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INITIAL OPERATION OF A 100% DUTY FACTOR 3 MeV ALVAREZ LINAC

J. Ungrin, J.C. Brown, B.G. Chidley, G.E. McMichael and S.O. Schriber

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0

Summary

A 100% duty factor 3 MeV Alvarez linac at the Chalk River Nuclear Laboratories has been successfully rf conditioned. A buncher has been commissioned and cw proton beams up to 1.2 mA have been accelerated to 3 MeV. Renewed experiments on drift tube stem mountings show stem currents to be the major cause of bellows overheating. A $2\beta\lambda$ Alvarez tank that models the geometry of a higher energy $\beta\lambda$ Alvarez tank is being built to test new linac design concepts at 100% duty factor.

Introduction

A 3 MeV Alvarez linac is being operated at the Chalk River Nuclear Laboratories as part of a development program for high current proton accelerators that could be used for electronuclear breeding of fissile fuel[1]. Economic arguments dictate a high duty factor for such accelerators. The present 1.605 m long 25 cell structure is being operated at 100% duty factor to investigate the rf and beam diagnostic problems associated with a high duty factor and high average current.

Description of Accelerator

The 3 MeV High Current Test Facility is shown in Fig. 1. The accelerator consists of a dc duoplasmatron ion source, a 750 keV, 7 gap, accelerating column, a beam transport system with 17 quadrupole magnets, two 45° bending magnets, a buncher, an Alvarez linac, and a high power beam dump.

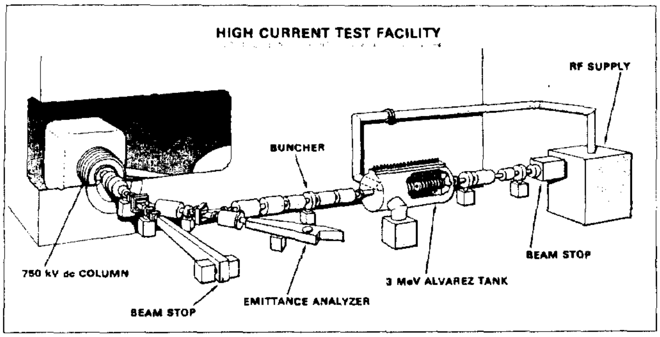

Fig. 1 Experimental arrangement of High Current Test Facility.

The 25-cell Alvarez linac which operates at 268 MHz has a design gradient of 2.0 MV/m and a maximum surface gradient of $\sim$ 10.4 MV/m (0.6 times the Kilpatrick limit). The cw rf power required to attain design fields is 168 kW, corresponding to an average surface power dissipation of 2.2 W/cm^2. Power is fed to the linac from a RCA 2054 triode capable of a cw output of 400 kW.

A single-gap single-frequency cavity buncher requires a rf feed of $\sim$ 240 watts and is fed from a separate 400 watt amplifier.

Rf Operation

High average rf power has resulted in several problems, particularly in the drift tube stem-to-tank joint region. Stem bellows heating began at low power levels ($\sim$ 15 kW) resulting in necessary design changes[2]. A design, shown in Fig. 2, using a collar with close fitting finger stock was partially successful. The collars provided a current path from the stems to the tank and prevented rf leakage into the bellows. Long term operation at 140 kW or above, however, resulted in finger stock damage. To allow commissioning of the Alvarez tank without a major redesign, slightly modified collars were soft soldered in place to fill the drift tube stem holes, with an allowance made for pumping. While this solution worked successfully up to 165 kW and allowed tank operation with beam, it prohibited any mechanical flexibility that may be required at this joint.

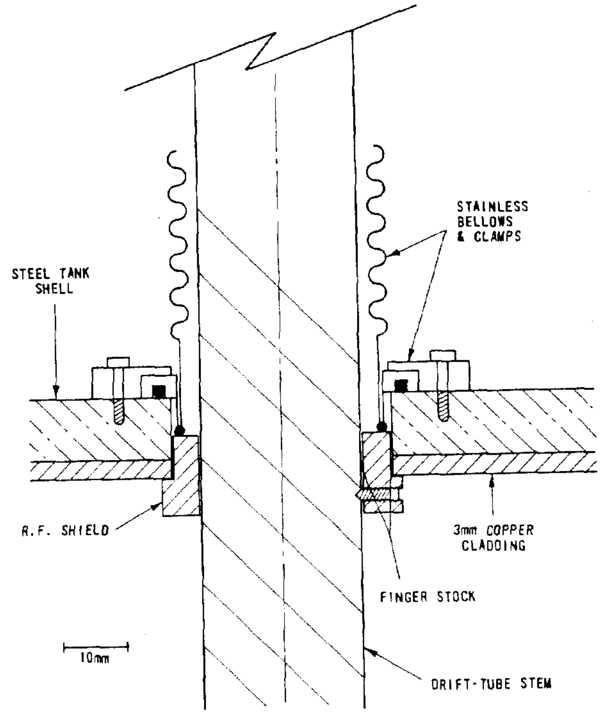

Fig. 2 Drift tube stem joint with copper collar.

An alternative solution shown in Fig. 3 was then installed on the last drift tube stem joint for ease of installation and because experience with previous methods of mounting drift tubes showed that overheating problems are most severe near the tank ends. A water-cooled copper sleeve was rolled into the tank wall to provide a cooled high-conductivity region for a distance greater than two hole diameters away from the tank inner surface. Field attenuation should be sufficient to allow mounting of the bellows without the overheating problems encountered previously, if field-induced currents are the main heating source.

The minimum rf power level in the tank with the triode in operation is normally 30-40 kW. At 35 kW the bellows became red hot within less than a minute,

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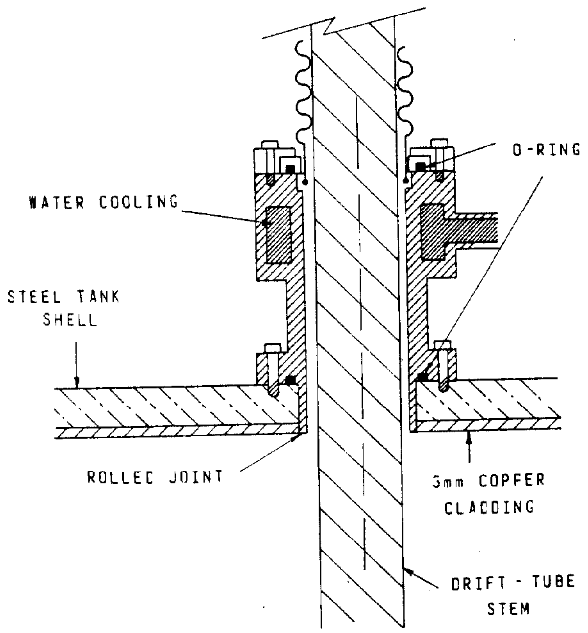

Fig. 3 Modified drift tube stem joint with cooled copper jacket.

indicating that drift tube stem currents may be the major cause of overheating. The rf endplate on which the final 1/2 drift tube is mounted is adjustable in longitudinal position to permit tank frequency and field tilt tuning. The drift tube gap length was increased to test the effect of cell tuning on the bellows temperature. Temperatures were measured in the 2-10 kW rf power level range and are summarized in Fig. 4. The temperature rise per kW could be reduced by a factor of 1000 by increasing the final accelerating gap from 16 mm required for correct field tilt to ∿ 22 mm. Since the tank is not post-coupler stabilized, this change, while decreasing the stem currents to an acceptable level, introduces a field tilt of ∿ 25% along the length of the tank.

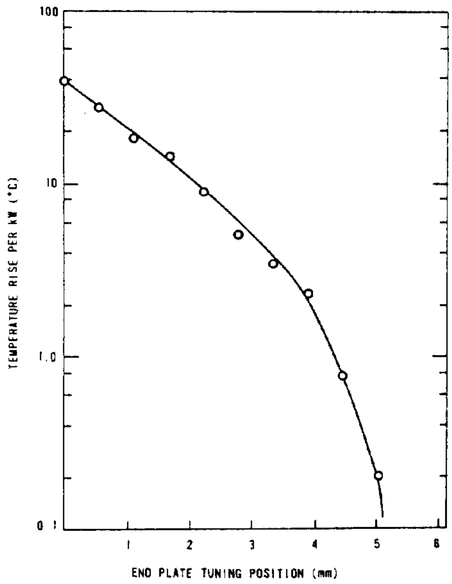

Fig. 4 Bellows heating dependence on endplate position.

Drift tube stems in an Alvarez linac are usually placed in the centre of the drift tube. While this mounting technique may be acceptable for low duty factor machines, it appears that a detailed determination of stem location for current balance may be necessary for cw operation if a flexible mounting scheme for the drift tubes is to be used. A search through past accelerator history reveals that 30 years ago this very problem was recognized and investigated for the 12 MHz MTA linac[3].

Beam Operation

Initial proton acceleration operation was performed with an unbunched beam. Observation of fast neutrons from the (p,n) reaction produced by lost beam on the copper drift tubes established beam acceleration to above the 2.16 MeV threshold for the ^{65}Cu(p,n) reaction. No bending magnet was available for these first measurements and so a retractable scandium target was mounted on the linac output beam line. The threshold energy for the ^{45}Sc(p,n)^{45}Ti reaction of 2.908 MeV is only ∿ 0.1 MeV below the tank design energy. Both fast neutrons from the target and positron decay of the ^{45}Ti reaction products with a 3.1 h half-life were observed. At 750 keV injection a rf power level greater than 112 kW was required for either reaction.

The minimum tank rf power required to accelerate beam above the copper fast neutron threshold was measured as a function of injection energy. Figure 5 shows a comparison of the data with the code PARMILA, assuming both the measured zero power Q and a Q value 7% lower. The improved fit to the data with the lower Q may be due to errors in rf power measurement or could be accounted for by an average 16°C temperature rise in the copper skin surface. Measurements of Q change as a function of rf power are being investigated but no conclusive results have yet been obtained.

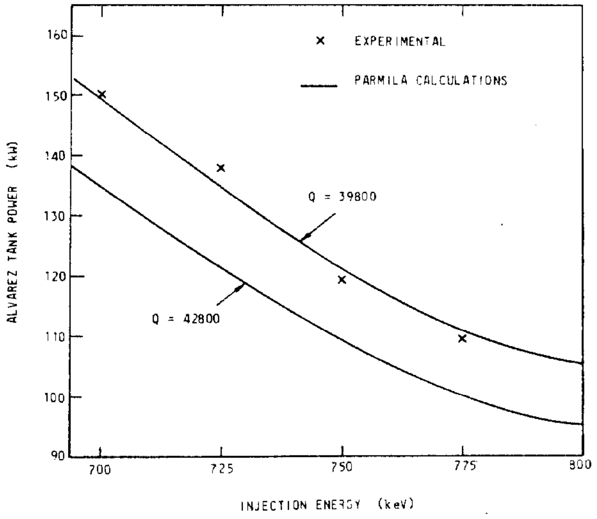

Fig. 5 Minimum tank rf level for acceleration as a function of injection energy.

Beam transmission without the buncher is ∿ 25%. A preliminary measurement of the energy spectrum with a pulsed magnet and a slit indicate that about 85% of the beam has an energy in excess of 2.25 MeV.

Beam transmission as a function of buncher phase is shown in Fig. 6. At the optimum buncher phase, transmission is a factor of 2.2 higher than that for the no buncher case. For stability reasons the tank was operated at 92% of design field. The maximum accelerated beam was 1.2 mA with a beam transmission of ∿ 45%. The code PARMILA predicts a transmission of 50% for this field level.

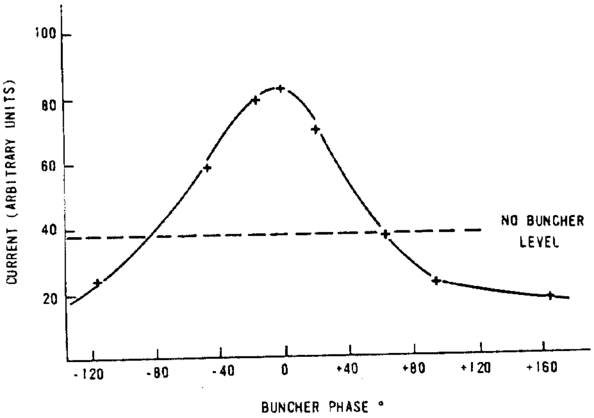

Fig. 6 Beam transmission as a function of buncher phase.

A small-aperture ion source capable of only ∿ 4 mA dc was used for the first beam tests. Beam acceleration tests were then suspended to test the drift tube stem support design discussed above. A source capable of delivering up to 20 mA dc of protons reliably to the linac is presently being installed. An energy analyzing magnet is being adapted for detailed measurements on the energy spectrum and an emittance unit with a kicker magnet and pepperpot has been adapted to the linac output beam line for emittance measurements.

Two Beta-Lambda Tank

Based on the recent successful development of the radiofrequency quadrupole (RFQ) at Los Alamos[4], the present conceptual design of a high current fuel breeder accelerator includes a 2.5 MeV RFQ as the injector for a drift tube linac. A $\beta\lambda$ linac cell at 2.5 MeV is essentially identical to $2\beta\lambda$ cell at 0.6 MeV. To model the first cells of the fuel breeder linac, and to incorporate and test a number of new concepts not included in the present tank a 268 MHz $2\beta\lambda$ tank (2BLAT) is being built. The 14-cell tank with an input energy of 0.6 MeV and an output energy of 2.6 MeV will use shaped drift tube faces to optimize shunt impedance and will use a bridge type drift tube suspension of the type used at CERN[5]. The existing rf system, injector, and input beam line system will be used. To gain operating experience with permanent magnets in a 100% duty factor Alvarez linac the first 5 drift tubes are being fitted with permanent magnets developed at New England Nuclear[6]. The main features of the tank are summarized in Table 1. The geometry chosen gives a maximum surface field that is ∿ 1.25 times the Kilpatrick limit (twice the field in the present tank).

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Table 1

$2\beta\lambda$ Tank Design Summary

Energy In	= 0.600 MeV	Energy Out	= 2.607 MeV
Number of Cells	= 14	ZT^2_{AV}	= 27.5 MΩ/m
Number of Post Couplers	= 6	Power	= 114 kW
Tank Diameter	= 71.0 cm	Drift Tube O.D.	= 13.5 cm
Tank Length	= 171.6 cm	Drift Tube I.D.	= 1.5 cm
Frequency	= 268 MHz	Drift Tube Face Angles	= 10° (cells 1-5)
			= 15° (cells 6-14)