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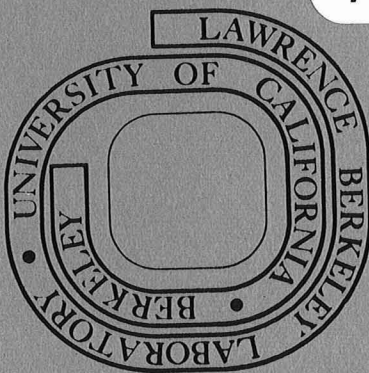
John W. Staples, Henry D. Lancaster and Roland B. Yourd

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A WIDERÖE-BASED HEAVY ION PREACCELERATOR FOR THE SUPERHILAC*

John W. Staples, Henry D. Lancaster and Roland B. Yourd**

Abstract

A new high-mass, high intensity injector for the SuperHILAC has been approved and is under construction at LBL. A high power intermediate charge state ion source and accompanying low-velocity linac will provide beams for subsequent acceleration by the SuperHILAC. Both axially and radially extracted ion sources will be accommodated and charge state analyzed in the 750 kV, 100 kHz Cockcroft-Walton terminal. The LEBT will provide isotopic analysis to 1 part in 300. A 5m long, 23.4 MHz Wideröe linac, operating in the π -3 π mode based on the GSI design accelerates typically a U^{+5} ion to 113 keV/a where it is stripped to U^{+11} by a perfluoropolyether vapor stripper and further accelerated by the SuperHILAC. The space charge limit of the system is several electrical mA which will be approached in the intermediate mass range.

I. Introduction

A low-velocity, high current Wideröe linear accelerator is under construction at LBL. This accelerator system, including a new ion source and pre-injector, will serve as an injector to the SuperHILAC, supplementing two presently operating injectors, increasing the mass range to uranium and increasing the flux for ion species higher than argon up.

As the basic parameters of this injector have been covered in a previous paper¹ we will emphasize the highlights of this design, particularly those items of novel or unique interest that have already been built and tested individually.

The basic parameters of the injector have remained essentially constant except for the selection of charge state of the design ion, uranium, and the selection of the maximum terminal potential of the Cockcroft-Walton preaccelerator. The design charge state has been adjusted downward to U^{5+} to provide a larger available flux of ions. This means that Ar^{1+} will also be available, allowing us to experiment with the effects of accelerating large currents through the machine, near its space charge limit of approximately 10 emA. The preaccelerator voltage has been raised to 750 kV to accommodate the reduction in charge state of the accelerated ion.

The Wideröe linac increases the kinetic energy of the accelerated ion from 15.8 keV/amu to 113 keV/amu for injection into the first tank of the

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1. J. Staples et. al, A Wideröe Pre-Accelerator for the SuperHILAC, 1976 Proton Linear Accelerator Conference, P. 81.

SuperHILAC. After the Wideröe, the beam is stripped in a Fomblin vapor stripper: The stripping efficiency into a single charge state has been measured at 11% for Pb, rising to 17% for Xe.

II. Preinjector System Summary

The preinjector consists of a 750 kV high-frequency Cockcroft-Walton stack containing two ion sources in the terminal. An axial source of the Ehlers type is provided for the noble gases and a sputter-arc radially extracted PIG for the metallic ions. 90 kVA of power is available in the terminal through a rotating shaft drive. A 150 hp., 1,800 rpm motor will be located in a pit in the floor beneath the terminal house and a vertical 10" OD by 0.5" wall filament wound epoxy tube drive shaft will transmit the power to two generators in the high voltage terminal: a 65 KVA 60 Hz unit and a 25 KVA 400 Hz unit. Cryogenic pumping will be used near the ion sources to recover rare and expensive source gases and to reduce the power and weight requirements. Terminal cooling will be by means of Freon-113 circulated from the ground end to high voltage through 2-1/2" diameter insulating plastic tubes (nylon or delrin) at a flow rate of 40 gpm.

The accelerating column will consist of three 30 cm long sections of commercially available titanium-ceramic modules in an atmosphere of SF_6 . Uniform grading is used, and the current limit is 15 emA at 750 kV. In the 60 cm space between the source analyzing magnet and the column entrance a series of magnetic quadrupoles focuses and matches the beam. The very short cell length reduces the maximum tune depression to less than 0.5 For the maximum uncompensated space charge.

The LEBT between the column exit and Wideröe entrance contains four sets of doublets, steering, a 90° analyzing magnet and one fundamental frequency buncher of the quarter-wave line type. For low to moderate current, the analyzer will provide an isotopic mass analysis of one part in 300, allowing us to use natural source material for all but the most intense beam requirements.

IIa. Axial Ion Source

For ions from gaseous source material, we will use an axially-extracted source similar to those developed at LBL by Ehlers² for neutral beam injection and reported on elsewhere in this conference³. We have accelerated 60 emA of Xe^{1+} from a version of this source to 475 keV and in another series of runs have shown that we can expect about 10% of the total beam output to be Xe^{3+} . This source shows a noise modulation of 0 to 10%.

IIb. Cockcroft-Walton

The CW power supply will be a half-wave cascade voltage multiplier operating at about 90 kHz. A stack of 10 decks will be topped by the

2160 ft³ terminal house. This arrangement results in a very compact structure. The support structure will be four 14" O.D. vertical support columns of filament wound fiberglass-epoxy tubes 10.75 ft. long. Each deck of the CW consists of two 200 kV PIV silicon rectifier modules, two 100 kV .025 μfd capacitors and surge limiting resistors. Spark gaps protect the components from excessive voltage during surge conditions: Ten decks, each rated to 100 kV are stacked to a height of ten feet, and the maximum gradient along the components of the power supply is 11 kV/inch.

The 90 kHz power is generated by two 4CW25,000 tetrodes operating class C into a resonator supplying the bottom end of the CW stack. Two regulation loops are provided: a slow one through a generating voltmeter and a fast one through a capacitive pick-off on the wall of the preinjector house. The power supply will provide a 10 ma average current with a maximum ripple of 500 volts. The load induced droop at 10 ma is about 3 kV which will be corrected by the drive to the 90 kV supply. No bouncer as such is used. The response time of the fast feedback system and the high frequency of the CW excitation provide adequate correction response time.

A CW power supply essentially identical to this one was recently put into successful operation at the SuperHILAC and has provided satisfactory service.

III. Wideröe Accelerator

The principle requirement of the injector system accelerator is to accelerate U⁵⁺ from a kinetic energy of 15.8 to 113 keV/amu. The Wideröe accelerator operates at 23.4 MHz and has a π-3 π drift tube arrangement with magnetic focussing quadrupoles in the even (long) drift tubes. The 5 meter long coaxial structure is supported by three stub lines which also control the resonant frequency and voltage distribution in the 34 drift tube gaps.

The tank will be fabricated from 0.5 inch 10% copper clad mild steel plate by a rolling and welding operation. Sealing between the tank and the end walls will be by O-rings and copper r.f. gaskets. At full gradient, the gap voltage varies along the structure from 100 to 250 kV, with a total peak power dissipation of 75 kW.

IIIa RF Power Amplifier

We will use an Eimac 4CW100,000 running Class AB₂ in the final amplifier stage. This tube can deliver over 200 kW in this mode giving us ample reserve to supply resonator losses and an expected 20-40 kW of beam loading. Running at 30% duty factor, we will have ample plate dissipation even when supplying reactive power to the beam load. In normal operation we will run at reduced filament voltage to extend tube life. It has been our experience that with the filament voltage reduced to about 90% of its rated value we can expect over 50,000 hours (5-7 years) of life on these tubes.

2. W. R. Baker et.al., Proceedings of the Symposium on Ion sources and Formation of Ion Beams, BNL Conference Report, 1971

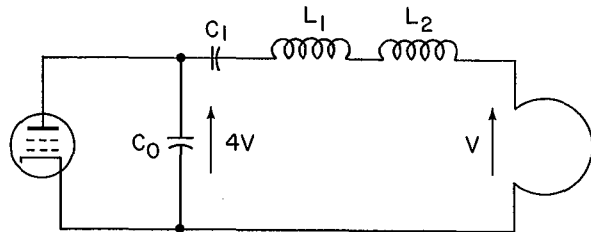
3. E. Zajec et.al., Operation of a High-Current Xenon Source, Paper B-18, this conference.

As in the design used successfully at the SuperHILAC, the final amplifier will be tightly coupled to the accelerating structure using a loop in one of the stub lines. The voltage equation for the coupling loop is

$$j\omega LI_L + j\omega HA = V_L$$

The second term is the voltage induced in the loop by the cavity field. This voltage is in phase with the input voltage, V_L , and accounts for the real power transfer to the resonator. The first term represents the voltage drop due to loop self-inductance. When coupling to Alvarez type linac cavities at the SuperHILAC this term is reduced to zero by adding a capacitive reactance to tune in out.

In an Alvarez type linac cavity the magnetic field at the wall is high enough so a reasonable size loop will give an induced voltage adequate for matching to high power r.f. tubes, about 15 kV, so there is no need for a matching network between the tube plate circuit and coupling loop. For the Wideröe structure the field at the stub line wall is much lower, and the dimensions are smaller. A reasonable coupling loop size gives an induced voltage of about 4 kV. Because this voltage is so low a simple matching network will be added between the 4CW100,000 and the coupling loop to increase the voltage by a factor of four. This will be done by adding an inductance in series with the coupling loop and adjusting it in conjunction with the 4CW100,000 output capacity for the proper step-up ratio. Figure 1 shows the equivalent circuit matching the plate impedance to the drive loop.



XBL 793-736

Fig. 1

The final amplifier and its driver will be built into an enclosure that is mounted directly on the side of the stub line of the Wideröe. The final amplifier has no plate resonator as such, just a decoupling choke for the B⁺ supply line. The r.f. to the driver stage will be derived from a solid-state 10 watt amplifier module located remotely.

IIIb. Tape-Wound Drift Tube Quadrupoles

The sixteen long drift tubes in the accelerator contain magnetic quadrupoles arranged in four groups. The integrated gradient-length product for all of them is 97.5 kgauss with the clear aperture diameter increasing from 1.6 cm for the first five units to 3.0 cm for the last seven. The most difficult quadrupole is the first with an effective length of 7.84 cm and a gradient of 12.44 kG/cm. We have build and successfully tested two versions of this device.

The construction techniques for tape-wound magnets have been published previously⁴. In this application, the requirements of high gradient in a short effective length were met by using pole tips 7.16 cm long and tapered made of vanadium perandur, contained in a yoke whose outer diameter is 20 cm. The coil is wound with 28 turns of 0.5mm thick copper tape and the measured efficiency at full field is 85%, the electrical requirements being 13.6 volts at 169 amperes.

The drift tube surfaces and magnet coil are flood cooled by Freon TF-113 at a flow rate of 3-5 gpm. The drift tube is supported from below by a single stem (inverted configuration) and the coolant return is from an aperture at the top (opposite the stem) so a gas bubble will not form and be trapped. The total weight of the drift tube assembly is 20 kg.

Figure 2 shows the completed prototype quadrupole. Sensing loops are shown placed around the pole base, pole tip and return yoke to monitor flux in those regions as a function of excitation.

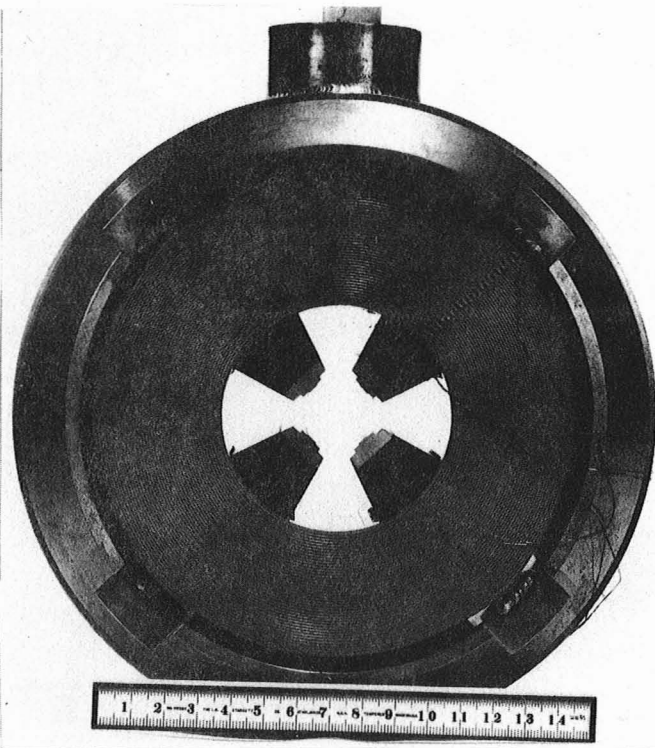


Fig. 2

IV. Matching, Stripping and Control

The beam is stripped immediately following the Wideröe and transported 12.5 meters to the entrance of the SuperHILAC. A vertical translation is included. At the SuperHILAC entrance, a fast switching magnet selects one of three possible injectors in any arbitrary 36 pulse per second sequence. The SuperHILAC itself and the beam switchyard presently have this fast beam multiplexing facility, providing at present two ion species. No debunching-rebunching will take place in the near future. Therefore about a 50% transfer efficiency of the selected charge state from the stripper to the SuperHILAC r.f. bucket is expected. When bucket matching is later introduced, the energy stability of the Wideröe

must be held to $2 \cdot 10^{-4}$.

IVa. Fluorocarbon Stripper

The stripper following the Wideröe raises the mean charge state of the beam so that acceleration can continue in the first tank of the SuperHILAC. The beam is analyzed in the transport line following the stripper to select the charge state required. The stripper material is a fluorocarbon vapor of high molecular weight at a pressure of about 1 Torr evaporated from a reservoir of liquid. This type of stripper imposes no limit on the beam power and is a low maintenance item. In addition, Fomblin cracks into lighter fragments in the presence of beam which are easily swept from the stripping area.

The vapor stripper will consist of a reservoir of Fomblin Y-Vac-25/9 liquid electrically heated to no more than 200°C by a resistance heater. At the top of the reservoir a water cooled surface thermally isolated from the reservoir will condense the vapor back into the heated bath.

The aperture diameter of the stripper is 1 cm. A cooled beam scraper will be located upstream of the stripper to protect it from missteered beam or halo.

The stripping characteristics of this material have recently been measured with the above desired stripper at LBL by Alonso and Leemann⁵ for Kr, Xe, Ho and Pb. The stripped beam shows a high asymmetry of the final charge state distribution, probably due to the long chainlike nature of the molecule. The mean charge state at a beam energy of 113 keV/amu lies between that for gas and solid strippers, but the skew toward the high charge states with Fomblin provides substantial fluxes of the charge states of interest. For a q/A of greater than .046, that needed by the SuperHILAC, 11.5% of Pb^{10+} is available, rising to 14.5% of Ho^{8+} , 17% of Xe^{9+} and 21% of Kr^{6+} , the percentages normalized by particle count. The corresponding numbers for a thin carbon foil stripper run between 17% to 25%. However, the equilibrium thickness for carbon is less than $1 \mu g$ and the power limit is low. The small angle scattering in Fomblin is significantly lower than that for a foil stripper. Figure 3 shows these charge state distributions.

4. R. M. Main and Ron Yourd, Edge Cooled Tape Magnet Coils for High Current Density Application, Forth International Conference on Magnet Technology, BNL (1972)

5. J. R. Alonso and B. T. Leemann, Fluorocarbon Stripping Stripping of Low Heavy Ions, Paper D-4, this Conference.

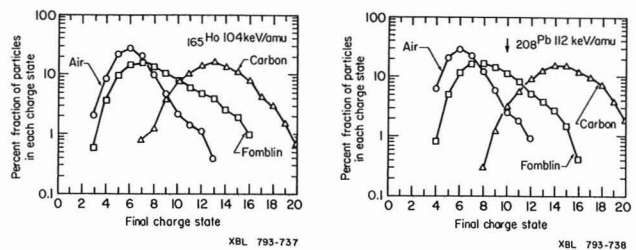


Fig. 3

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