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A compact atomic-beam type of polarized ion source, under construction at Kyushu University, is described. Newly developed permanent sextupole magnets are used and their operational characteristics are measured precisely and analyzed. In order to optimize the strong magnetic field electron impact ionizer performances, a computer code has been developed which simulates the trajectories in the ionizing volume of the electrons and the positive ions produced. A method of optimizing the radio-frequency unit is proposed. This polarized ion source will be used for a variety of research, especially for the polarized fuel fusion reaction study.

I. INTRODUCTION

Spin-polarized nucleons are indispensable for the study of low and high energy nuclear physics. Recently, however, their effectiveness in the field of solid state physics has been shown experimentally.[1] Furthermore, intensity improvement in the polarized ion sources has widened the applicability of spin polarized nucleons to other fields of science. For example, enhancement of low energy fusion reaction rates for polarized D T and D ^{3}He reactions are typical, and lead to very interesting applications in nuclear fusion technology.[2] Though an optical pumping source is another promising source for polarized particle production, there still exist some problems to be overcome. On the other hand, the characteristics of the atomic beam source have been technically well understood and it is expected to be able to achieve a very high intensity (more than mA) and a high degree of polarization ($>85\%$). In the present paper, we describe the present status of the development of a compact, high intensity, and highly feasible atomic beam polarized ion source, dedicated to the study of low energy fusion reactions (polarized fuel fusion) at Kyushu University.

II. GENERAL DESCRIPTION OF POLARIZED ION SOURCE

Figure 1 shows, schematically, the constituents of the atomic beam polarized ion source facility under development at Kyushu University. Liquid He is used to cool the accommodator of the dissociator to form intense atomic beams through a skimmer. Atomic beams are then electron-spin selected by a newly developed permanent sextupole magnet.[3] Electron spin polarization is transferred to nuclear polarization, going through the weak and strong field radio-frequency transition units (RFTs). Table I shows the obtainable hyperfine substates of deuterium and the theoretically expected degree of polarization in the present configuration of the sextupole magnets and RFTs. Nuclear polarized beams are ionized by the strong magnetic field ionizer. A permanent solenoid magnet induces an axially symmetric magnetic field. Extracted polarized ions from the ionizer are focused by an einzel lens and then the direction of the polarization may be changed in any direction relative to the beam transport direction (z axis), when passing through the Wien filter. These ions are accelerated up to a maximum voltage of 170 kV by a small Cockroft–Walton accelerator. The accelerated polarized ion beams are energy-selected by the dipole magnet and transported onto the target where nuclear reactions take place. Various parts of the apparatus are evacuated by either cryopump, oil diffusion pumps or turbomolecular pumps. The entire length of the polarized ion source is about 1.5 m, which is very short compared with the ordinary atomic beam source. The beam current we expect is more than 1 μA on the target. In the following sections, the newly developed parts of the source will be explained.

III. PERMANENT SEXTUPOLE MAGNET

We use two kinds of permanent sextupole magnets already shown in Ref. 3. The first is composed of two types of magnet. One is a 50 mm long tapered magnet and the other is a 50 mm long magnet with a flat pole tip. The second one has a flat pole tip throughout the entire 100-mm length. The inlet radius of the first magnet is 6 mm and outlet is 12 mm. The second flat one is 12 mm throughout the whole length. The details of construction of the tapered and flat sextuple magnets are shown in Fig. 2. The magnetic field distributions were precisely measured with a small Hall probe. Figure 3 shows the measured

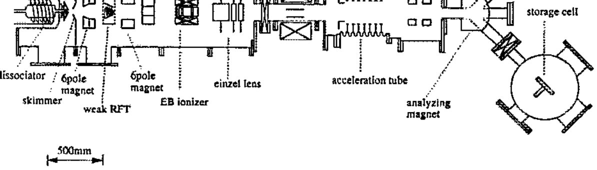

FIG. 1. Kyushu University polarized ion source facility.

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TABLE I. Possible combinations of sextupole magnet and RFT unit. Maximum vector (P_z) and tensor (P_{zz}) polarization are shown. (1) ~ (6) refer hyperfine substates of deuterium. (2) → (6) and (3) → (5) mean RFT induced transitions.

1st Sextupole magnet	Weak field RFT	2nd Sextupole magnet	Strong field RFT	Vector polarization P_{zz}	Tensor polarization P_z
Inserted	(4)(3)(2)	removed	off	$-\frac{2}{3}$	0
Inserted	(4)(3)(2)	(1)(2)	off	$-\frac{1}{2}$	$-\frac{1}{2}$
Inserted	(4)(3)(2)	(3)(2)	(3)(6) [(2) → (6)]	0	+1
Inserted	(4)(3)(2)	(3)(2)	(5)(2) [(3) → (5)]	0	−2
Inserted	off	(1)(2)(3)	(1)(6)(3) [(2) → (6)]	$+\frac{2}{3}$	+1
Inserted	off	(1)(2)(3)	(1)(2)(5) [(3) → (5)]	$+\frac{1}{3}$	−1

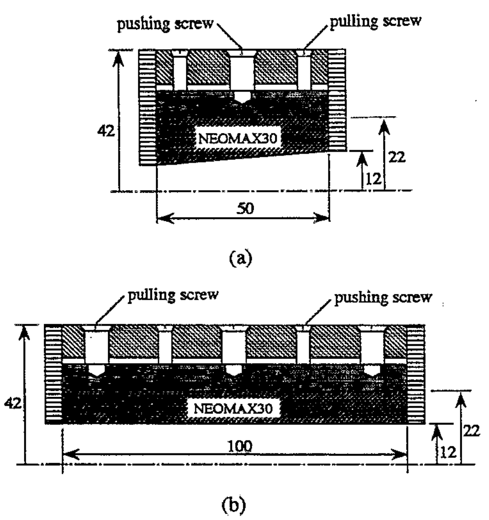

FIG. 2. Details of permanent sextupole magnets. (a) Tapered sextupole magnet ($L=50$ mm). (b) Flat pole piece sextupole magnet.

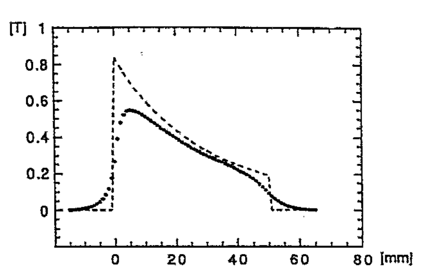

FIG. 3. Magnetic field distribution Br(z) of tapered permanent magnet of 50 mm length. ●: measured values; - -: theoretical values.

magnetic field [Br(z)] distribution of the tapered magnet, with the thoretical values, in the axial direction (z axis). In Fig. 4 is shown the same for the flat type magnet (100 mm long). Figure 5 shows the radial magnetic field [Br(θ)] distribution of the flat pole tip magnet together with the theoretical calculation. The agreement is quite good. The existence of higher order multipole components is also reduced by Fourier analysis. Table II shows the result of this analysis. The influence on the beam transport characteristic of these higher order multipole components is at most, 23% (4-pole component). These components can therefore be ignored in the present operation of the source.

IV. STRONG FIELD IONIZER

Polarized ion beams are produced in a strong magnetic field ionizer of electron bombardment type.[4] Though the ionization efficiency is small, the construction is simple compared with, for example, an ECR ionizer. Therefore, in order to obtain as high an ionization efficiency as possible, we have analyzed the trajectories of electrons and ions produced inside the ionizing volume so as to optimize the configuration of each electrode and its operational potential. The axial strong magnetic field is produced by a permanent solenoid magnet. The magnetic field distribution along the axial direction and the radial direction were mea-

TABLE II. Multipole components. Flat 100: flat pole piece sextupole permanent magnet of length 100 mm. Tapered 100: tapered pole piece sextupole permanent magnet of length 50 mm.

	Flat 100	Flat 50	Taper 50
2 pole	4.3%	10.5%	0.2%
4 pole	11.8%	23.0%	4.6%
8 pole	3.9%	1.7%	1.3%
10 pole	2.7%	6.1%	0.7%

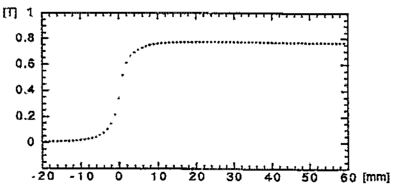

FIG. 4. Axial magnetic field distribution Br(z) of flat pole piece permanent sextupole magnet of 100 mm length.

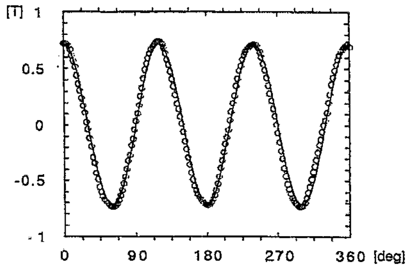

FIG. 5. Radial magnetic field distribution Br(s) of flat pole piece permanent sextupole magnet of 100 mm length. O: measured values; - -: theoretical values.

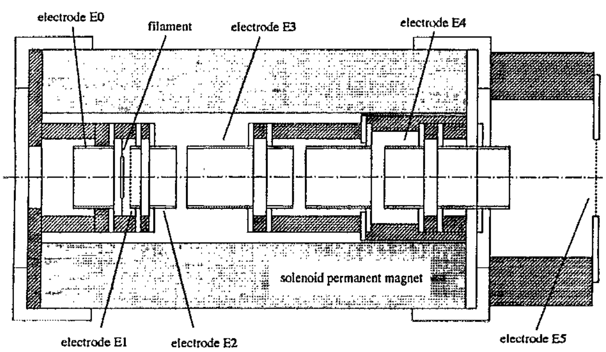

FIG. 6. Electrode configuration of strong magnetic field ionizer.

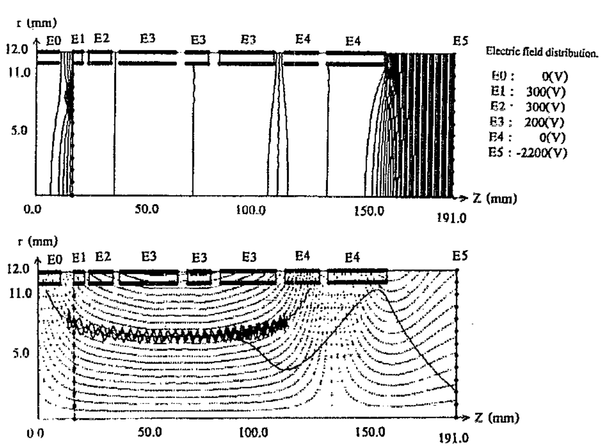

FIG. 7. Trajectories of electron and produced ion in the ionizing volume and equivector potential lines.

sured in order to derive the vector potential of the magnetic field. From these measurements, we calculated beam trajectories based on the axial ray approximation. Figure 6 shows the ionizer used schematically in the calculation. Figure 7 shows a typical result of calculated trajectories of electrons and ions and equivector potential after being optimized. It is clearly seen that electrons travel back and forth between electrode E_0 and E_4, spiraling along the magnetic field. Ions produced by electron bombardment are extracted by electrode E_5 with good focusing property.

V. RADIO-FREQUENCY UNIT

In the present source, one weak field unit and one strong field radio-frequency unit (RFT) are used to enhance the degree of nuclear polarization. The strength of the static magnetic field should be optimized to attain as high polarization as possible at fixed rf frequency. A small piece of electromagnet is inserted between the upper and lower yoke to adjust the strength of the static magnetic field. General characteristics of the weak field transition unit are studied under the operation of dissociator and sextupole magnets. If the weak field RFT is working properly the atomic beam intensity should be halved due to (1) to (3) transitions for the case of the hydrogen atom. Though the results have not been satisfactory so far, this method seems to be effective and simple to adjust, not only for the weak field but also for the strong field RFT unit. Further improvement of the operational characteristics of RFT units will be made by this method.

VI. SUMMARY

The atomic beam polarized ion source is composed of dissociator, sextupole magnets, RFT units, and ionizer. Each constituent should be optimized separately before optimizing the whole system. In this paper, we have described the results of the optimization of sextupole magnets, RFT units, and ionizer. The permanent sextupole magnets are found to operate properly with good characteristics. An end effect which might cause the loss of atomic beam and electron spin polarization in the case of a rectangular sextupole electromagnet was not observed in the permanent sextupole magnet, as shown in Fig. 4. Detailed analysis of this effect is progressing. We have also developed a computer code to analyze the electron and ion beam trajectories in the electron-bombardment strong field ionizer. This code can be used for the design of various kinds of electron-impact ionizer. The polarized ion source described here will be used to study the basic physics underlying the polarized fuel fusion proposed by Kulsrud[5] of Princeton University.

[1] D. Fick, R. F. Haglund, Jr., E. Beckman, B. Horn, and E. Koch, Nucl. Instrum. Method B **2**, 360 (1984).
[2] H. Hasuyama and Y. Wakauta, Helvetica Physica Acta **59**, 723 (1986).
[3] Y. Wakuta *et al.*, Nucl. Instrum. Methods A **260**, 543 (1987).
[4] H. F. Glavish, Nucl. Instrum. Methods **65**, 1 (1968).
[5] R. M. Kulsrud, H. P. Furth, E. J. Vareo, and M. Goldhaber, Phy. Rev. Lett. **49**, 69 (1982).