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AN INTENSE H$^-$ SOURCE FOR THE IPNS-I RAPID CYCLING SYNCHROTRON*

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Summary

Increases in the intensity of the Intense Pulsed Neutron Source (IPNS-I) at Argonne National Laboratory will eventually require that the present H$^-$ ion source be replaced with a higher current source. Laboratory studies of a Penning H$^-$ ion source for this purpose have been carried out. The source design is essentially due to Allison.[1] The source has operated continuously for more than a week at 15 Hz with 45 mA of H$^-$ current during the 80 μs pulse. For shorter periods, it has delivered the same current at 30 Hz with 45 μs pulses. At present, two technical problems prevent the source from being operational. It is not adequately reliable, and the beam emittance at 20 keV is larger than expected.

Introduction

The present RCS ion source uses double charge exchange of a low-energy proton beam to produce H$^-$.[2] This source is highly reliable; however, it is limited to 12 mA at 20 keV. In order to reach the RCS design goal of 3×10^{12} protons per pulse, a source is needed which will deliver at least 40 mA at 20 keV. The technique due to Dimov et al.[3] of using a cesium vapor in a conventional Penning or magnetron source to directly extract a high H$^-$ intensity is well known. Schmidt has developed the magnetron source to be a reliable source for the FNAL synchrotron.[4] At present, no Penning H$^-$ source is used as an operation injector for a synchrotron. The Penning source has been studied for the RCS because of the general belief that the Penning design can be operated with a higher duty cycle than the magnetron design.

General Description

The general layout of the source is shown in Fig. 1. The beam is extracted from the source at 20 kV. It is then bent through 90° by a magnetic dipole and focused by a magnetic quadrupole triplet. In an operational version, the entire source would be installed in the terminal of the Cockcroft-Walton preaccelerator. The terminal voltage is 730 kV. The source box, pump, and quadrupole triplet are at terminal ground, and the source itself, gas valve, and cesium system are at 20 kV below terminal ground. A CAMAC-based microprocessor-controlled system operates the source in the terminal. The CAMAC in the terminal is optically linked by a serial highway to the RCS control room.

Arc High Voltage Power Supply

The arc power supply is a delay line charged by a dc power supply. The delay line consists of a series-parallel arrangement of eight 6 μF capacitors and eight 6 μH inductors. The delay line acts as a supply with an internal impedance of one ohm and a maximum pulse length of 96 μs. The delay can be crowbarred if a shorter pulse is desired. The arc impedance is approximately 0.8Ω. The dc power supply is nominally set to 225 V. This voltage establishes the arc and leads to a 100 V, 125 A arc. Series resistors can be switched in to obtain lower arc currents.

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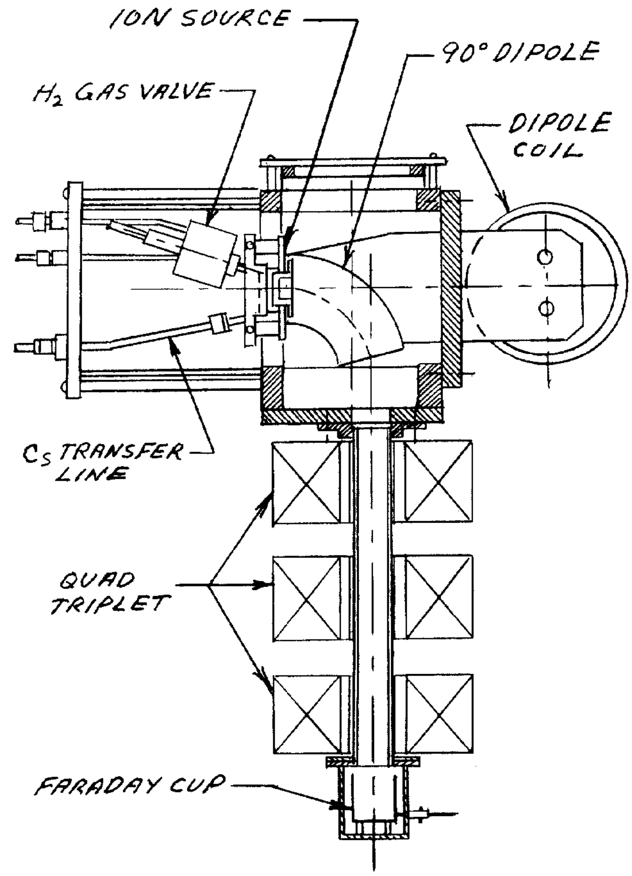

Fig. 1. Drawing of Penning H$^-$ Ion Source As Set Up in Laboratory

Pulsed Extractor Supply

The extraction voltage is provided by a 20 kV dc supply that is stiffened by a 1 μF capacitor. The extractor is switched by a 4PR250C tube. At a typical operating voltage of 16 kV, the extraction system draws 200 mA. This is assumed to be primarily electrons. However, the beam intensity is measured by a Faraday cup only after exiting from the dipole. Therefore, the H$^-$ beam lost in the dipole is unknown.

Gas System and Vacuum System

The hydrogen gas is injected into the discharge volume by a Veeco PV-10 piezoelectric valve. The nominal delay between the gas valve trigger and the arc trigger is 600 μs. However, the source performance varies little with delays between 500-1200 μs. At 30 Hz the minimum gas consumption that has been obtained which is consistent with reliable source operation is 8 sccm. The source performance is extremely sensitive to the gas consumption. The system is pumped by a turbopump rated at 1100 liters/s for hydrogen. The source box pressure is 2×10^{-4} torr. This pressure is higher than desired. However, if the repetition rate is instantly lowered to 15 Hz, the pressure drops in half, but the beam current does not change. This suggests that higher pumping speeds would not improve the beam intensity. The effective pumping speed of the turbopump is 500 liters/s. Presumably, this can be increased if the present 15 cfm

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backing pump were replaced by a substantially larger one. It is estimated that, in operation in a terminal, 95% of the gas would be pumped by the turbo and the rest would go through the high voltage column.

The Cesium System

An external cesium boiler is used to provide cesium vapor into the discharge volume. The boiler is typically operated at 160°C. However, the performance shows no particular change as the temperature is varied from 150-185°C. The transfer line from the boiler to the source is always maintained above 300°C to avoid clogging of the transfer line. A valve in the transfer line is used to isolate the boiler when required.

Table 1. Typical Operating Characteristics

H^- Current (at end of dipole)	45 mA
H^- Current (at end of quad triplet)	20 mA
Arc Current	125 A
Arc Voltage	100 V
Duty Factor	30 Hz × 45 μs
Average Gas Flow	8 sccm
Extraction Current	200 mA
Beam Energy	16 kV

Ion Optics

The emission slit is 10 mm horizontally by 0.5 mm vertically. This large aspect ratio results in the space charge blowing the beam up primarily vertically. The 90° dipole has a radius of curvature of 8 cm and n = 0.85. This produces very strong vertical focusing. Studies using space charge TRANSPORT show that the beam should leave the dipole converging at 40 mrad vertically (if the usual assumption of space charge neutralization is made). Intensity measurements made with a Faraday cup 15 cm downstream of the dipole show typical intensities of 45 mA. Intensities as high as 80 mA have been obtained. A quadrupole triplet was installed downstream of the dipole to capture and focus the beam. The quadrupoles have a 7.5 cm aperture and are 10 cm long. Optics studies show that if the beam is space-charge neutralized, then the triplet will capture the beam. Measurements show that almost half the beam is lost in the triplet. The origin of this loss must be an unexpectedly large emittance. However, the reason for the high emittance is not understood at present.

Control System

The control system was designed to serve a fully-operational source and, therefore, provides controls and readouts for all pertinent parameters, both from a remote location and locally at the source. The data handling is based on the CAMAC protocol but, as with any source where millivolts and kilovolts are processed, all in a hostile environment, a great deal of interfacing is also needed. All data processing and display is provided by a Kinetic Systems 3880 CAMAC-based microprocessor.

The major control system elements are: a color video display and a special purpose keyboard; a CAMAC crate housing the microprocessor and primary interfacing modules; and a set of NIM-type bins housing the special purpose interfacing modules. Three general types of interfacing are employed: direct connections for local-ground systems such as vacuum and magnet power supplies; motor controls for a few special situations; and fiber-optic links for most other parameters. About 25 six-foot fiber-optic links are used to interface the many parameters at the pulsed 20 kV extractor potential. They are used to send timing pulses to control pulsed power supplies, they are used to return analog information by FM, and they are used to control the many heating systems by line-synched SCR control pulses. They are, of course, also used for sending timing and control information from building ground potential.

Operator Interface

The operator display and control method is designed to provide all information in easy-to-understand form and allows multiparameter tuning to be easily accomplished. The TV format provides for 16 binary status parameters (name displayed if abnormal, blank if normal), about 30 dependent and independent variables, each with title, numeric value, and units, and an operator communication area. All variables are shown with a two-digit ID code and are subdivided into subsystems such as "vacuum" and "extractor" system.

A parameter is selected for control by entering its two-digit code and then selecting a color at the special keyboard. The parameter and its value are then displayed with one of four background colors (red, blue, green, or yellow), corresponding to the four colored sets of up-down buttons used for control. In this way, any four related (or unrelated) parameters can be controlled without having to reselect them while the color clue relationship allows rapid identification of the proper control.

Besides the above implied duties, the microprocessor also scales the data so that readouts are in proper engineering units and provides for blinking parameter values that exceed operator-entered limits.

The remote control console has identical display and keyboard attributes so that only one control methodology need be learned. The ground-based microprocessor has nearly identical software, the only difference being the bit-serial CAMAC highway communication protocol necessary to link it to the source potential CAMAC crate.

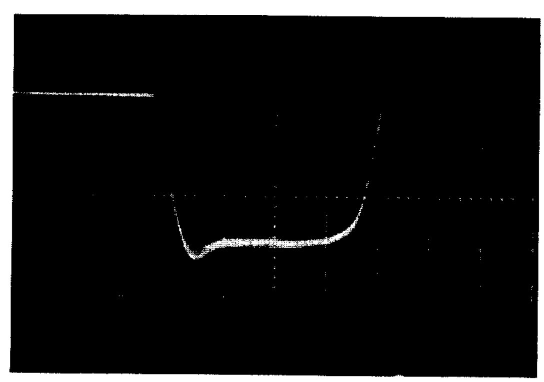

Fig. 2. Arc Current Pulse During 30 Hz Operation. Scale is 50 A/Div. and 20 μs/Div.

Operation

Normal operation (see Table 1) of the source can be established in approximately 2½ hours, starting from a cold source if the system is pumped down, and if the source is well conditioned. Startup begins by heating the cesium transfer line to 300°C and the boiler to 160°C. The arc voltage is set to about 300 V and the gas flow to 12 sccm (for 30 Hz operation). The system is designed to operate pulsed only. After a few hours, the low impedance arc will suddenly "snap" in (see Fig. 2). For a while, the source may shift erratically between the low impedance "cesium" mode and the high impedance "hydrogen" mode. After the low impedance arc is established, the gas consumption and arc voltage can be reduced. During normal operation with a duty cycle of 0.14% (for example, 30 Hz × 45 μs), the cathode temperature is almost 300°C. The arc current and beam current are normally very quiet.

Acknowledgments

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