DESIGN OF A HIGH POWER ELECTRON LINAC

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Summary

The conceptual design of a cw electron linac to produce 500 kW of beam power at 10 MeV is described. Examination of klystron availability, structure efficiency and system physical size has led to the selection of 2.45 GHz as the operating frequency. The development of accelerating structures operating at 2 MeV/m and beam loaded at 63% allows the system to operate with two 500 kW klystrons. A new scheme for start-up is modeled on cw microtron procedures, providing pulsed diagnostic information during a gradual run up to full power.

Introduction

CRNL has a long-standing interest in the development of high power particle accelerators. The past decade has seen the development of a cw linac[1] which has accelerated 20 mA of electrons to 4 MeV in the study of highly beam-loaded cw accelerators. This is a topic of interest to designers of electron storage rings, cw microtrons and linacs for electronuclear breeding. Experimental work has proceeded in parallel with theoretical studies in beam dynamics, coupled-cavity structure design, beam-cavity interaction and thermal stress analysis. This paper describes the results of a study undertaken to determine the feasibility of designing and building a cw electron linac to provide beam currents up to 50 mA at energies up to 10 MeV for industrial applications. Most components are commercially available and only modest development is required on others.

Basic Design Choices

The three main factors determining the basic characteristics of the accelerator are energy gradient, operating frequency and structure type. For many potential applications of a cw linac, a premium is placed on reducing the overall length so operation with a high accelerating gradient is desirable. Accelerating gradients have increased sharply in recent years, for example, in cw tests of CRNL[2] and LANL/NBS[3] structures gradients of 1.9 MeV/m and 2 MeV/m respectively have been reported. Calculations[4], reported elsewhere at this conference, indicate that values as high as 3.7 MeV/m should be attainable in room-temperature structures with reasonable coolant flows.

The choice of gradient is closely related to the choice of operating frequency, because the power required to produce a given accelerating field varies inversely as the square root of the frequency, and because klystrons of suitable size are available at only a few of the frequencies that may be of interest. Figure 1 is a plot of the structure power required to produce a total energy gain of 10 MeV for three different gradients. With the well-tested Mainz structure[5] as a reference point it illustrates the advantage of choosing a high frequency which has the additional advantage of smaller structures and hence lower material costs. However, it also implies a lower current limit, more brazed joints, more demanding machining tolerances, reduced vacuum conductances and higher surface power densities.

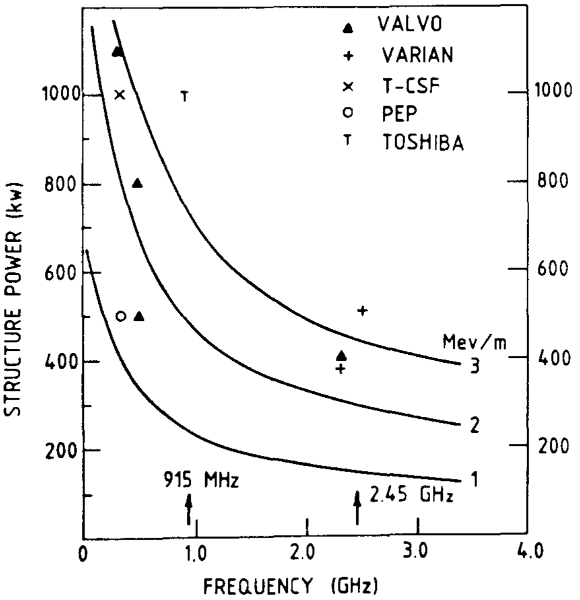

Fig. 1 Structure power and frequency for three different energy gradients. Commercially available klystrons are identified by manufacturer. The number of klystrons at low frequency is the consequence of recent developments for high energy storage rings. The industrial frequencies of 915 MHz and 2450 MHz are highlighted.

These considerations have led to the choice of a system based on two VKS-8269A 500 kW klystrons operating at 2450 MHz. The klystrons have recently been developed by Varian Associates for the Princeton fusion program[6]. At an accelerating gradient of 2 MeV/m, from Fig. 1 we find that 300 kW will be dissipated in the structures, and 500 kW will go into the beam, leaving a 200 kW margin for waveguide and other losses.

Either side-coupled and on-axis coupled resonator structures would be suitable for the linac. We have chosen the on-axis coupled system, with its somewhat easier tuning and greater vacuum conductance. The 5 m of accelerating cavities would be subdivided into four structures, as shown in Fig. 2, one graded in β and the others designed for $\beta=1$. Each section consists of 21 accelerating cells and requires about 75 kW to establish the accelerating fields.

The power-handling capability of the structures has been analyzed with the thermal stress analysis code MARC. Sufficient cooling channels have been added to the web to reduce the temperature difference between the nose and the outer wall, that the limit on power dissipation within the structure is determined by the onset of film boiling not the mechanical distortion arising from the temperature difference. For the present design, the limiting power dissipation is well above the reference value of 60 kW/m. Wall and web cooling channels are internally connected in series and parallel respectively. Simplified cross sections of the channels are shown in Fig. 3a and 3b. Further details of the design will be found in a companion paper at this conference[4].

Two tuners are required in each structure to compensate for the cold/hot frequency shift of 900 kHz. Calculations with the LOOPX code[7] indicate that a first neighbour coupling constant of 8% is required to keep the field tilts associated with tuner operation to the acceptable level of 7.3%.

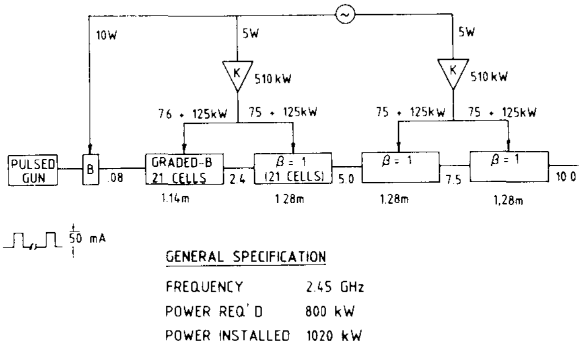

Fig. 2 Distribution of the rf power to provide the accelerating field and the power for a 50 mA beam.

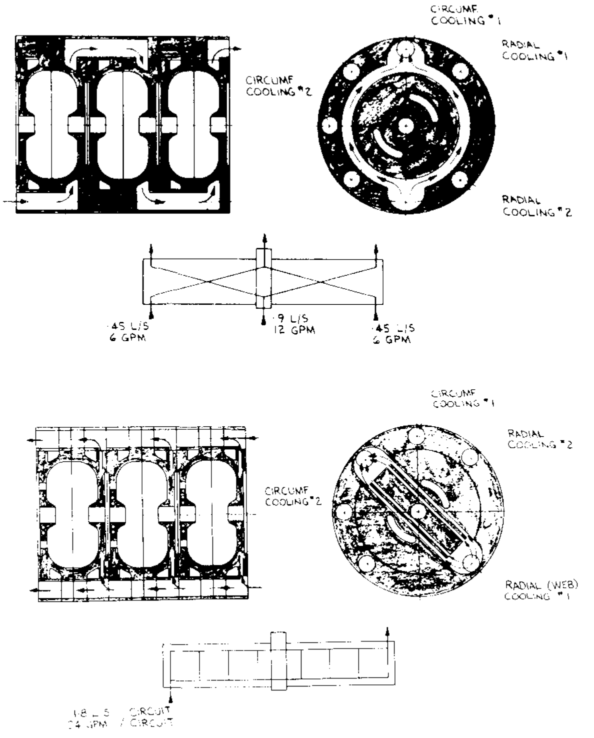

Fig. 3 The cooling system used for high energy gradients of 2 MeV/m.
(a) circumferential (b) web cooling.

Beam Transport and Dynamics

The electron gun is a new, grid controlled design specifically developed for use on a cw linac. It is similar to the Hermosa[8] Model 7-1 built for the National Synchrotron Light Source at Brookhaven, but with a redesigned copper anode structure provided with external water cooling. The pulser uses VMOS transistor technology and fibre optic links to bring the trigger signal up to the 80 kV high voltage deck. The gun provides 200 ns duration pulses at pulse repetition frequencies variable from 500 Hz up to 5 MHz. At the upper end of this range a special "lock-up" circuit provides a true dc output.

The advantage of this unique pulsed/cw capability is that it provides a means to tune up the beam transport system at the full peak current, but with an average current sufficiently low that beam-line components are not at risk if the beam is mis-steered. For this pulsed beam operation the rf structures operate in stored-energy mode, with a field depression of 18% by the end of the pulse.

The design of the injector has been developed using the computer code, PARMELA[9]. Figure 4 shows the zero-current transverse acceptance figure of the single-harmonic buncher/graded-β linac combination. The acceptance ellipse area is 4.1 x 10^{-3} π cm•rad while the emittance of the gun is 10^{-3} π cm•rad - comfortably smaller than the acceptance. Beam loss, mainly that not captured longitudinally, occurs primarily at low energy in the graded-β structure. PARMELA computations predict acceleration of 65% of the input current to design energy. To meet the 50 mA beam specification the gun is designed for 80 mA emission.

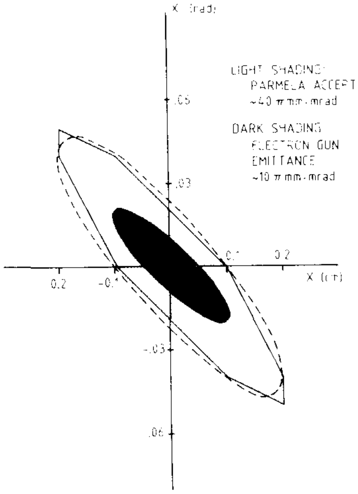

Fig. 4 Zero current acceptance of the injector and estimated emittance of an 80 mA beam from the proposed pulsed electron source.

Beam loading is 63% for all structures at the design current. The rf system, critically coupled to the linac at full current, is designed to accommodate the VSWR of 2.6 at zero current. Appropriate intertank spacing and waveguide run lengths are used to deflect the reverse power from a hybrid tee into a matched load, while the klystron is protected from load imbalances by a circulator designed for the full 500 kW forward power.

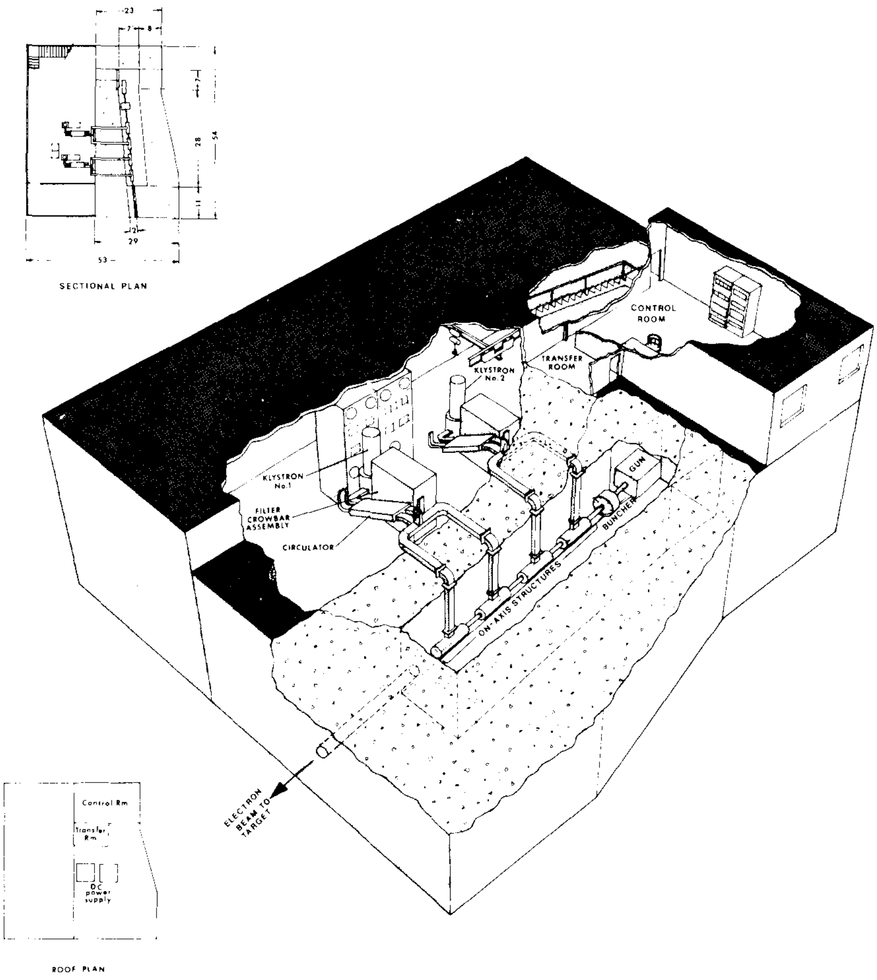

Fig. 5 Artist's view of proposed accelerator inside its concrete shield.

Shielding and Services

Figure 5 shows a drawing of the accelerator inside its concrete enclosure. The tapered wall has 2.44 m of normal concrete at the source end and 3.35 m at the 10 MeV end. The forward peaked angular distribution of the bremsstrahlung requires a thickness of 4.37 m on the end wall. This assures that radiation outside the tunnel is less than 2.5 mSv/h. The doses calculated[10] with exponential attenuation were corrected by dose build-up factors. The shielding will attenuate neutron doses from (γ,xn) reactions in copper and steel by a factor of 10^{11} hence no appreciable radiation dose from neutrons will exist outside the shield.

Power and water requirements are 2.5 MVA and 7300 L/min to cool a primary circuit of distilled deionized water (2650 L/min) for klystron and accelerator cavity cooling.

References

1. J.S. Fraser, G.E. McMichael, J. McKeown and S.H. Kidner, "The Chalk River Electron Test Accelerator", Proc. of 1972 Proton Linear Accelerator Conference, LA-5115, p.226.
2. J. McKeown, R.T.F. Bird, K.C.D. Chan, S.H. Kidner and J.-P. Labrie, "High Power, On-Axis Coupled Linac Structure", Proc. of the 1981 Linear Accelerator Conference, Santa Fe, NM, LA-9234-C, 332 (1982).
3. L.M. Young and J.M. Potter, "CW Side-Coupled Linac for the Los Alamos/NBS Racetrack Microtron", IEEE Trans. Nucl. Sci., NS-30 (4), 3508 (1983).
4. J.-P. Labrie, H. Euteneuer and J. McKeown, "Energy Gradient Limits in Room Temperature CW Linacs", this conference.
5. H. Euteneuer, "Design, Performance and Blow-up Properties of the MAMI Structure", Proceedings on the Conference on Future Possibilities for Electron Accelerators, University of Virginia, January 1979, P-1.
6. N. Bowen, A. Bohr, H. Burrin, J.O. Lawson, W. Newman and F. Schnabl, "2.45 GHz System for Lower Hybrid Current Drive" on the Princeton Large Torus, Princeton University internal report.
7. LOOPX, A Coupled-Loop Circuit Model Computer Code, written by S.O. Schriber, CRNL.
8. Hermosa Electronics, California 94025.
9. K.R. Crandall, private communication.
10. K.C.D. Chan, internal communication, CRNL.