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# 6.8 RF Acceleration System for 3 GeV Proton Synchrotron in JAERI-KEK Joint Project

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## Abstract

RF acceleration system for 3 GeV proton synchrotron in Joint JAERI-KEK high intensity proton accelerator project is described. In this synchrotron, since $8.3 \times 10^{13}$ protons must be accelerated from 400 MeV to 3 GeV within 20 ms, wide-band frequency range and high accelerating voltage are required, and the system must be stable under heavy beam loading.

From the results of R & D works over the past several years, high gradient rf cavity loaded with Magnetic Alloy and 1.2 MW class push-pull tetrode tube amplifier will be chosen for this system. Their design and R & D works for this synchrotron are reported.

Furthermore, since longitudinal beam emittance will be controlled at injection and extraction by the rf manipulation because of alleviation of space charge effect, some simulation results for longitudinal motion by a particle tracking code are reported.

## 1 Introduction

The high intensity proton accelerators are proposed for the joint project between JAERI and KEK [1]. In this project, there is a rapid cycling proton synchrotron at a repetition rate of 25 Hz, where $8.3 \times 10^{13}$ protons will be accelerated from 400 MeV to 3 GeV within 20 ms, then an average beam power of 1 MW at 3 GeV will be produced for neutron experiments and other purposes.

On the rf acceleration in this 3 GeV PS, a high accelerating voltage is required due to the rapid cycling under limited length of straight section, and since the average circulating beam current becomes 12 A, it causes heavy beam loading and space charge effects.

In order to achieve the high accelerating field gradient and the stability under the heavy beam loading, an rf cavity loaded with Magnetic Alloy(MA) has been developed during the past several years [2, 3, 4, 5]. We also have got the field gradient of 50 kV/m on CW operation by the test MA cavity with 250 kW class amplifier. Furthermore, it has been installed with 60 kW class amplifier and operated at HIMAC heavy ion synchrotron successfully [6].

From the results of test MA cavity, we have started design and R & D works for the Joint Project, another MA cavity with 1.2 MW class amplifier, which is almost satisfied the specifications for the joint project, has been constructed and demonstrated to collect data precisely in order to fix the final design. The cavity has been installed with Direct Digital Synthesizer(DDS) system in KEK 12 GeV PS and will be operated regularly to develop the beam intensity [5].

Based on these R & D results, we will describe the design of the rf accelerating system for the 3 GeV PS at the present status.

## 2 Cavity and Amplifier

The parameters of 3 GeV PS dedicated to the rf system are shown in Table 1, and the change of the accelerating voltage and the synchronous phase are shown in Fig. 2, which was calculated by RAMA [7] including the space charge effects.

Table 1: The parameters of 3 GeV PS.

| | |
|---|---|
| Number of Particle | $8.322 \times 10^{13}$ ppp |
| Injection Energy | 400 MeV |
| Extraction Energy | 3 GeV |
| $\Delta p/p$ at Injection | $\pm 0.85$ % |
| Harmonic Number | 2 |
| RF Freq. Range | $1.364 \sim 1.857$ MHz |
| Accelerating Voltage(Max.) | 421 kV |
| Synchronous Phase(Max.) | 43.2 deg. |
| Long. Beam Emittance | 3.2 eVs |
| Momentum Compaction Factor | 0.013 |

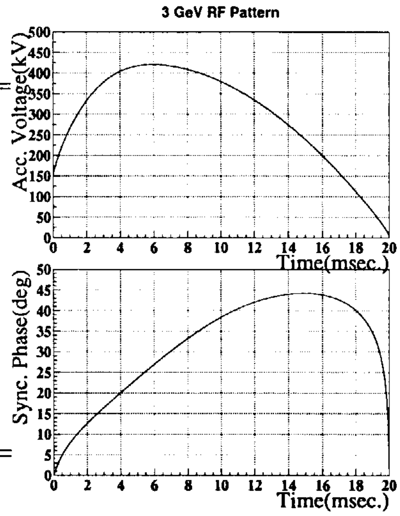


Figure 1: The rf pattern of 3 GeV PS.

The maximum 421 kV of accelerating voltage should be obtained in ~20 m of straight section under the constraint of lattice design [8]. Considering the maximum anode current of the tetrode tube which should be comparable with the beam current due to the stability under the heavy beam loading, we choose that ten cavities will be prepared to generate such voltage, where each cavity has three accelerating gaps. When the cavity is driven by a 1 MW class push-pull amplifier, the cavity should have an impedance of 700 $\Omega$ at one gap, and it will be realized by 8 MA cores per gap.

Since we plan the 2nd higher harmonic voltage will add at the injection and the extraction in order to increase the longitudinal beam emittance to suppress the space charge effects and some instabilities, the cavity has to generate the 2nd harmonic one over the frequency 2.728 – 3.714 MHz with same cavity simultaneously, so the quality factor should be smaller than 3 at least when the resonant frequency is chosen at 2 MHz in consideration of optimum de-tuning.

The MA has a low Q-value of 0.7 intrinsically, but very low Q-value causes large rf bucket distortion, so the Q-value should be made higher to cover the frequency range of the acceleration without a resonant frequency tuning. For this purpose, radial cut core of MA will be used to change the Q-value [2].

The specifications of the cavity are summarized in Table 2, and the preliminary design of the cavity is shown in Fig. 2.

Table 2: The parameters of MA cavity for 3 GeV PS.

| | |
|---|---|
| Fund. RF Freq. Range | 1.364 ~ 1.857 MHz |
| 2nd HOM RF Freq. Range | 2.728 ~ 3.714 MHz |
| Number of Accelerating Gaps/Cavity | 3 |
| Accelerating Voltage/Cavity(Max.) | 43 kV<br>(Field Gradient 26 kV/m) |
| Impedance/Gap | 700 Ω |
| Quality Factor | 3 |
| Number of MA Cores/Cavity | 24 Cores |
| Core Size | O.D. 900 mm × I.D. 360 mm × t 26 mm |
| Power Loss at MA Core(Ave.) | 5 kW/Core |
| Cavity Length | ~1.65 m |

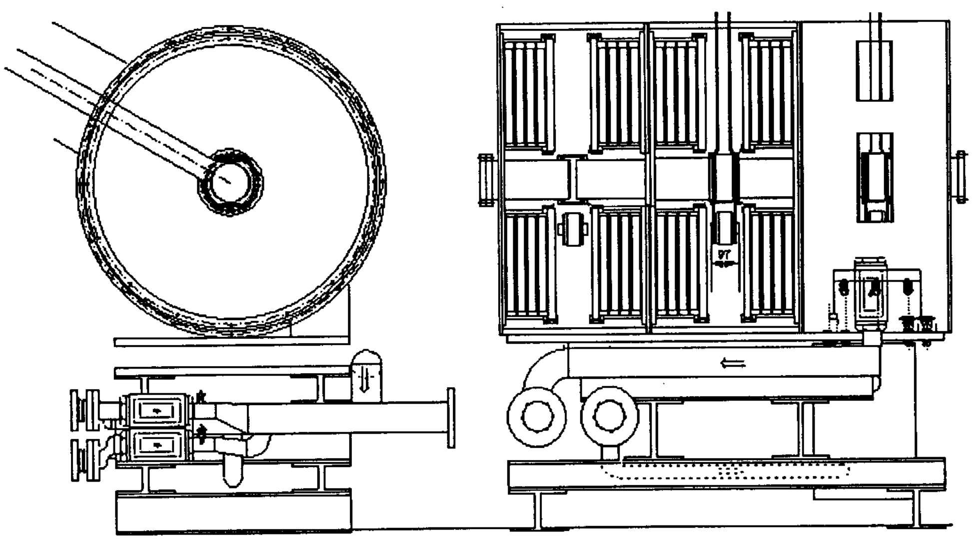

Figure 2: The design of MA cavity for 3 GeV PS.

The amplifier will consist of two tetrode tubes of 600 kW class, each of them feeding the maximum peak current of 250 A into the cavity, which provides fundamental voltage, 2nd harmonic voltage and the beam loading. The control grid of the tube will be driven by a 6 kW transistor Amplifier which should cover the frequency range of 1−4 MHz. Since the cavity will be driven at 50 % duty cycle, the rf power consumed at the amplifier becomes half of the maximum.

Table 3: The parameters of the amplifier of MA cavity for 3 GeV PS.

| | |
|---|---|
| Power Amplifier | |
| Number of Tetrode | 2 |
| Peak Current(Max.) | 250 A |
| RF Power Output(Max.) | 720 kW(Ave. 360 kW) |
| Plate Dissipation(Max.) | 520 kW(Ave. 260 kW) |
| Total Power(Max.) | 1.24 MW(Ave. 620 kW) |
| Pre Power Amplifier | |
| RF Power Output(Max.) | 6 kW |
| Output Impedance | 50 Ω |

The specifications of the amplifier are summarized in Table 3.

## 3 Low-level System

The DDS system will be used to generate the rf signal based on the R & D works for KEK 12 GeV PS [5], which can manage fundamental and 2nd harmonic signal. We also plan for the feedback system to be digitized, the R & D works of it for the rapid processing will be done.

Since the cavity has a wide-band frequency range, the beam loading by up to 2nd higher harmonics should be compensated for the stable acceleration, and it is planned that the feed forward method [9] will be adopted for the system.

## 4 Particle Tracking Simulation at Injection

On the low energy region, since the space charge effects are dominant in the proton synchrotron, the peak beam current should be low as possible. Therefore, it is planned that 2nd higher harmonic voltage is added with the fandamental one to make the bunch shape flatten,

In order to investigate the effect of the 2nd higher harmonic, particle tracking simulations on the longitudinal motion were performed.

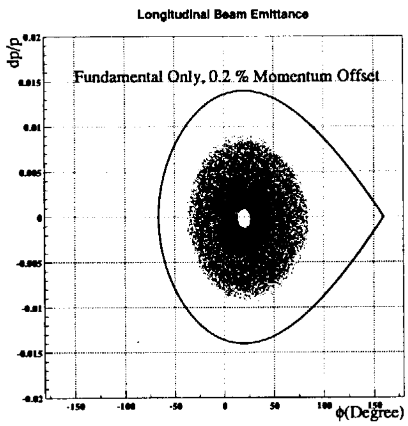


Figure 3: The beam emittance only fundamental voltage.

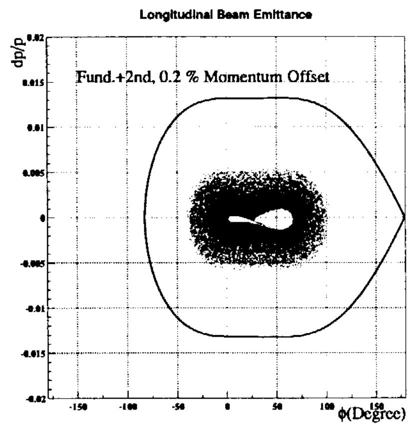


Figure 4: The beam emittance in case of fund. + 2nd harmonics ones.

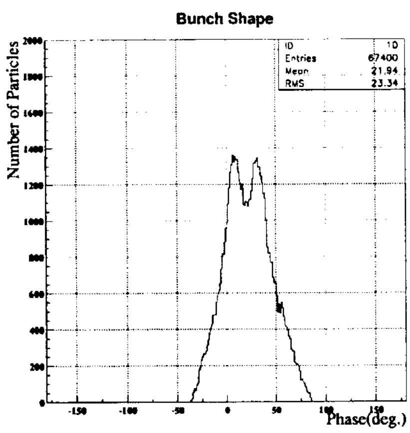


Figure 5: The bunch shape only fundamental voltage.

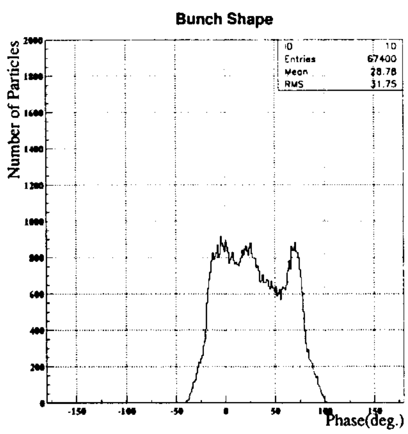


Figure 6: The bunch shape in case of fund. + 2nd harmonics ones.

The figure 4 and 4 show the beam emittance on the longitudinal phase space in the case of only fundamental voltage and fundamental + 2nd harmonic voltage, and the figure 4 and 4 show the bunch shape in the case of only fundamental voltage and fundamental + 2nd harmonic voltage, respectively.

In this simulation, the multi-turn injection was simulated, that is, the 400 MeV Linac provided macro bunches to 3 GeV PS during 337 turns. The macro bunch was chopped at the end of the Linac, the bunch had a maximum of $1.235 \times 10^{11}$ protons in 396 ns length, and bunch separation is 733.2 ns(average beam current of 50 mA).

Furthermore, momentum offset of $\Delta p/p \sim 0.2$ % with respect to the synchronous momentum was introduced for the injected bunches because the bunching factor will be improved.

As clearly seen from the simulation results, the bunch shape was more flatten by adding 2nd harmonic voltage, then the bunching factor became 0.321 in the case of adding 2nd harmonic voltage rather than 0.225 in the case of only fundamental one.

## 5 Summary

RF acceleration system for 3 GeV proton synchrotron in Joint JAERI-KEK high intensity proton accelerator project is described. The high gradient MA cavity with 1.2 MW class push-pull tetrode tube amplifier will be chosen for this system. Their design and R & D works are going now.

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