IMPROVEMENT OF THE RF SYSTEM AT KEK PS FOR DEUTERON ACCELERATION

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ABSTRACT

In July 1991,the KEK PS accelerated deuteron beam up to 7.2GeV. The frequency ranges of the accelerating systems are modified to lower than those of proton acceleration. The improvement consists of attaching of capacitors at accelerating gaps in the cavities, and upgrading of the ferrite bias power supplies.

GENERAL

In order to accelerate deuteron beam[1] the frequency range of the booster rf system has to be 1.1 ~ 3.9MHz(for proton 2.26 ~ 6.02MHz), and that of main ring 3.9 ~ 7.9 MHz(for proton 6.01 ~ 8MHz). Both rf cavities have to be changed their lowest resonating frequency.

The resonating frequency range of a ferrite loaded cavity is determined by the permeability of the ferrite. Let's f_{MAX} be the highest frequency, and f_{MIN} the lowest, their ratio is given by

$$\frac{f_{MAX}}{f_{MIN}} = \sqrt{\mu_r/\mu_s} \simeq \sqrt{\mu_r/10}$$

where μ_r is the relative permeability of the ferrite at remanent state,and μ_s its saturated value. We have used the approximate value of $\mu_s \simeq 10$.

The relative permeability of the ferrite used for the booster cavity is 150, and for main ring 100. Therefore,the frequency range of the booster cavity is given by $f_{MAX}/f_{MIN} \simeq 4$, and the ratio of the main ring cavity is 3. Hence, the rf cavities of both booster and main ring can be used for the deuteron acceleration.

In the operation of a cavity at lower frequency range,the shunt impedance of the cavity decreases, therefore, the power dissipated in the ferrite has to be analyzed.The shunt impedance of the ferrite loaded cavity is proportional to the (μQf)-product of ferrite in the cavity. The quality factor Q varies with rf flux density;$Q = Q_o/(1+\eta B_{RF}) \simeq Q_o/(\eta B_{RF})$,where η is a constant depending upon the ferrite,and it has an order of 0.01[gauss^{-1}]. For a given rf voltage, the flux density is inversely proportional to the frequency. Therefore, the shunt impedance varies with the square of the frequency. In a lower frequency range operation of a given ferrite loaded rf cavities,the rf voltage has to be reduced.

Practically, the shunt impedance of the cavity also depends strongly upon the operating rf voltage. The peak rf voltage must be determined by the measured shunt impedance at the actual operating condition.

KEK PS RF SYSTEM

The schematic diagram of our rf system is shown in Fig. 1. The equivalent circuit of the cavities of the booster and the main ring seen by the amplifier is also shown in Fig. 2. Two accelerating stations are installed in the booster,and main ring has four rf stations. In the case of our booster, the inductance of the cavity is 5.2μH. The capacitance at the gap is 1.7nF. Therefore, 2nF of additional capacitor is necessary to resonate at 1.1MHz.We attached four 500pF vacuum capacitors on the busbars connecting the acceleration gap.The rf current at the capacitor is 50A at 3MHz and 5kV, therefore the vacuum capacitors are selected because of their higher rf current. For the main ring cavity, the inductance of the cavity is 4μH, the additional capacitor is 200pF. We installed two 100pF vacuum capacitors on the busbars.

The shunt impedance of the booster cavity at actual operating condition is compared with that of proton acceleration in Fig. 3. In calculating the shunt impedance, the rf drive current of the cavity is calculated from the cathode current of final vacuum tubes[3]. The shunt impedance of the main ring cavity is~4kΩ at 4MHz and at 20kV.The minimum value is 1.3kΩ at the beginning of acceleration.

MAIN RING FERRITE BIAS CURRENT POWER SUPPLY

The ratio of the maximum to minimum resonating frequency of the main ring accelerating cavity is at present ~1.5. The maximum output current in this case is 500A. To extend the resonating frequency range of main ring rf cavities, the upgrading of the ferrite bias current power supplies(bias p.s.) is necessary. A test bias p.s.[2], which is designed to measure the ferrite bias characteristics, is used for deuteron acceleration experiments. The output current of this p.s. is from -100A to 1200A. Because of the test of a hysteresis in μ-H_{bias} curve, the minus current is necessary. The voltage drop at the load is limited to 10V.

By test experiments, we have concluded that the maximum current of the p.s. for deuteron acceleration have to be 1500A. The design of the bias p.s. is based on the test bias p.s. but with higher output current. In order to decrease the power at the final transistor stack,the output voltage is limited to 10V.Two feeder cables, which connect the cavity and bias p.s. in parallel with the present cables to reduce the load resistance to 5mΩ, are wired. The maximum current will be obtained at 7.5 V voltage drop at the load.

THE LOW LEVEL RF SYSTEM

Two modifications were necessary to accelerate deuteron beam. The first one is to write the data in ROM's in the booster and main ring function generators which generate the accelerating frequencies of both accelerators.
The second one is to extend the frequency range of the phase shifters,which are used for the cavity-phase lock systems in both machines.

EXPERIMENT

The experiment was performed in July 1991.At this time the improvement of the booster rf had been finished. The booster accelerated $3\cdot10^{11}$ deuterons/pulse. The peak accelerating voltages of the two rf stations are 10 kV x 2.

In order to check the low level electronic circuits, we tried to accelerate the deuteron beam at the main ring. The test was performed with only one rf station.To accept the booster bunches, the rf voltage at the main ring have to be ~60kV at injection, whereas the accelerating rf voltage is only 20kV. To minimize the bucket shrink at the beginning of the acceleration, the rate of change of the guide field was reduced to 1/3 of the normal operation.

The main ring accelerated $3\cdot10^{11}$ deuterons/pulse up to 7.2GeV. The top energy is limited by the maximum current of the present bias p.s. The injected beam intensity was nearly $2\cdot10^{12}$ deuterons(Fig.4).The large losses at injection and just after the acceleration are firstly due to the lower rf voltage and secondly due to the mismatch between the pulse width of kicker magnets and the deuteron bunch width at booster extraction.The deuteron bunch width is more than 150ns at extraction, while the pulse width of the present kicker magnet in the booster is nearly 100ns which enables to transfer the beam of width 80ns. Therefore, more than a half of the deuterons in the bunches are lost at transfer process.

The third trace in Fig.4 is the ferrite bias current. It has a jump at the beginning of acceleration.This phenomenon is explained by the hysteresis in μ-H_{bias} curve of the ferrite.For long time, we have suffered from this jump in bias current, since the shunt impedance decreases drastically at the jump. The procedure to avoid the jump is under investigation.

CONCLUSION

We have completed the improvement of the booster rf system for the deuteron acceleration. Even though the main ring rf system has succeeded to accelerate deuteron beam, the upgrading of the ferrite bias power supplies is necessary for physics experiment. Within April 1992, three bias p.s. will be replaced by the new type.

We also have to extend the pulse width of the booster extraction and main ring injection kicker magnets.

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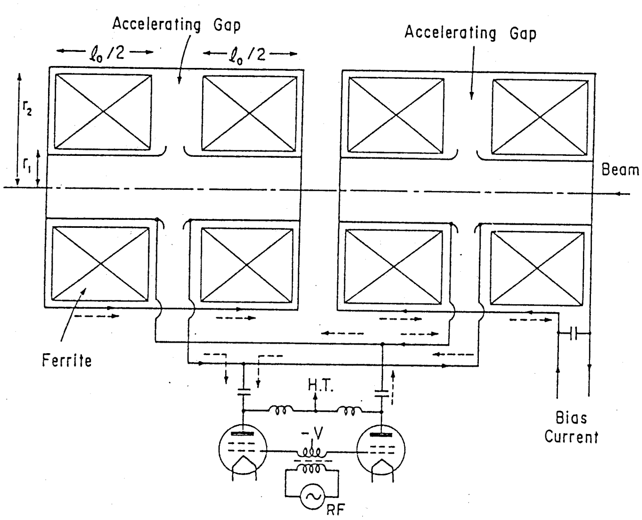

FIG. 1 Schematic Diagram of KEK PS RF System.

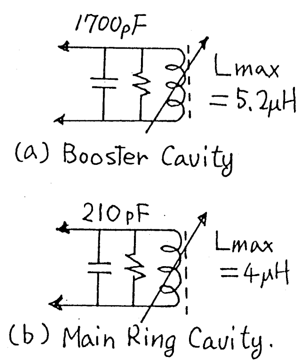

FIG. 2 Equivalent Circuits of The Booster and Main Ring RF Cavities Seen by The Amplifier.

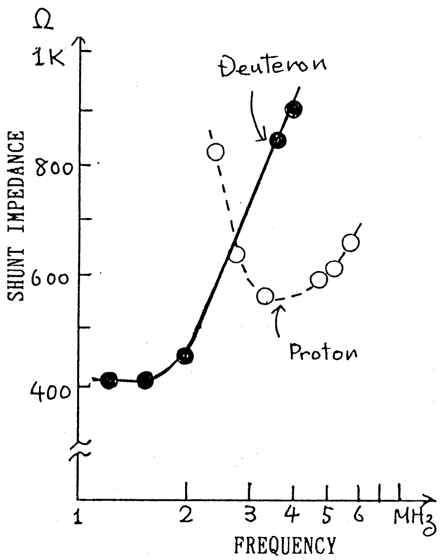

FIG. 3 The Shunt Impedance of The Booster #1 Cavity at Actual Operating Condition.

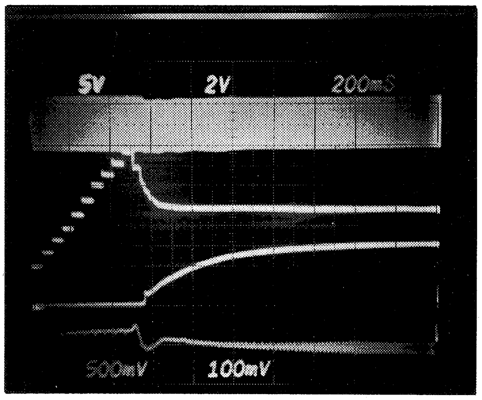

FIG. 4 Acceleration of Deuteron Beam at Main Ring. Top; RF Voltage ~ 20 kV, Second; Deuteron Beam Intensity, Third; Ferrite Bias Current, and Bottom; Phase Error of Automatic Tuning.