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PULSED HEAVY ION SOURCE FOR THE BEVATRON*

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Summary

A Phillips ion gauge source (Fig. 1) of the type used by the heavy ion accelerator in Berkeley has been adapted for use at the Bevatron.[1] The objective was to achieve high charge state ions (4+, 5+) of carbon and nitrogen. All source parameters are pulsed. The ion source performance regarding linac acceleration is discussed. The light ion (deuteron, alpha) performance of the PIG source and duoplasmatron is compared.

Introduction

To accelerate heavy ions in an existing synchrotron and linac requires several changes, none being so significant as the ion source itself. Prior to choosing a PIG source several tests have been made with the existing duoplasmatron. And indeed triple charged nitrogen has been observed in usable quantities. However we felt that higher charge states from the duoplasmatron could only be obtained with a substantial development effort, which we were unwilling to undertake.

Source Performance on Test Stand

Table I gives the Faraday-cup current in μA obtained (with CO_2, helium, and nitrogen gas) through a pair of 0.25-in-wide slits spaced 6 in apart and located 10 in from the magnet exit. The ions are accelerated to 80 keV, and the source parameters are optimized for $^{14}N^{5+}$. The best $^{14}N^{5+}$ performance occurred at the lowest gas pressure consistent with arc stability; for a source exit aperture of 0.062 in x 0.625 in, the source gas pressure was 98 μ with a flow of 0.5 cc/min.

Pre-Injector Source Performance

By providing an adjustable pedestal to support the pulsed magnet, we were able to fit the PIG ion source to the lens box in the pre-injector terminal in the place previously occupied by the duoplasmatron. The existing lens system was slightly modified to accept the PIG ion source beam; and in addition, a digital monitoring system was installed to read all source parameters at any desired time during the arc current pulse, which in turn led to a better understanding of the ion source.

Positive identification of $^{14}N^{5+}$ ions at 360 keV was assured by use of the rapid emittance measuring equipment located at the pre-injector exit. This equipment consisted of a 0.005-in-wide collimator, a pulsed magnet, and a Faraday cup with a 0.005-in-wide aperture. The source magnet was tuned to $^{14}N^{5+}$ and then to $^{14}N^{4+}$, and in each case the beam pulse was analyzed with the rapid emittance equipment. The ratio of the B field values (source magnet vs. emittance magnet) of the two beams was identical; and as a further verification, hydrogen gas was let into the source and the $^2H^+$ peak was found in its proper place.

Operating lifetime of the source was limited by cathode insulators and cathode erosion. A typical cathode insulator would run 100 before accumulating enough deposits of titanium to give way to arc instability. The titanium cathodes would last for 500 h at a duty cycle of 1% and an arc current of 3 A.

Linac Operation with Heavy Ions

Operation of the PIG source with regard to linac acceleration is compared with the duoplasmatron source in Table II. The linac was operated in the 2βλ mode for acceleration of particles of e/m $\leq$. The velocity of the particles in the 2βλ mode is one-half that of the proton accelerated in the 1βλ mode; hence the kinetic energy for our 20-MeV proton accelerator is approximately 5 MeV/nucleon. Particles with e/m of less than 1/2 require additional electric field gradient to maintain stable phase during acceleration. Two μA of $^{14}N^{5+}$ ions were accelerated at a relative linac RF gradient of 1.4 as compared with a relative RF gradient of 1 for deuterons. Figure 2 indicates 5.5 μA of $^{14}N^{4+}$ accelerated with the maximum available electric field gradient at the time being 2% below optimum.

A standard drift-tube magnet strength was used for acceleration of protons, deuterons, and alphas; and an increased strength of (1.4 and 1.75) times the standard gradient was used for nitrogen of charge state (5^+ and 4^+), respectively.

An aluminum stripping foil of density 1 mg/cm^2 stopped all low-energy beam that drifted through the linac, and served as an aid in tuning (Fig. 3). Aluminum foil of density 20 mg/cm^2 would stop the $^{14}N^{5+}$ ions but would allow accelerated protons, deuterons, or alphas to pass through. Faraday cups were used for beam monitors. The $^{14}N^{5+}$ particles were stripped to $^{14}N^{7+}$ with an aluminum foil of density 40 μg/cm^2 with an efficiency of ~ 50%. The energy spread of the 5 MeV/nucleon $^{14}N^{7+}$ beam at base width and at (FWHM) measured 2.6% and 0.8%, respectively.

Source Description

A schematic drawing of the source is shown in Fig. 4. The source measures 3.5-in long and fits snugly inside the vacuum chamber. Alumina cathode insulators isolate the cathodes from the tank walls. The stainless steel anode has a 0.250-in inside diameter, is 2.5-in long, and is spaced on both ends by alumina insulators. The anode is machined to accept a replaceable thin (0.010 in) tantalum plate having an exit aperture measuring 0.031 in by 0.625 in. Anode and cathode water cooling is provided by 0.125-in diameter stainless steel tubing. The cathodes are 0.375-in diameter by 0.5-in long titanium rods, and are copper plated to allow a soft solder joint to the cathode holder.

The tungsten extractor jaws are 0.032-in thick and are secured to the extractor body with screws that allow aperture adjustment. A typical aperture width and gap spacing is 0.040 by 0.080 in. An alumina support insulates the extractor from ground and allows transverse adjustment across the anode aperture. Electrical connection between the source extractor and the lens box is provided with a thin stainless steel shield.

The pulsed magnet design of the ion source made it mandatory that the vacuum tank be constructed of lightweight (0.062 in) stainless steel sheet that could be installed in the magnet gap without disassembling the magnet.

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The extractor shield insulators and the ion source assembly is used to support the vacuum load.

The source position within the magnet was determined by use of a ray-tracing code[2] using actual field data, and is shown in Fig. 5. The magnet is rotated to provide a 6-deg exit wedge for vertical focusing. The total particle bend is 96 deg. A test bench fixture provides precise alignment of the anode axis with the magnetic field.

Pulsed Ion Source Magnet

Power limitations in the pre-injector terminal indicated the choice of a pulsed magnet. It is an air cooled H-magnet with a 4-in gap and a design field of 6.5 kG over a pole area that measures 6.5 by 8 in. The core is a laminated sandwich of 0.025-in electrical sheet steel and dacron cloth bonded with EccO-bond type 45 epoxy. The core is fabricated in 4 sections and would permit magnet-gap modification.

Each of the two coils is wound with 144 turns of 0.1285-in heavy film polythermaleze coated copper magnet wire. The coil layers are insulated with 3 sheets of nomex paper each, then half lapped with glass tape; the coils are then impregnated with Furane 202 resin and d-40 hardener. Input power to magnet is 700 V at 360 A for a rise-time of 16 ms. Total power at 1% duty factor is approximately 300 W.

Power Supplies and Monitoring

Pulsed magnet current is supplied by a 800 V, 400 A power supply using two capacitor banks which are discharged through the magnet on alternate pulses. An SCR switching bridge is used to keep the current in the magnet in the same direction. Pulse rate is 1 pulse per second at rated output.

The arc supply is a dual supply providing an adjustable triggering spike of 0 to 7 kV and a pulse line capability of 4.5 kV with a 35 Ω source impendance. The spike supply uses a capacitor discharge to fire the arc, whereupon the pulse line is then discharged through the arc for 800 μs.

The extractor voltage pulse is started 100 μs after the arc to insure that the arc is stabilized before trying to extract ions. The extractor supply is rated at 40 kV and 10 mA. Voltage is applied to the extractor by charging a 0.25-μf capacitor through 2 MΩ and then applying it to the extractor by switching an Eimac 4PR250C. A 10-kΩ resistor is in series with the extractor and pulse rise-time is 30 μs.

Conclusions

Although the source has performed well in its present form, several changes are under way with the goal of achieving greater high charge state output, improved particle separation, and a longer operating time. These changes include redesign of the source to allow a greater particle bending angle, shielding the cathode insulators from the arc discharge, and a study of the extractor-exit aperture area to improve source emittance.

Acknowledgments

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References

1. (a) J.R.J. Bennett, High Charge State Heavy Ion Sources, IEEE Trans. Nucl. Sci., NS-18 (3), 55-62 (June 1971).

   (b) C.E. Anderson and K.W. Ehlers, Rev. Sci. Instr. 27, 809 (1956).

2. Duane A. Spence, BLUSER, Fortran Ray Tracing Code, H-5-69-02, Hilac, Lawrence Berkeley Laboratory.

TABLE I. Faraday-cup current in μA.

CHARGE STATE	5^+	4^+	3^+	2^+	1^+	V_{ARC}	I_{ARC}	P_x
Carbon		28	240	340		2600	2.5a	80μ
Nitrogen	10	32	180	500		2600	2.5a	98μ
Helium				200	2000	2700	1.6a	450μ

TABLE II. Comparison of duoplasmatron and PIG sources.

PARAMETER	DUOPLASMATRON SOURCE		PIG SOURCE			
BEAM:	DEUTERON	ALPHA	DEUTERON	ALPHA	NITROGEN	
					N^{5+}	N^{4+}
PRE-INJECTOR	30 mA	15 mA	5 mA	1 mA	50 μA	300 μA
LINAC	1.0 mA	95 μA	250 μA	80 μA	2 μA	* 5.5 μA
SOURCE DATE:						
GAS P_x	250 μ	115 μ	450 μ	210 μ	70 μ	70 μ
ARC (V)	260	1800	650	1300	1800	1800
ARC (A)	4	8	2.0	2.0	3.5	3.5
SOURCE MAGNET (G	—	—	3950	4100	3800	4800
EXTRACTOR (kV)	54	40	31.0	36.0	31.0	30.0
FOCUS	100	92	70	32	81	92
E1	18	14	21	19	23	27
E2	41	40	39	40	40	40
PRE-INJECTOR ENERGY (kev)	258.0	257.4	259.1	257.3	360.4	434.1
LINAC RF LEVEL (rel.)	1.0	1.0	1.0	1.0	1.40	1.72
BUNCHER RF LEVEL	9.0	7.0	7.0	6.8	8.5	12.0
DRIFT TUBE MAGNETS	STD	STD	STD	STD	1.4xSTD	1.75xSTD

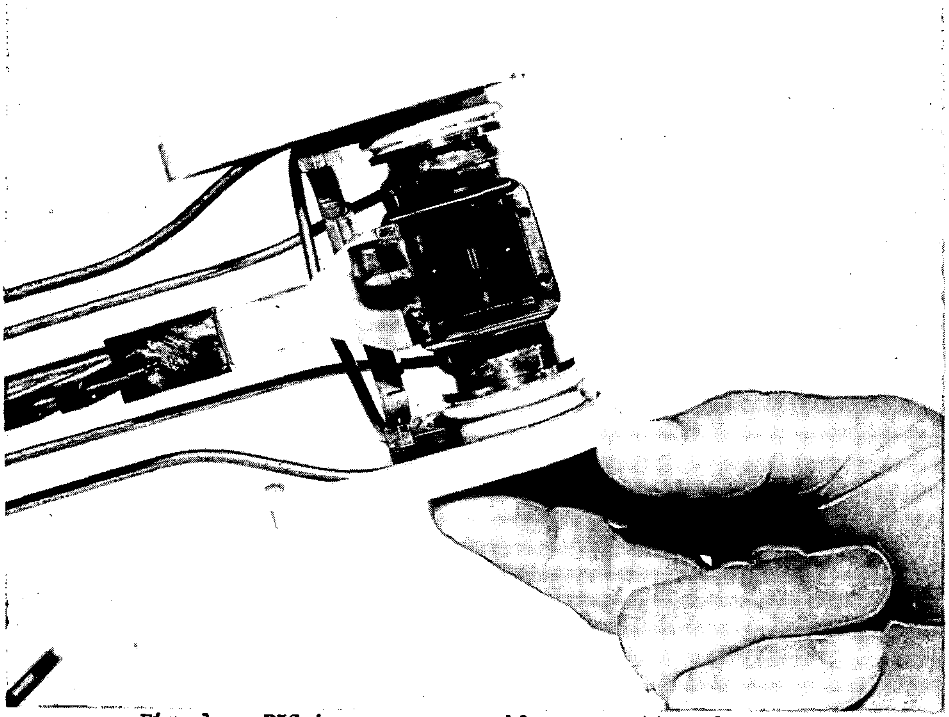

Fig. 1. PIG ion source assembly on mounting plate.

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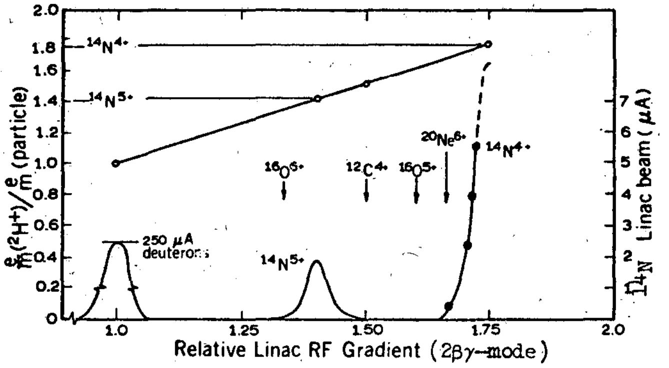

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Fig. 2. Required linac RF gradient for ^{12}C, ^{14}N, ^{16}O, ^{20}Ne; and current distribution vs linac RF gradient for ^{2}H and ^{14}N.

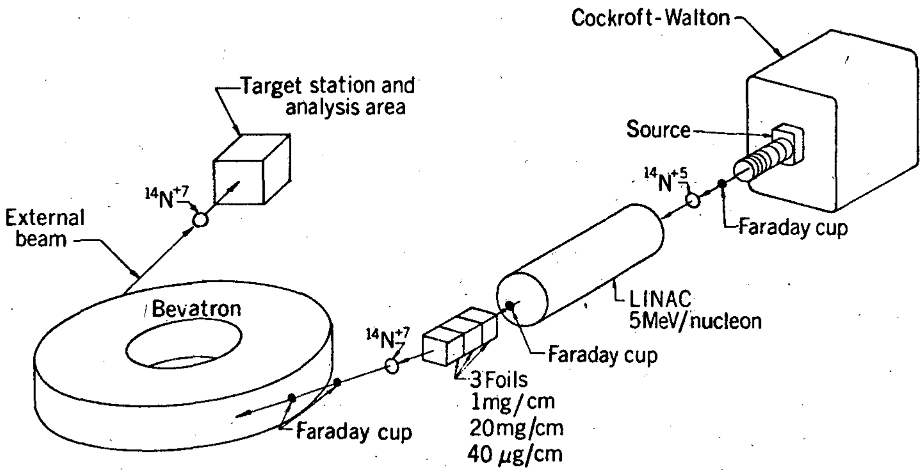

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Fig. 3. Schematic representation of high energy heavy acceleration at the Bevatron.

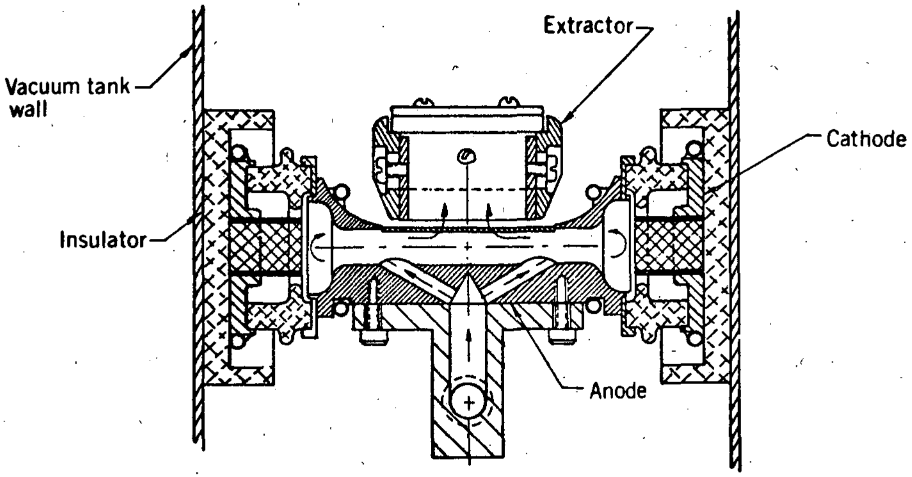

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Fig. 4. Cross section of the pulsed PIG source from the Hilac adapted for Bevatron use.

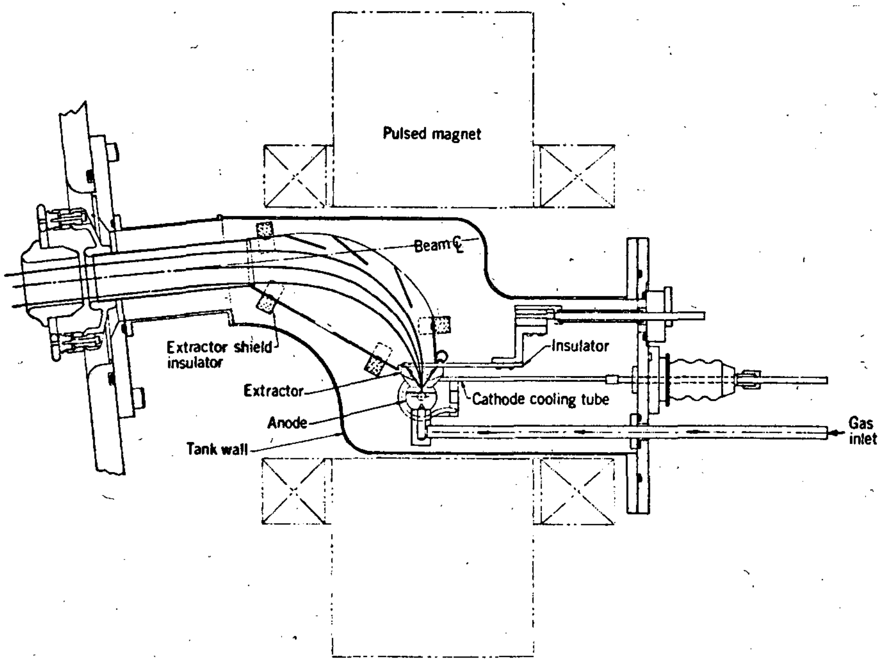

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Fig. 5. PIG source assembly in the vacuum tank.

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