CONVERSION OF THE AGS LINAC TO H⁻ ACCELERATION

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Summary

The AGS 200 MeV linac was converted to an H^- accelerator during the summer of 1982 using a magnetron-type source in the column of the second pre-injector pit. Because of the re-entrant electrode design, a 20 keV transport line was required to carry the beam to the first electrode. Several changes were made to the source which enhanced its performance over previous designs. The same H^- beam current is available at 2.75 times the duty factor with reduced deterioration of its output over several months of operation. The source, 750 keV transport, and linac modifications and performance will be presented.

Introduction

The AGS has been operating since October 1982 with H^- charge exchange injection.[1] The plans and objectives for this conversion have been previously described.[2] The change was made in parallel with operation of the AGS program which used the existing duoplasmatron proton source. Because of the re-entrant electrode design, a 20 keV transport line was required to carry the beam to the first electrode of the high-gradient column. The 750 keV H^- beam is brought to the Linac through a new low energy transport line (LEBT II).

One objective of the project was the reduction of beam loading on the rf system, with an anticipated increase in tube life. The extension of the pulse length of the beam provided to the Brookhaven Linac Isotope Production (BLIP) facility was desirable in order to preserve the required dose levels at the lower peak current of the H^- beam.

The first section of this paper will discuss the development and commissioning of the H^- ion source. The second section will describe the new hardware specific to the pre-injector installation. The LEBT beam transport system and the operating parameters and beam characteristics will be discussed in the third section.

Source Research and Development

Two magnetron assemblies were obtained from FNAL[3] for use at BNL. A test stand was built to evaluate the source performance and provide operating experience with which to adapt the source to the air-insulated BNL high gradient column. The detailed results of these tests appear in Ref. 4.

It was found that 40 - 60 mA of 20 keV H^- at a nominal 1 Ω impedance could be maintained for prolonged periods if the duty factor was kept at 0.1%, as at FNAL. It was also observed that the emittance varied significantly with time unless the background gas pressure was raised, suggesting space charge effects to be present.

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Installation of the source in Pit II was completed in July 1981. Considerable difficulty was encountered in bringing the Cockcroft-Walton (CW) up to full voltage, possibly due to contamination with vacuum pump oil in its past. Minimal cleaning of the column permitted the voltage to be raised to 800 kV.

After the source was installed in the dome, it was not possible to reproduce the high current, low voltage (typically 140 V, 120 - 140 A) arc conditions seen in the test stand. The source would initially show these characteristics but would decay away in 8 to 24 hours to a "3 Ω" mode (210 V, 70 A). The source was repeatedly removed and cleaned or replaced. The boiler was replaced several times, but the results were always the same.

Because the behavior often suggested poor cesium delivery, a number of changes were made in this system. A larger (1/4" dia.) feed tube was installed to improve the conductance, and the copper boiler in which a glass ampule of cesium was crushed was replaced with a stainless steel boiler charged with cesium. The boiler temperature had to be reduced from 190^0 C to 165^0 C, but the same source behavior was seen. After six months of investigation the source still was not able to operate in the 1 Ω mode for more than one to two shifts before going to the more stable 3 Ω condition.

T. Sluyters suggested that even at 3 Ω more current could be extracted by curving the cathode to increase the surface area which would contribute to the extracted current.[5] Consequently, a cathode was machined to have a groove with an arc length four times the height of the anode slit and was installed in the source. It conditioned just as before, reaching a current of 120 - 140 A and 140 V. As the source impedance increased, the power supply was lowered until a 50 A discharge was maintained. The gas was adjusted to give a reasonable pulse shape while the pulse was widened to 320 μs (maximum of the PFN) to keep the temperature as high as possible.

Under these conditions the beam current in LEBT II increased from approximately 15 mA to 40 - 45 mA over a period of 24 hours. At this time the source voltage was 150 V at a current of 50 A. These conditions were maintained stably for more than three months after which the delivered current had dropped by 20 - 25% from its early peak.

Inspection of this source showed an image of the anode slit etched in the center of the cathode groove of depth 0.016 in. at the maximum point. The interior of the source showed significantly less debris than in the high current operating mode. No damage to the MACOR ceramics was seen.

It had never been possible to see extracted beam on the current transformer at the end of the 20 keV transport line with the dome grounded, yet when the CW voltage was brought to 40 - 50 kV, current could be seen. This was due to charging of the first electrode by the beam. With no CW voltage, extracted beam was observed when a 15 kV power supply was connected to the first electrode.

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The beam rise time is 1 μsec in the dome but 50 μsec in LEBT II, due to space charge.[6] This can be compensated by increasing the background gas pressure using a controlled leak, or, by timing the discharge late in the gas burst. In this way the LEBT II beam rise time can be made 10 μsec.

Changes to the discharge pulser PFN allowed a pulse width of 500 μsec for a duty factor of 0.275%. The source has operated in this mode for the last six months since the start of full H^- operations. After three months the source was inspected, cleaned and re-installed. It is now completing another three-month run. Typical operating conditions are shown in Table I.

Table I

DISPS	311.0	V	Discharge p.s. voltage
EXTRV	17.35	kV	Extractor voltage
DMVAC	82.0	μTorr	Dome vacuum
CSTMP	146.5^0	C	Cs boiler temperature
90DGI	643.0	mA	90^0 magnet current
DISV	152.0	V	Discharge voltage
DISI	56.7	A	Discharge current
CSVT	329.7^0	C	Cs valve temperature
CSFTT	339.5^0	C	Cs feed tube temperature
SANT	150.4^0	C	Anode temperature
SCAT	368.0^0	C	Cathode temperature
CBOXT	-49.0^0	C	Cold box temperature
EXTDL	1830.0	μs	Extractor delay time
EXTPW	470.0	μs	Extractor pulse width
GASDL	900.0	μs	Gas delay time
DISDL	900.0	μs	Discharge delay time
EDIS	500.0	μs	End of discharge

The reason for the improved performance has not been established. It may be that the line etched in the cathode during operation has a smaller effect since current comes from more of the cathode than in the flat cathode. Another possibility is that at the lower arc current there is less debris built up in the source which can occlude the anode slit.

Dome Hardware

The source is shown in Fig. 1, with the shroud and glass tube removed. Figure 2 is a layout of this same equipment. Except for the groove in the cathode, the source is as described in Ref. 3.

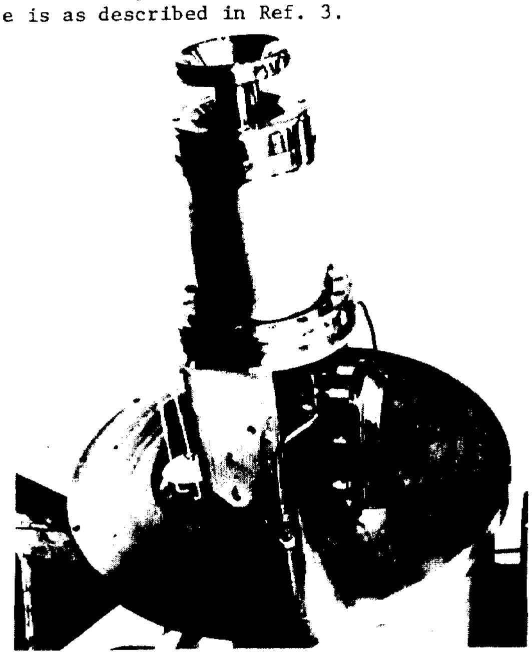

Fig. 1. H^- source assembly without shroud and glass tube

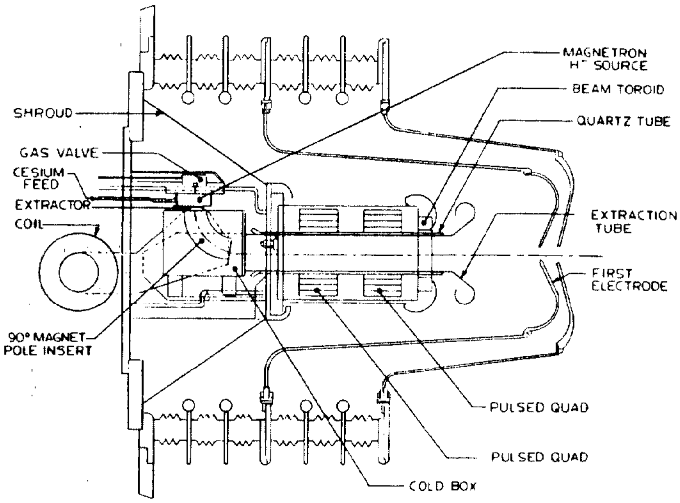

Fig. 2. Schematic of BNL H^- source assembly

The cesium vapor produced in the stainless steel boiler flows through a heated valve and feed tube. The flow rate of the cesium is controlled by a servo-loop around the boiler heater and a thermocouple which maintains the temperature to $\pm 0.1^0$ C. A local interlock turns off the boiler power supply if the temperature exceeds a hardware limit or if the cold box temperature rises to -15^0C. A servo-loop adjusts the piezoelectric gas valve pulse width to keep the average vacuum readback constant to within 0.02 μTorr. One problem, however, is that the circuit cannot distinguish between increased background and changes in the pulsed gas. A new circuit which separately reads the gas peak and background is undergoing tests.

The arc is produced by the triggering of an SCR to dump a PFN in the discharge pulser. The original circuit of FNAL design has been modified to provide 145 μsec per section with an impedance of about 2 Ω to better match present source conditions.

An extractor pulser provides a voltage of up to 20 kV. This circuit provides up to 4 A to charge the capacitance of the extractor, cold box, 20 kV transport tube and cable, allowing a 6 μsec voltage rise time resulting in a 1 μsec beam rise time.

A thyratron is used to provide a rapid shutoff of the beam pulse in case of an accelerator fault.

A quadrupole doublet of Septier configuration provides focussing along the 20 keV transport line in the dome. These are powered by transistorized pulsers which can provide up to 250 A regulated to 0.1% for up to a 1 msec flat top.

The control system[1] in the dome uses a microprocessor to interpret optically transmitted data from the ground station and control the source. A second microprocessor performs the same functions for LEBT II and also provides a local display. (See Fig. 3).

The interface to the AGS control system is by means of a second microprocessor (the interface CPU) on the same bus as the ground control CPU. This card can access the common memory to set or read data while the control CPU remains dedicated to its tasks.

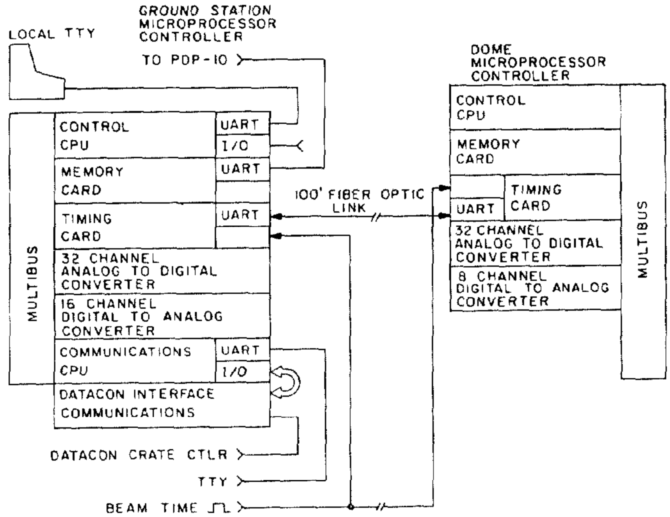

Fig. 3. H⁻ pre-injector microprocessor control system

System features include a self synchronizing data transmission code between dome and ground CPU's, and a heartbeat circuit for auto restart of the CPU's.

Within the dome, optical cabling has been used to isolate the CPU from the controlled equipment. Analog signals are sent using VFC/FVC encoding. Noise and drift are less than 20 mV. There have been no arc-induced failures in the controls.

Low Energy Beam Transport

Pit II and LEBT II were intended as the back-up pre-injector to the Linac with source development as a second function. Figure 4 shows the line layout. The stub line contains two water-cooled pulsed quadrupole triplets of 7.6 cm diameter. The first 60^0 dc magnet, when off, allows the beam to reach the emittance devices in the viewing box.

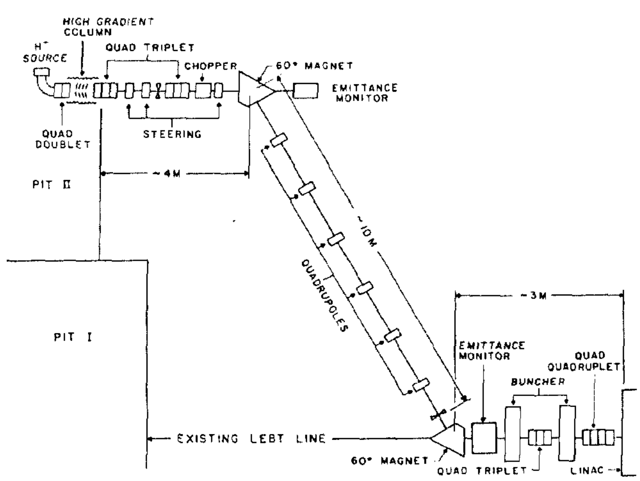

Fig. 4. LEBT II transport line

When the 60^0 magnet is powered, beam is carried to the cross-over line. This section uses six dc air-cooled quadrupoles of 10.2 cm diam. which with the two 60^0 bending magnets form an achromatic line. This has proven hard to achieve in practice since space charge effects strongly influence the transport.

Once the beam is in LEBT I, emittance devices can be used to match the conditions at the entrance to Tank I so that no linac quadrupoles had to be changed.

The chopper in LEBT II can be used to eliminate the sloping portions of the beam. For the AGS, a 150 - 250 μsec slice can be selected from a more uniform portion of the 450 μsec, 750 keV beam. It has been observed, however, that the chopped beam still shows a slope at Tank I. This is possibly due to the build up of positive ions in the residual gas in the line, neutralizing space charge effects. Normal vacuum in the line is 3×10^{-7} Torr. By turning off one or more of the three ion pumps in the cross-over line, the vacuum can be raised to 2×10^{-6} Torr. When this was done, the beam at Tank I could be made to tilt up or down or be flat, according to the vacuum. More study of this effect is needed.

Transmission from the column to the first beam current transformer is nominally 90% with 90% of the beam transported to the entrance of the first buncher. The buncher system efficiency then permits 70% of the beam at that point to be captured and accelerated in the linac.

Conclusion

The magnetron type H⁻ source, modified with a grooved cathode, appears to provide stable operation at lower discharge current and higher duty factor than for a similar source with a flat cathode. Source current degradation with time also appears to have been significantly reduced.

The use of a 20 keV beam transport system to adapt the large source assembly to a highly re-entrant electrode structure is practical, although some emittance growth probably occurs.

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