LOW ENERGY 100% DUTY FACTOR ALVAREZ LINACS AT CHALK RIVER

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Summary

Experience with rf joints in a cw Alvarez linac is reviewed together with details of renewed tests on a flexible drift tube suspension. Mechanical and rf design of a replacement 268 MHz linac are discussed.

Introduction

Linear accelerators with a 100% duty factor (cw) are being operated at the Chalk River Nuclear Laboratories as part of a program to develop an economic fissile fuel breeder[1,2]. The high average power density deposited by cw operation introduces problems on rf cavity joints and penetrations. A 25 cell Alvarez tank with a design field gradient of 2.0 MV/m has been operated at full power and has been used to accelerate 1-2 mA proton beams up to 3 MeV. This tank continues to be used as a test bed for the investigation of high-power cw rf problems. Based on experience gained from the operation of the existing tank a replacement linac is being designed to test several new design concepts.

Description of Linac

A cross section of the Alvarez accelerator is shown in Fig. 1. Input and output energies are 0.75 MeV and 3.0 MeV respectively. The 0.711 m diameter cavity is 1.605 m long and resonates in the TM_{010}-like mode at 267.5 MHz. Power to the structure is delivered by a RCA 2054 triode. To attain the 2 MV/m design gradient requires 168 kW of cw power. The cavity has no adjustable tuner and has a frequency shift with power of 0.9 kHz/kW. Tank frequency is used to correct the frequency of the low power oscillator that feeds both the tank high-power rf system and the amplifier driving a single gap 267.5 MHz buncher.

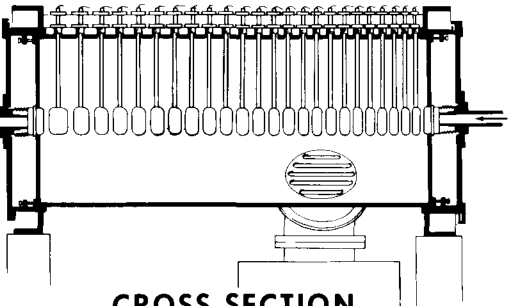

Fig. 1 CROSS SECTION OF ALVAREZ TANK

The half-drift-tubes of the first and last accelerating cells are mounted on flexible end plates. These copper plates (Fig. 1) form the ends of the rf cavity and are connected to the tank vacuum end wall with bellows. The end plates are electrically connected to the cylindrical cavity walls through a spring loaded copper-copper knife edge contact and can be used to adjust field tilt along the length of the structure.

Drift-tubes are mounted to the outer wall by a complex mechanical system that permits drift-tube alignment from the outside. Each drift tube has a quadrupole electromagnet with a 9 mm bore radius and 6.5 kG/cm field gradient. The drift-tubes were aligned conventionally with a high quality optical telescope centred on the magnetic quadrupole magnet centres.

Vacuum during operation is maintained by a 1000 ℓ/s ion pump that is connected to the tank via a manifold in which a sublimation pump is mounted for additional pumping during rf conditioning. The tank vacuum connection is made with a series of water cooled slots. A copper plate is mounted inside the manifold to reduce the penetration of rf field from the tank into the ion pump.

Rf power is coupled to the tank by a central horizontal nominal 150 mm (6-1/8 inch) coaxial line not shown in the figure.

Cooling for the tank shell is provided by water circulating in long pipes soldered to the tank body. The rf end plates are cooled near the center by conduction from the water cooled half-drift-tube and by a cloverleaf pattern of water tubing brazed to the outside surface. End plate cooling, particularly in the area of the joint to the cylindrical tank wall, is barely adequate for cw operation.

The beam line from the injector to the linac is 7.5 m long and consists of seven quadrupole doublets, a quadrupole triplet and two 45° bending magnets. A single gap buncher, powered by a separate 400 W amplifier, is located 1.26 m from the first linac accelerating gap. The buncher aperture is 15 mm. The high average power of dc beams in the input beam line requires careful cooling all along the beam line, particularly at the first bending magnet and at the entrance to the tank and buncher. Cooled apertures are built into the line at several locations and all bellows are lined with cooled solid shields to protect them from scattered beam.

The output beam line consists of a quadrupole doublet, a beam diagnostics section and a high power beam dump. For the initial beam measurements[3] a fast kicker magnet has been used in the diagnostic section. An energy analyzing magnet capable of operation in the cw beam is presently being fabricated.

Rf Operation

The main overheating problem encountered during rf commissioning was associated with the bellows connecting the drift-tube stems to the cylindrical cavity walls. Severe heating of the bellows occurred initially at about 10% the design power. Several techniques were tried to short the rf currents that feed through the bellows but were unsuccessful. As a temporary solution copper shunts were soldered between the stems and the tank wall[4]. This solution, however, does not permit mechanical realignment and makes replacement a very difficult task.

The drift-tube stem was extended and a waveguide beyond cutoff approach, where the rf field should be highly attenuated before reaching the bellows, was then attempted on the last drift-tube stem because it was the most accessible. Severe heating (~40°/kW) again was found to occur. Shifting the cell boundary by flexing the high-energy end plate 5 mm outward from its design position reduced this heating to < 0.1°C/kW[3], with an associated small charge in on-axis field pattern along the tank. This experiment showed that net stem currents arising from unequal charging currents on adjacent cells were the main cause of heating. A careful choice of stem location on the drift-tube boundary might minimize the net currents.[5] Shifts in tuner or postcoupler positions, once operation of the tank begins, would be expected to easily perturb this balance, and a renewed search for a current-shorting mechanism was started.

Figure 2 shows a stem-to-tank wall geometry that has been high power tested. Two 3.68 mm diameter (uncompressed) copper-beryllium springs[6] were located between grooves on the 25 mm diameter stem about two stem diameters from the inside wall of the cavity. This geometry which is similar to one tested in a TEM mode cavity at Los Alamos[7] kept the bellows temperature rise at full power to about 1°C even at the correct end plate position mentioned above. Tests are continuing to accumulate many hours of operation before disassembly and inspection of spring contacts. The measurements do demonstrate the suitability of such a joint for high-power cw DTL tanks.

High power cw operation has resulted in a number of coupling loop problems and in overheating of the end plate-to-cylinder joint. The coupling loop problems are described in a companion paper at this conference[8]. New construction techniques described below should eliminate the end plate problem.

Future Development

A 2.0 MeV output energy radiofrequency quadrupole (RFQ) will serve as the injector for the Alvarez linac of the ZEBRA accelerator[9]. A 2.0 MeV βλ drift-tube cell is essentially identical to a 2βλ cell at 0.5 MeV. It is therefore possible to model the early cells of a higher energy βλ linac with a conventional injector. A 14 cell 2βλ replacement tank (2BLAT) that models the first cells of the ZEBRA linac is being designed. Output energy will be 2.6 MeV and cw proton beam current will be 20 mA. The existing 750 keV injector at CRNL will be used but will be run at 600 keV to improve realiability. The operating frequency will be 268 MHz to make use of the existing high power rf source.

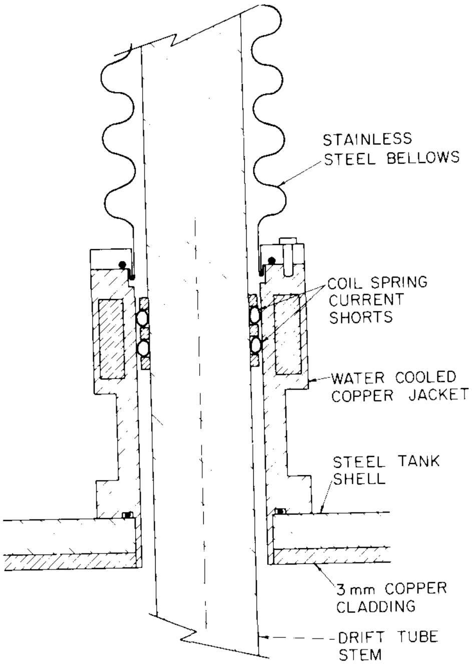

Fig. 2 Drift-tube stem-to-wall joint with coil spring current shorts.

The tank shell will be made of solid copper because of difficulties in obtaining copper-clad steel. A girder drift-tube suspension scheme will be used to gain experience for future accelerator breeder structures where remote handling may be necessary. The use of the girder system permits the end plates to be an integral part of the tank shell and removes one source of overheating encountered on high duty factor tanks. A spring joint similar to the one described above will be used to short rf currents at the stem-girder interface.

Two tuners will be used to stabilize tank frequency against shifts with temperature. Cavity joint problems similar to those experienced with the drift tube stems are expected with the tuners[2] and will be initially investigated on a 270 MHz resonant rf load[10] that is under construction. Post couplers on every second cell will be used to stabilize the accelerating fields against tilts introduced by the tuners.

Permanent quadrupole magnets purchased from New England Nuclear Corp. will be used in the first five drift-tubes to obtain experience with these magnets in a cw accelerator. The drift-tube diameter, however, is maintained at 135 mm to allow these drift-tubes to be replaced with ones containing electromagnets should the need arise.

The increased cell lengths afforded by higher injection energy of the RFQ permit shaping of the drift-tube faces of the first cells to improve the shunt impedance (up to 35%) while maintaining sufficient quadrupole magnet space. The maximum gradient on the drift tubes is 1.25 times the Kilpatrick limit. This value is twice the field in the present linac.

Conclusions

Experience with cw operation of a drift-tube linac demonstrates a continuing need for improved rf contacts. A workable solution has been found for drift-tube stem joints. It is expected that this solution should suffice also for post-couplers. A new linac to be completed in 1983 is being assembled. It will allow testing of tuners and several new construction techniques.

References

1. S.O. Schriber, "Electronuclear Fuel Production using High Intensity Accelerators", Atomkernergie 32, 49 (1978).
2. J. McKeown, et al., "High Power, On-Axis Coupled Linac Structure", proceedings of this conference.
3. J. Ungrin, et al., "Initial Operation of a 100% Duty Factor 3 MeV Alvarez Linac", IEEE Trans. Nucl. Sci., NS-28 (3), 3495 (1981).
4. B.G. Chidley, J. Ungrin and J.C. Brown, "Conditioning Experiments on the 100% Duty Factor 3 MeV Alvarez Linac", Proc. 1979 Linac Conf., Montauk, Brookhaven National Laboratory, Report BNL-51134, 360.
5. M. Dazey, et al., "RF Field Investigations on a 1/10 Scale Mark I Cavity", University of California, Report UCRL-1173 (1951).
6. Continental Electronics Manufacturing Co., Dallas, Texas 75227.
7. M.V. Fazio, D.W. Reid, J.M. Potter, "Experimental Investigation of Heating Phenomena in Linac Mechanical Interfaces from RF Field Penetration", IEEE Trans. Nucl. Sci., NS-28 (3), 2895 (1981).
8. J.C. Brown and R.M. Hutcheon, "Design Considerations for a Developmental High Power Coupling Loop to Drive a Resonant Load", proceedings of this conference.
9. S.O. Schriber, "The ZEBRA Program at CRNL - 300 mA-10 MeV Proton Linac", ibid.
10. J. Ungrin, et al., "Construction of a High Power RF Resonant Load", ibid.

Discussion

In our sparking experiments, we will have 400 kW available, enough to exceed twice the Kilpatrick limit. We do not include a transit-time correction in our Kilpatrick limit numbers.