Acceleration of Deuteron Beam in the KEK Proton Synchrotron

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(abstract)

Deuteron beam has been successfully accelerated in the KEK PS up to the energy of 11.2GeV(5.6GeV/u), the limiting energy of the ring. The first physics experiment with deuteron beams was carried out in April of 1992 after this success. Helium beam acceleration is scheduled in April in 1994.

I. INTRODUCTION

Acceleration of heavy ion beams in the KEK PS was discussed about more than 8 years ago. However, the project was stopped by several reasons and heavy ion acceleration in the KEK PS has not been realized so far. Very recently, as one of the possible candidates among the future plans of the KEK PS, the PS-Collider, which aims to accelerate and collide heavy ion beams with the beam energy of up tp 7GeV/u for a gold beam, has been proposed.[1] The PS-Collider is designed to use the present KEK PS as its injector, therefore a much more simple scheme compared with the previous one for accelerating heavy ions in the PS has been examined carefully for ease of operation. Simultaneously, possibility of a polarized deuteron beam acceleration in the PS has been also studied.[2]

In November of 1990, the PAC(Programme Advisory Committee) of the KEK PS has conditionally approved an experiment using a high energy deuteron beams of 2 ~ 5 GeV. According to the request from the PAC, a task force for aiming deuteron beam acceleration in the PS has been initiated in the accelerator department. On Jan. 31 in 1992, deuteron beam has been successfully accelerated in the KEK PS up to the energy of 11.2GeV(5.6GeV/u), the limiting energy of the ring. The first physics experiment with deuteron beams was carried out in April after this success.[3] In this paper, the outline of the deuteron acceleration scheme and the experienece of the first long term operation are described and the future plan for heavy ion beam acceleration is also presented.

II. MODIFICATIONS FOR DEUTERON BEAM ACCELERATION

Earnest studies of examining the beam behaviors in deuteron acceleration according to the newly proposed scheme has been carried out for each part of the KEK PS. [4] Some components of the accelerator were replaced or modified for this purpose.

(a) Injector: The injector consists of the 750-keV Cockcroft-Walton preinjector and the 40-MeV Alvaretz linac. The ion source which has been used at the KEK PS is a plasma-sputter type of negative hydrogen ion source. It generates more than 20 mA negative hydrogen ion beam with the 90% normalized emittance of 1.5 mm.mrad.[5] This type of ion source can be converted to produce negative deuterium ions by changing a gas species from hydrogen to deuterium. The negative deuterium ion beam extracted from the ion source is accelerated by the Cockcroft-Walton preinjector and injected into the linac. The acceleration energy is 375-keV, which is a half of that for proton acceleration, because the linac is operated in 4π mode acceleration for deuteron acceleration. In order to accelerate heavy ions whose Q/A = 0.5 in an Alvaretz type of proton linac, 4p mode acceleration can be used. When deuteron acceleration is performed in 4π mode, the energy gain in each(ΔW_d)cell should be half of that for proton(ΔW_p). Thus,

$$\Delta W_d = m_p/m_d\, \Delta W_p = 1/2\Delta W_p\,, \qquad (1)$$

where m_p and m_d are the masses of proton and deuteron , respectively. Since the transit time factor of each cell for 4π mode acceleration is almost a half of that for 2π mode acceleration, the condition of eq.(1) is satisfied.

(b) Booster Beam parameters of deuteron acceleration in the booster is summarized in Table 1.

Table 1 Beam parameters of deuteron acceleration in the booster

	injection	extraction
Energy(MeV)	19.28	293.8
Bρ(Tm)	0.8994	3.636
βγ	0.1438	0.5812
harmonic number	1	
RF frequency(MHz)	1.132	3.996
RF voltage(max. kV)	~25	
emittance(pmm.mrad)		
horizontal	90	22
vertical	40	10
ΔP/P	+-0.5%	+-0.4%
bunch width(nsec)		100

There are two RF cavities in the booster at the moment. In deuteron acceleration, the RF frequency at the beam injection is 1.132MHz, which is almost a half of that for proton acceleration. The capacitance of each RF cavity is about 1000pF and the maximum inductance of each RF cavity is about 6 mH when the ferrite DC bias current is zero, respectively. Therefore, another capacitance of about 2000pF should be added for each RF cavity so as to tune the injection RF frequency to

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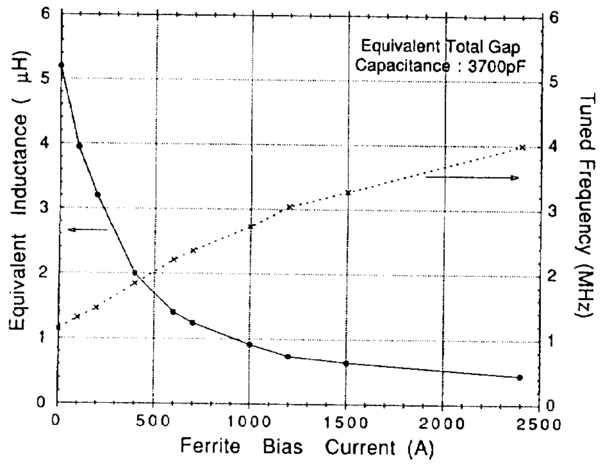

Fig. 1 Measured variations of inductance and tuned frequency as a function of the ferrite DC bias current of the cavity, when the vacuum capacitor of 2000pF was attached to the RF cavity.

each RF cavity so as to tune the injection RF frequency to 1.132MHz. Practically, this can be made by attaching a vacuum capacitor to the accelerating gap of each cavity. Figure 1 shows measured variations of inductance and tuned frequency as a function of the ferrite DC bias current of the cavity, when the vacuum capacitor of 2000pF was attached to the RF cavity. The inductance was changed for more than 13 times. This might be enough for deuteron acceleration. The shunt impedance of the cavity was also measured. The shunt impedance was about 400 W at the beam injection, which was approximately 40 % of the minimum shunt impedance for proton acceleration. However, since the RF voltage at the beam injection has to keep small to raise a longitudinal capture efficiency by an adiabatic process, the power loss in the ferrite of the cavity due to the low shunt impedance can be eliminated. The bucket height at the beam injection is relatively large for deuteron acceleration compared with proton acceleration. This is caused by the fact that the velocity of the deuteron beam at injection is a half of that for proton acceleration.

(c)Main ring: Beam parameters for deuteron acceleration in the main ring are summarized in Table 2. In deuteron acceleration in the main ring, the RF frequency range is as follows: finj = 3.996MHz, fext = 7.869 MHz and fext / finj = 1.97. For proton acceleration, finj = 6.027 MHz. The RF frequency can be lowered by adding extra capacitance to the accelerating gap of each RF cavity used in the main ring. Since the maximum inductance of the present RF cavity is approximately 6mH, the total capacitance of about 260 pF is required for deuteron acceleration. The present total capacitance of each cavity is about 110 pF, so another 150 pF should be added. The variations of the RF frequency as a function of the ferrite DC bias current were measured when the vacuum capacitor of 150 pF was attached to the accelerating of the RF cavity. It was observed that the frequency increased up to 7.9MHz when the ferrite DC bias current was raised to 1100A. The variations of the shunt impedance were also measured carefully and no serious power loss in the ferrite of the cavity due to the shunt impedance reduction was not observed.

Table 2 Beam parameters of deuteron acceleration in the Main Ring.

	injection	extraction
Energy(GeV)	0.294	5.6
Bρ(Tm)	3.636	43.04
harmonic number	9	
transition energy	5.32GeV/u	
betatron wave number	7.11(H),7.25(V)	
RF frequency(MHz)	3.996	7.9
RF voltage(max. kV)	~69	
dP/P	+-0.35%	
bunch width(nsec)	100	

III. ACCELERATION OF DEUTERONS

The first trial for deuteron acceleration in the main ring of the KEK PS has been performed from July 17 in 1991 and on July 19, the deuteron beam was successfully accelerated in the main ring up to the energy of 7.2GeV(3.6GeV/u). In this acceleration test, only one RF cavity of the main ring was available in accelerating deuteron beam. There was just only one ferrite bias power supply which was capable to swing its current up to 1100 A. Therefore, the maximally attainable RF voltage in this test was about 23 kV. The RF voltage of at least 50 kV is necessary for beam acceleration in the main ring when a field ramping rate of the bending magnets (dB/dt) equals to 3.17 T/sec as used in normal proton acceleration. In this acceleration test, we have reduced dB/dT to one third of the normal value, although the attainable deuteron beam energy was somewhat decreased to 7.2GeV(3.6GeV/u). In December of 1991, another two ferrite bias pwoer supplies were ready for use in operation. On January 31 in 1992, deuterons was accelerated to 11.2GeV(5.6GeV/u), the limiting energy of the ring. In April of 1992, the first physics experiment with deuteron beams was carried out. Characteristics and performance of each part of the accelerator in the deuteron acceleration are briefly described in the following.

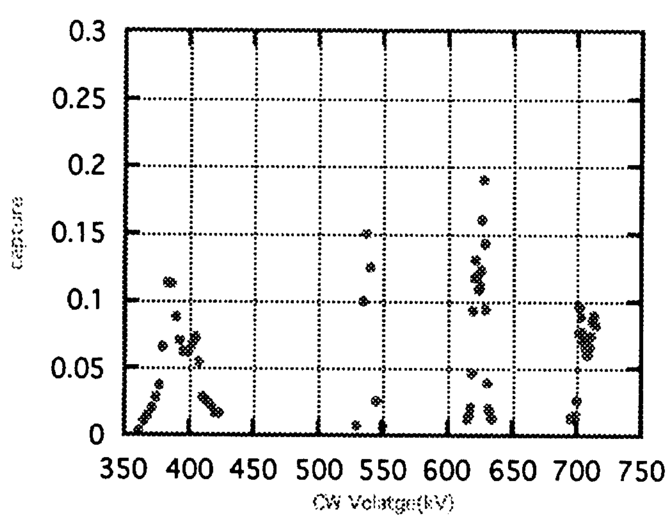

Fig. 2 Variations of the beam capture efficiency of the linac for 4π mode acceleration as a function of the injection energy.

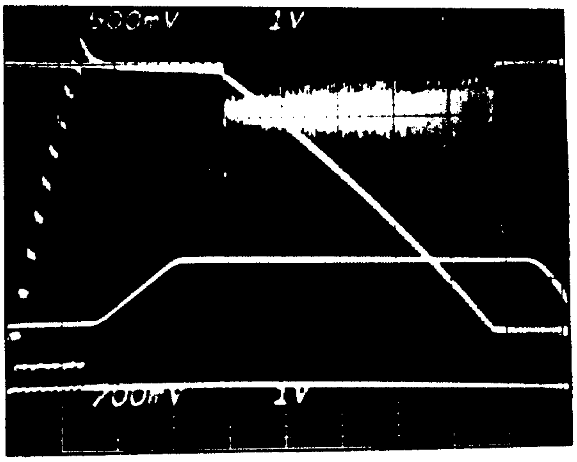

Fig. 3 Accelerated deuteron beam intensity in the main ring is shown simultaneously with a magnetic field pattern.

The ion source has produced negative deuterium ions by feeding a deuterium gas instead of a hydrogen gas. More than 15 mA negative deuterium ion beam from the ion source was accelerated by the Cockcroft-Walton preinjector and 12mA negative deuterium beam was injected into the linac. One of the most different operating parameters of the ion source compared with proton beam operation was a cesium consumption rate. The cesium consumption rate was relatively large for negative deuterium ion beam operation. In this type of ion source, negative ions are generated on the cesium covered molybdenum surface by ion sputtering in the plasma. Thus, the large cesium consumption was probably caused by a mass effect of sputtering ions.

In 4π mode acceleration of deuteron in the linac, the possible injection energy is not only 375 keV, which is a just half of that for proton. A relatively high energy of 540keV is also possible.[6][7] In Fig. 2, variations of the beam capture efficiency of the linac for 4π mode acceleration are shown as a function of the injection energy. It is found that not only the beam energy of 375 keV but the higher energies such as 540keV can be acceptable for the linac. In normal operation, 540keV injection was chosen and the optimized beam capture efficiency in the linac was reached to about 30 %.

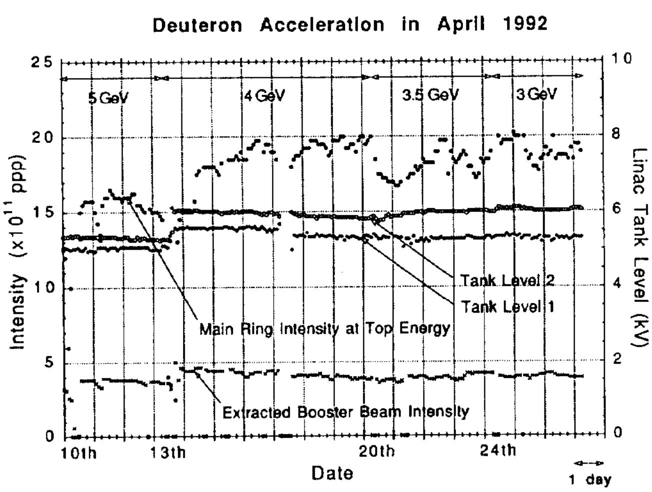

Fig.4 Beam intensity variations for one-month operation in deuteron beam acceleration of April in 1992 is summarized.

The injected beam momentum of the booster for deuteron acceleration is about 3% less than that for proton acceleration. Not only the magnetic field of the booster at beam injection was decreased but the beam transport elements between the linac and the booster were re-tuned to match the deuteron beam momentum. By tuning them carefully, almost 90 % injection efficiency was achieved in the booster. More than 95 % of the beam was extracted from the booster and transported to the main ring. The typical beam intensity in the booster is about 4×10^{11}ppp.

In Fig. 3, the accelerated deuteron beam intensity in the main ring is simultaneously shown with a magnetic field pattern. The typical accelerated deuteron beam intensity at the maximum energy in the main ring was 2×10^{12}ppp. According to the requests from physics experimentalists, the variable energy beam extraction from 2GeV(1GeV/u) to 11.2GeV(5.6GeV) has been tried for the deuteron beams so far. In Fig.4, the beam intensity variations for one-month operation in deuteron beam acceleration of April in 1992 is summarized.

IV. CONCLUSION

Deuteron acceleration is added to the routine operation of the KEK PS from April in1992. The intensity of accelerated deuteron beam reached to about 2×10^{12} ppp at the beam energy of 11.2GeV(5.6GeV/u). The variable energy beam extraction from 2GeV(1GeV/u) to 11.2 GeV(5.6GeV/u) is also available. In April of 1994, the helium beam acceleration is scheduled.

The authors would like to express their sincere appreciation to Director General of KEK, H. Sugawara, and Profs. M.Kihara and Y.Kimura for their continuous encouragement. They are also indebted to Drs. M.Numaziri and K.Kondo for their helps on radiation estimations in deuteron acceleration.

[1]PS-Collider design group;KEK Report 89-20,1990(in Japanese),KEK Report 90-13,1990(in English).
[2]H.Sato,Y.Mori,S.Ninomiya,T.Toyama,S.Hiramatsu;Accelerator Study Note,ASN 293(KEK),1988.
[3]J.Chiba et al.;
[4]Proc. of the Workshop on Deuteron Beam Acceleration in the KEK 12GeV PS:edited by Y.Mori, KEK-Proc. 91-12,1991(in Japanese).
[5]Y.Mori,A.Takagi,K.Ikegami,S.Fukumoto;Proc. of the fourth International Symp. on Production and Neutralization of Negative Ions and Beams,AIP Cof. Proc. Series No.158,1987,page378.
[6]S.Ohnuma, Th.Sluyters;Proc. 1972 Linac Conf.,Los Alamos,1972,page 191.
[7]T.Kato;KEK Report 86-5(1986).