product (μ: relative permeability of a ferrite, Q: quality factor of a ferrite and f: operation frequency) is one of the key parameters when the cavity impedance is determined. A shunt impedance (R_{sh}) in an equivalent circuit of the resonant cavity is given by;

$$R_{sh} = \omega L Q \propto \mu Q f. \quad (1)$$

On the other hand, the beam current flows in the opposite direction of the generator current. The beam induced voltage acts on decelerating the beam. The maximum peak current of circulating beam is 7 amperes. Though its fundamental fourier component (I_b) depends on the bunching factor and the longitudinal distribution, its maximum value is twice of the peak current and 14 amperes. This enormous beam current affects on all the RF system through the accelerating gaps and feedback systems. The stability for the beam loading is estimated by a relative beam loading Y, $Y=I_b/I_o$, where Io is an RF generator current to give the same gap voltage without beam load and with cavity tuned to resonance and equals to shunt-resistor current [3]. For stability Y must be less than 2. In order to reduce the relative beam loading, a low plate-resistance tetrode is considered to use because the resonant cavity resistance can be reduced.

In our design, for instance, the required RF generator current is ~ 10 amperes; Y = 1.4. Peak power loss in ferrites is set to be ~200 kW per cavity. In this case, the shunt impedance of 4000 Ω and ferrite materials of which minimum $\mu Q f$-value is greater than 4×10^9 , would be necessary.

B . Feedback System

The rf-generator current Io is smaller than the circulating beam current. Specially, during the beam capture process in the booster, because the accelerating voltage should be low to avoid a longitudinal emittance growth. The relative loading Y becomes larger and the beam loading effects grows big. To reduce such loading effects, several rf-feedback systems must be considered to control the accelerating rf-system in stable[3].

For the resonant cavity, beam induced voltage (V_{beam}) is;

$$V_{beam} = -R_{eff.sh} \cdot I_b, \quad (2)$$

where $R_{eff.sh}$ is an effective shunt impedance which is an impedance seen from a beam. The effective shunt impedance must be reduced to minimize the beam induced voltage.

III. RF System for The Main Ring

In the 50 GeV main ring, the rf-frequency is swept 3 % during the acceleration, and the average acceleration rate is ~ 20 GeV/second, which is ten times less than the booster acceleration rate. However, the beam loading current in the main ring is more than twice larger than in the booster. The choice of ferrite materials and the design, which take into consideration such a heavy beam loading, are very important.

A. Cavity and RF-station

The number of the rf-stations is 5 in the main ring. As the accelerating rate is ~ 20 GeV/second, the required accelerating voltage is 40 kV per rf-station at the synchronous phase angle of 30 degrees. The rf-frequency is swept from 6.86 to 7.07 MHz. The beam intensity is 4×10^{14} ppp. The corresponding peak current is ~13 amperes. Considering twice of the peak current as the beam loading current, even if the relative loading Y allows 2, the generator current becomes larger than that in the booster. The RF feedback system is definitely required to compensate such a heavy beam loading.

Table 2 summarizes RF parameters for both the booster and main rings.

IV. Summary

In the recent high intense proton synchrotrons, the beam current inclines to be larger than the generator current. Nevertheless, the ferrite-loaded resonant cavity is the most practical as a tunable cavity in the frequency regime of several mega-hertz. In those ferrites, the heat loss limits to increase the generator current and RF voltage, because the quality factor and the curie point of ferrite materials are relatively low.

In FY1995, we have started to examine the ferrite materials. In these examinations, the basic parameters of loaded ferrites will be cleared.

The preliminary design for the RF systems for both 3 GeV booster and 50 GeV main ring synchrotrons are described. As the performances of ferrite materials are not clear, the design is limited at this moment.

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V. References

[1] Y.Mori et al., "Outline of JHP Synchrotron Design", in this proceedings.
[2] T.Adachi el al., "Design of Magnets and Power Supplies of 3 GeV Booster for Japan Hadron Project", in this proceedings.
[3] F. Pedersen, "Beam Loading Effects in The CERN PS Booster", IEEE Trans.Nucl. Sci. vol. NS-22, No. 3, June 1975.

Table 1
Specifications of the booster and main ring synchrotrons

		3 GeV Booster	50 GeV Main Ring
Circumference		339.4 m	1442 m
Transition gamma		6.25	27 i (imaginary)
Beam energy	inj. / ext.	200 MeV/ 3 GeV	3 GeV / 50 GeV
$B\rho$	inj. / ext.	2.15 / 12.8 Tm	12.8 / 170 Tm
$\beta\gamma$	inj. / ext.	0.687 / 4.08	4.07 / 54.3
Revolution frequency	inj. / ext.	0.50 / 0.86 MHz	0.20 / 0.21 MHz
Repetition rate		25 Hz (50 Hz)	6 sec
Accelerating period		20 msec	2.5 sec
Accelerating rate		220 GeV/sec	20 GeV/sec
Number of particles		5×10^{13} ppp*	4×10^{14} ppp
Beam current		200 μA	10 μA
Circulating current (peak)		4 ~ 7 A	13 A
Beam power		0.6 MW	

* protons per pulse

Table 2
RF parameters of the booster and main ring synchrotrons

	3 GeV Booster	50 GeV Main Ring
No. of acceleration gap per station	2	2
Max. rf-voltage per gap	20 kV	20 kV
Max. phase angle	45 degree	30 degree
Accelerating voltage	400 kV	200 kV
Number of RF stations	10	5
RF harmonic number	4	34
RF frequency sweep range	2.00 ~ 3.43 MHz	6.86 ~ 7.07 MHz
Length of rf-station	3 m	3 m
Diameter of beam pipe	20 cm	20 cm
Duty Cycle	50 %	42 % (2.5 sec./6 sec.)