PRODUCTION OF INTENSE PROTON BEAMS

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SUMMARY

An ion source system employing mass selection has been developed for use in the terminal of an accelerator. The beam from a duoplasmatron is accelerated to 40 keV and focused by an einzel lens through a 20° permanent magnet inflector. A beam waist is formed at a 6.35 mm rejection aperture located on the acceleration axis. Dispersion is sufficient to provide a proton beam of greater than 99% purity. Proton currents up to 7 mA were obtained during bench testing. Performance demonstrations on the Dynamitron accelerator at the University of Birmingham have shown proton beam power in excess of 6 kw at energies from 2 to 3 MeV.

INTRODUCTION

A high current proton source system has been developed for and successfully operated in the terminal of a Dynamitron accelerator. The motivation for this effort was discussed in detail by M. R. Cleland.[1] Briefly, the proton beam current intensity of Dynamitron accelerator systems has never matched the capability of this type of cascaded rectifier power supply. Loading effects in the acceleration tube limit the current intensity to a few milliamperes of hydrogen ions. Molecular ions in the beam increase the load on the power supply and contribute a disproportionate share of the tube loading effect. Monatomic yields of one-third are typically obtained from standard Duoplasmatron ion sources operating at a few milliamperes of hydrogen ions.

One approach to reduce the molecular ion content of the beam is to use a small source anode aperture and run the source at high arc and magnet currents; that is, to optimize the proton performance of the source. To evaluate this approach, a detailed parametric study of the operation of the Dynamag Duoplasmatron source was performed.[2] High arc current dissociates the triatomic ions and increases the proton yield to nearly 70%. However, at source pressures above 400 microns the yield of diatomic ions is relatively insensitive to the source operating conditions and remains about 20%. Since significant quantities of these undesirable molecular ions are still present even under the best source operating conditions, the obvious alternative is to analyze the beam in the terminal prior to acceleration.

A design aim of 5 mA of protons was established for the ion source system. It is designed for the model RPEA-3 vertical Dynamitron at the University of Birmingham in England. Guaranteed specifications are 2 mA protons at 3 MeV, and 80% of the beam contained within a 1 cm diameter. In the following sections, a description of the source system is given, the source test bench results are presented, and the accelerator system operation is discussed.

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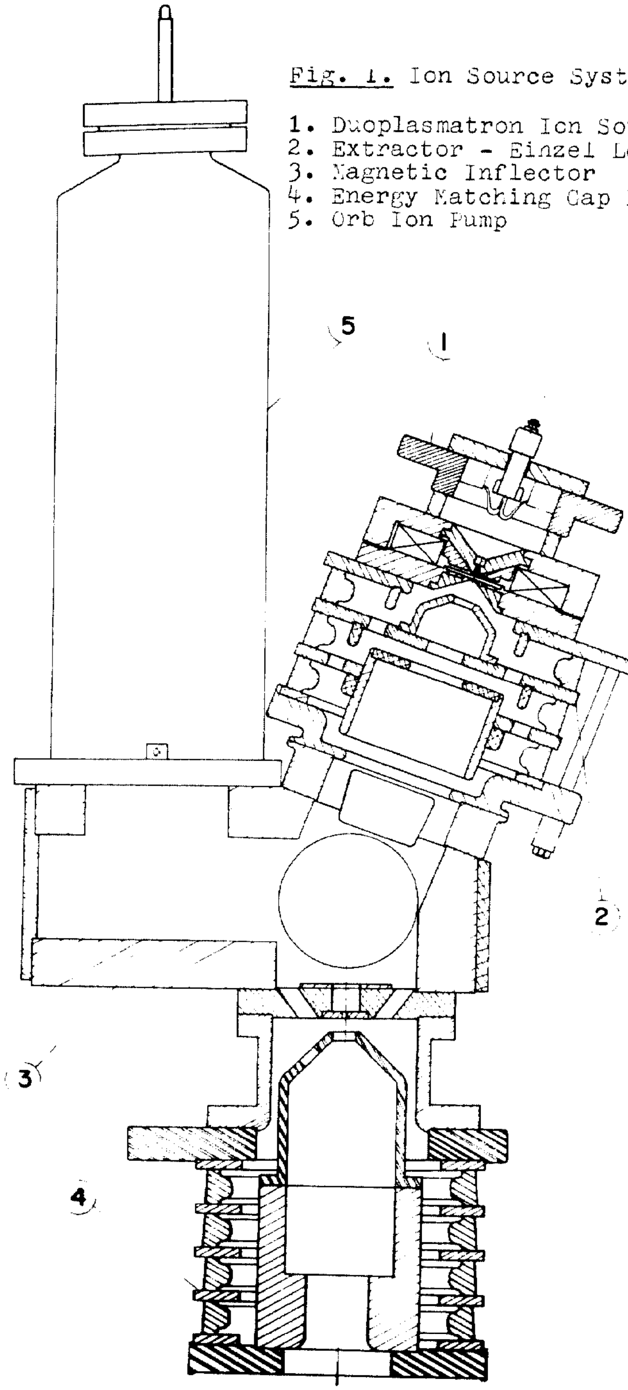

Fig. 1. Ion Source System

1. Duoplasmatron Ion Source
2. Extractor - Einzel Lens
3. Magnetic Inflector
4. Energy Matching Cap Lens
5. Orb Ion Pump

SYSTEM DESCRIPTION

The ion source system of fig. 1 is mounted on the centerline of the accelerator. All components are packaged within the accelerator terminal (91.4 cm in diameter and 137.2 cm long including the hemispherical top section) and are immersed in 6 atmospheres of SF6 insulating gas. The power available is 4 KVA, 681 Hz with 50 Hz drive. Cooling is provided by a closed loop freon system with a liquid to SF6 heat exchanger.

The major components are described below, designated as in fig. 1.

1./ A Dynamag[3] duoplasmatron has been modified for use with this system. The source head is a separate sub-assembly held together by cinch rods. Alignment is maintained by four insulated jacking screws which are initially adjusted by peaking the electron output of the source and then locked to enable the alignment to be recovered upon reassembly. A 0.25 mm anode aperture is used. The source head is elevated to +40 kVDC above terminal ground by a 50 kV, 30 mA extraction power supply.

2./ The ion beam is accelerated to 40 keV by a conical extraction electrode. Deceleration and divergence result in the first gap of the einzel lens by applying a potential of -2.5 kV to the center electrode with respect to the source anode. Strong convergence of the beam results upon acceleration back to extractor potential at the second gap. The beam then converges to a waist at the rejection aperture located after the magnetic inflector.

This unit is mounted on a "V band" flange to facilitate disassembly. The assembly is constructed from pyrex rings, epoxy-sealed, and maintained in compression by delrin cinch rods. Voltage holding capability is 25 kV in open air and 50 kV in one atmosphere of SF6. The electrode structure is designed similar to the low aberration, strong einzel lens described by Septier[4]. Each stainless steel electrode element is independently mounted on a cooled copper support flange. A pair of electrostatic plates is mounted after the lens to sweep the beam transversely across the rejection aperture, thus providing programable modulation of the proton beam. Programing of the sweep voltage is performed by a pulse generator in the accelerator console and information is transmitted to the accelerator terminal by a light link.

3./ Since the beam waist is formed at the rejection aperture close to the magnet, the weak optical properties of the 20° inflector are effectively eliminated. The magnetic circuit consists of 10 cm diameter cylindrical poles, separated by a 3.75 cm gap, and driven by permanent magnets. The magnetic field between the poles is approximately 800 gauss, which provides a mass energy product of 40 keV-amu. Penetration of the fringing magnetic field is limited by a steel field clamp mounted on the rejection aperture. A large cooled copper flange supports the molybdenum rejection aperture and is faced with a molybdenum disc to prevent erosion of the copper surface caused by beam sputtering. An aluminum manifold supports the poles, rejection aperture flange, lens mounting flange, and pump.

4./ The entire assembly mounts on the acceleration tube. Consequently the electric field of the acceleration tube penetrates into the base of the energy matching lens and becomes the dominant optical element of the system. The object point of this lens is the rejection aperture and the image point is an external aperture located beyond the ground end of the acceleration tube. Both these distances are fixed. A constant focal length must be maintained if the object and image points are to remain conjugate. In this case, the condition is fulfilled if the voltage ratio between the terminal potential and the injection potential is about 50. A reversible polarity 40 kV power supply is connected to the base of the energy matching lens. Cooling is required on the base of the copper flange as it is the limiting aperture which defines the angular acceptance of the system.

5./ A 15 cm NRC orb ion pump is used to differentially pump the gas load from the ion source. When the pump is mounted on the system, the center of gravity is near the axis of the acceleration tube.

SOURCE TEST RESULTS

In order to evaluate the performance of the source system, it was mounted on the apparatus described in ref. 5. The energy matching gap was replaced by a drift section.

Proton current intensity was measured for three different rejection aperture diameters. Figure 2 illustrates the proton current as a function of extractor load current. The intensity of the proton beam appeared to be directly correlated to extractor load current and relatively independent of source parameters.

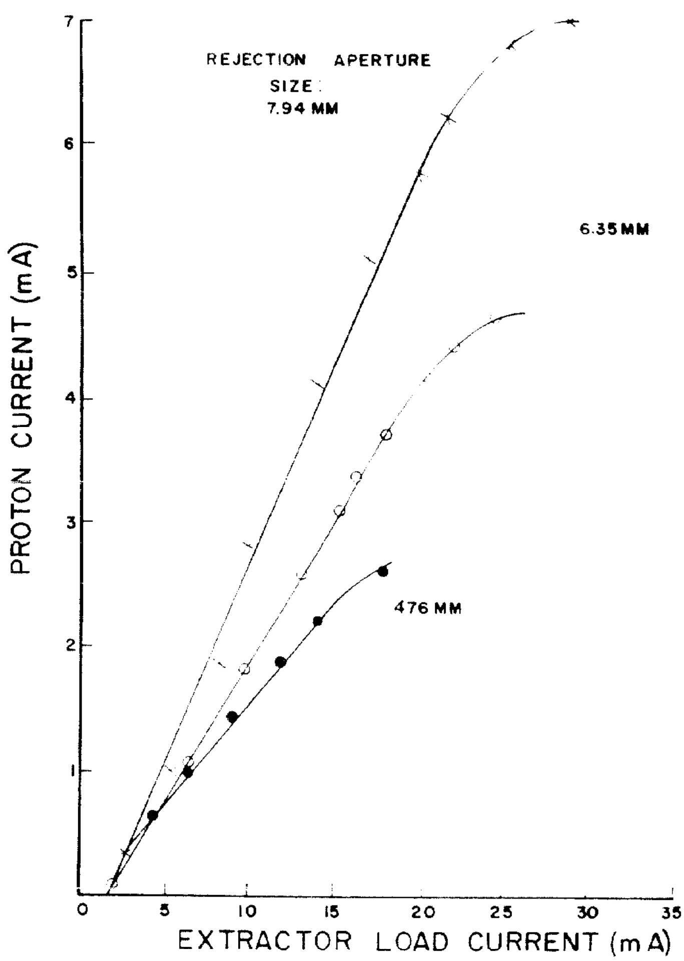

Fig. 2. Proton Beam Current as a Function of Extractor Load Current.

At the same extractor load, the ratio between arc and magnet currents had only a 20% effect on the proton output. This can be expected because the proton yield has a similar dependence on magnet current as on arc current. Therefore, a given extraction load can be obtained with either high arc current and low magnet current, or the reverse, and the proton yield will not be very different.

Space charge expansion determines the beam size. This can be demonstrated by changing the magnetic field and thus the extraction voltage. Larger apertures give higher current intensities at the same extractor load current, and the output is insensitive to small changes in the extraction voltage. Thus, the beam must be larger than the rejection aperture.

Protons were obtained through the rejection aperture with 40 kV on the extractor, diatomic hydrogen ions were found at 20 kV, and triatomic at 13 kV, as expected. The proton beam was analyzed and the highest diatomic ion content measured was less than 0.2%. Ions of higher masses were completely absent. Similar measurements on the diatomic ions demonstrated an equivalent purity to that observed for protons. The 6.35 mm aperture size was chosen for the system since magnifications slightly less than 2 are anticipated for the acceleration tube entrance lens in this geometry. For this aperture, 3.5 kV applied to one sweep plate reduced the proton current to zero.

ACCELERATOR SYSTEM OPERATION

Performance measurements on the system were made during the testing of the Dynamitron at Birmingham. After exiting from the acceleration tube, the converging beam could be centered by magnetic angle steerers on an insulated water-cooled copper aperture located approximately 2 meters below the accelerator. A water-cooled copper target was used to collect the primary beam. A negative bias was applied to the housing to suppress secondary electrons. Vacuum pumping was provided by a 15 cm NRC VHS pump, with a net pumping speed at the ionization gauge of approximately 1000 liters/sec. Ionization induced leakage current was measured by returning the insulated liners of the Dynamitron power supply to ground through appropriate metering. Calibrations of the high voltage resistor divider were performed using (p,n) thresholds on ^{65}Cu and ^{7}Li.

Earlier data on the effects of terminal pumping were confirmed. Typical no-load base vacuum was 1.5 x 10^{-7} torr. With the machine delivering 2 mA of proton beam at 2 MeV, the base vacuum was 7 x 10^{-7} torr with terminal pumping and 2.3 x 10^{-6} torr without terminal pumping. Corresponding leakage currents were 100 μA and 370 μA, respectively.

Purity of the accelerated beam was checked by comparing the count rate from ^{7}Li (p,n) for identical currents of diatomic and monatomic ions at an energy about 100 keV over threshold. Count rates were greater than a factor of fifty different, which implies that the diatomic beam has less than 2% proton contamination.

In fig. 3, the ionization induced leakage current is shown as a function of proton beam current for 2 and 3 MeV operation. The higher slope for the 2 MeV data is probably the result of residual gas scattering in the acceleration tube which is a regenerative effect and is more significant for the softer beam. Proton beams in excess of 3 mA at 2 MeV and 2 mA at 3 MeV were routinely achieved. An arbitrary maximum power of 6 kW was established for the target. This limitation prevented the full capability of the ion source from being demonstrated through the accelerator system.

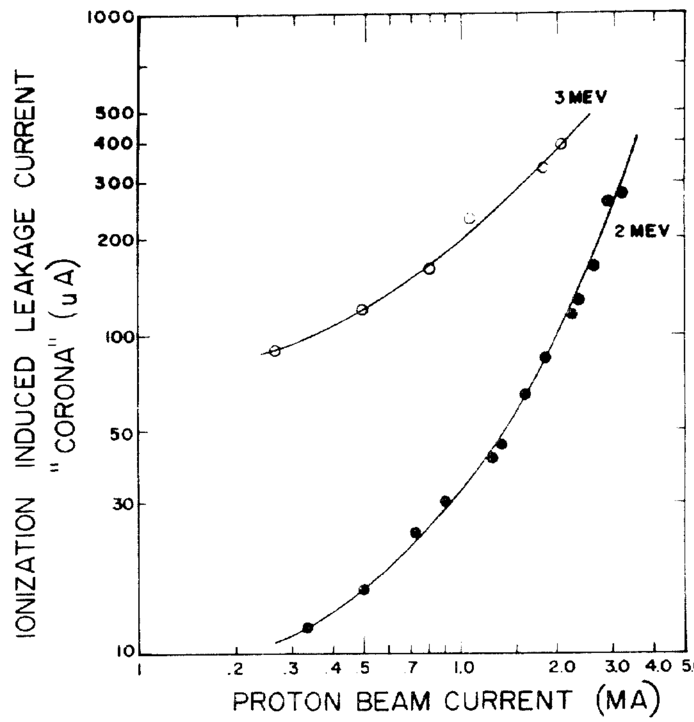

Fig. 3. Ionization Induced Leakage as a function of Proton Current.

Extrapolation of these results to 4 or 5 mA of proton beam suggests that leakage currents of about 1 mA would result. This is well within the capability of the power supply, so that 4-5 mA proton beams can probably be achieved with the present accelerator and ion source system. Future systems with proton currents of the order of 10 mA will probably require magnetic suppression in the acceleration tube to reduce the leakage currents, as well as a rotating target or beam scanner to withstand the high power densities which can be anticipated.

REFERENCES

1. M. R. Cleland, P. R. Hanley and C. C. Thompson, IEEE Trans. Nucl. Sci., NS-16, 3, June 1969.
2. J. Wells and P. R. Hanley (RDI internal report, TIS-69-3) (to be published).
3. M. R. Cleland and C. C. Thompson, U.S. Patent #3,458,743, July 29, 1969.
4. A. Septier, CERN 60-39, Oct. 1960.
5. J. Wells and P. R. Hanley, Proc. Symp. Ion Sources BNL 50310, Oct. 1971.