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THE HARWELL 136 MeV ELECTRON LINEAR ACCELERATOR

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Summary.

A 136 MeV., L-Band electron linear accelerator design and performance specifications are presented with operational characteristics measured during the commissioning trials. These results confirm the machine's operational flexibility for operation over a wide specification range without readjustments as required by the beam sharing design concept. By variation of the R.F. power and phasing beam current energies in the energy range 2 to 136 MeV are available. The machine is fully protected from high beam power damage by current, duty cycle and beam off-centre trips. All trip systems are fully compatible with beam sharing control techniques. In parallel with the machine contract, additional development work has progressed on power multiplexing units for the electron gun amplitude and pulse length control systems.

Accelerator Design Parameters and Specification.

The major design parameters and performance specifications are summarised in Table I.

Introduction.

The machine was designed, manufactured and commissioned by Radiation Dynamics Ltd., for the Nuclear Physics Division of the United Kingdom Atomic Energy Authority, Harwell, to be used mainly for nuclear physics research [1] in reactor designs, radiation effects and radiation chemistry using either neutrons or electrons from the primary beam. Its design specification includes low and high energy beam facilities, short and long pulse lengths and a high duty cycle within a basic design compatible with beam sharing operations by multiplexing the beam between the experimental cells from the central control room. Beam outputs from the linac are provided after the second and eighth accelerator sections with an additional option after the first injector section to be used in later experimental programmes. Initially the machine will operate with four experimental target cells, a fast neutron, neutron booster, condensed matter and a low energy cell.

Table I Design Parameters and Specifications

OPERATING FREQUENCY..	1300MHz (L-band).
NUMBER OF KLYSTRONS (THOMSON C.S.F. T.V. 2022)...	4.
NUMBER OF ACCELERATOR SECTIONS...	8 x 2 metres
R.F. FILLING TIME	1μ sec.
MAXIMUM STORED ENERGY	64 joules.
TOTAL PEAK R.F. POWER	80MW.
TOTAL AVERAGE R.F. POWER...	160kW.

KLYSTRON MAXIMUM R.F. DUTY CYCLE.	0.002 (20MW/40kW)			0.004 (10MW/40kW)		
MODULATOR PULSE LENGTH - (μS)	7.6	3.8	2.0	7.6	3.8	2.0
MAXIMUM R.F. PULSE LENGTH - (μS). ...	6.6	3.3	1.6	6.6	3.8	1.6
MAXIMUM ELECTRON BEAM PULSE LENGTH - (μS)	5.0	2.0	0.4	5.0	2.0	0.4
MAXIMUM BEAM PULSE REPETITION FREQUENCIES (Hz)	300	600	1000	600	1200	2000
MAXIMUM AVERAGE R.F. POWER (kW).. ...	160	158	128	160	158	128

ELECTRON PULSE LENGTH - VARIABLE -	5 nS minimum. 5 μS maximum.
MAXIMUM SHORT PULSE CURRENT	6 to 11 amps.
MAXIMUM LONG PULSE CURRENT.	0.6 to 1 amp.
UNLOADED BEAM ENERGY (Eo)..	136 MeV.
BEAM CURRENT AT MAXIMUM EFFICIENCY AT (½ Eo).	0.9 Amps.
MAXIMUM SHORT PULSE BEAM POWER...	30 kW.
MAXIMUM LONG PULSE BEAM POWER	90 kW.

General Description of the Linac System.

To satisfy the short pulse, stored energy, beam current and energy specification requirement and minimise the long pulse beam break up (B.B.U) effects together with a high duty cycle requirement using existing R.F. power klystrons, an R.F. frequency of 1300 MHz, L-band, was chosen for the Linac system design. The linac consists of eight 2 metre lengths of V = C corrugated wave guides powered by four TV2022 power klystrons, with an interconnecting wave guide system incorporating R.F. power and phase control as shown in fig. 1. Electron beam current is provided by a triode electron gun [2] driven from a single gun pulse modulator with a pulsed cathode injection energy of 100 KeV. Beam current bunching is performed by a single cavity velocity modulation prebuncher and the first corrugated wave guide accelerator injector section. Full machine beam protection is provided by duty cycle interlocks, beam current loss and off centre trip systems.

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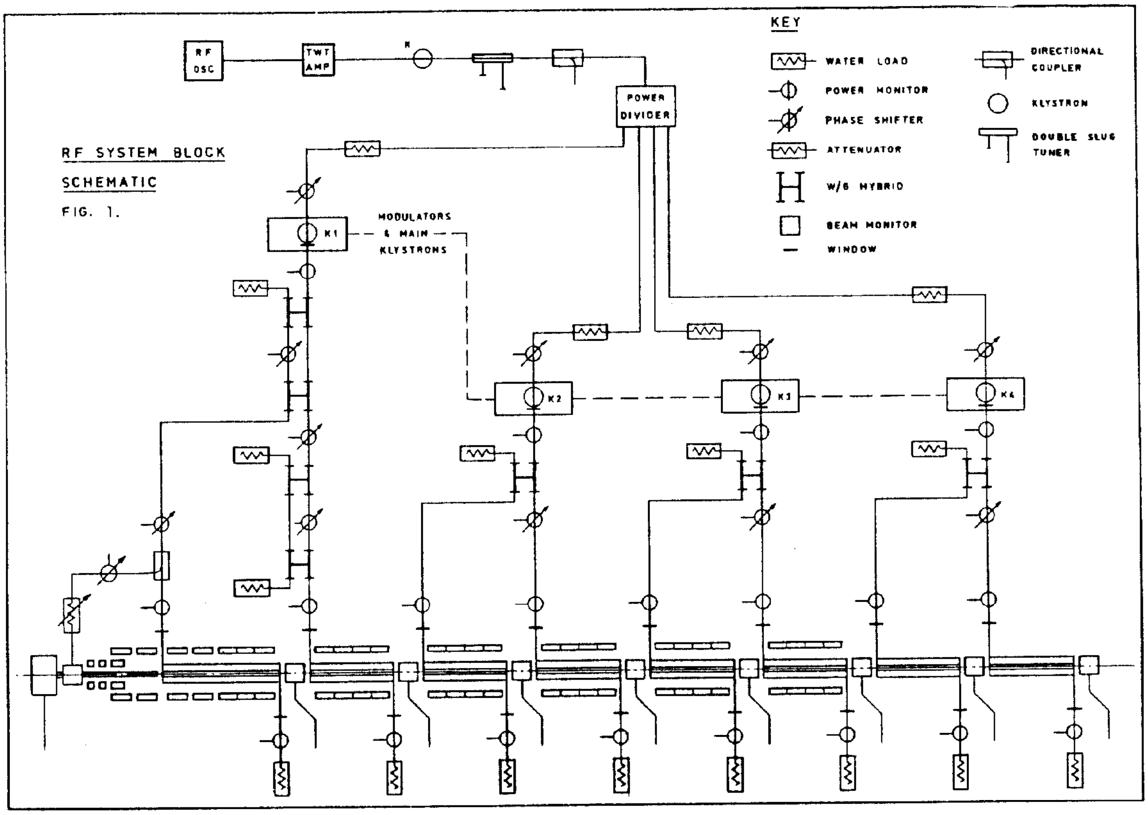

RF SYSTEM BLOCK SCHEMATIC

FIG. 1.

Injector System.

The electron gun has a convergent beam flow, Pierce triode geometry, with a 25 mm diameter oxide coated cathode. Both cathode and grid are pulsed to - 100kV from the pulse transformer of the first modulator via an air spaced coaxial cable. Maximum anode beam current transmitted is 15 Amps. A co-axial grid cathode support structure is used with an impedance of 50Ω. The anode is at earth potential with the grid at - 350 volts for normal "cut off" operation. Beam current and pulse lengths are generated by a single gun pulse modulator, which drives the gun cathode negative with respect to the grid. A gun pulse modulator drive located in the control room transmits pulse length signals to the gun modulator via an optical link which allows the gun pulse length to be multiplexed for beam sharing operation, with provision for including pulse amplitude data for future extension to amplitude multiplexing. Magnetic fields in the injector contain the beam in a Brillouin flow type operation with a shunt plate at the gun anode to prevent the magnetic field linking with the cathode surface. A single cavity prebuncher operating with up to 15 kW maximum R.F. power provides approximately 55° pulse phase width injection conditions. R.F. power is coupled from the input waveguide to the first accelerator via a 28 dB coupler and is controlled remotely by phase shifters to vary amplitude and phase.

Accelerator System.

The accelerator consists of eight 2.0 metre non uniform impedance, $\pi/2$ mode and $V = C$ corrugated waveguide accelerating sections designed to work with an approximately constant electric field gradient at zero beam current. R.F. power is coupled into and out of the corrugated accelerator waveguides by "door knob" mode transformers, with excess R.F. power being absorbed in separate R.F. loads. The injector waveguide has a filling time of 0.8μS, shunt impedance of 38 MΩ and 2 dB R.F. power attenuation without beam current. All the other waveguides have filling times of 1μS, shunt impedances 40MΩ and R.F. attenuations of 3 dB, without beam. Waveguide irises are manufactured from O.F.H.C. and assembled by electroforming techniques. Maximum average field gradient is 90kV/cm for zero beam current ($I = 0$). The waveguides are tuned to operate at a $V = C$ condition for 1299.7 MHz., 36°C and the mode transformers matched with a bandwidth of approximately 1 MHz, and 0.1 dB losses.

Beam Focusing System.

Solenoid focusing or beam containment coils are used on the first six accelerator sections to prevent beam de-focusing. An axial magnetic field of 0.15T to 0.035T is needed for this purpose.

R.F. System.

The four power modulators operate at either 10 or 20 MW power level, from one of three pulse forming networks switched by a thyratron into a pulse transformer which provides high voltage to the klystron R.F. power source cathode.

R.F. excitation for the power klystrons is provided by a crystal oscillator and both T.W.T. and klystron amplification stages with ± 60° phase adjustment to each power klystron. Each power klystron supplies power to two accelerator waveguides via a feed waveguide system containing a power splitter and phase shifter. The first modulator has a more complex system allowing complete R.F. power and phase flexibility as required to optimise the machine beam parameters.

Future Development.

To satisfy future research programme requirements, design modifications to up-rate the beam short pulse facilities are being investigated, together with increased energy and power proposals.

Accelerator Measurements.

Accelerator endurance trials have been satisfactorily completed, together with performance measurements of beam energy, energy spread, beam size and emittance for the specified pulse lengths as a function of current at the first (injector), second and complete machine beam output facilities. High power beam tests to 45 kW only have been completed due to the test target power limitations. Full power trials will be completed during the research programme with an experimental target. All the performance specifications stated in table I have been successfully achieved. Long pulse normal mode beam operation measurements are given in figure 2 together with the theoretical maximum beam energy and efficiency for the complete Linac. A typical energy spectrum for the 0.6 Amps at 80 MeV is shown in figure 3.

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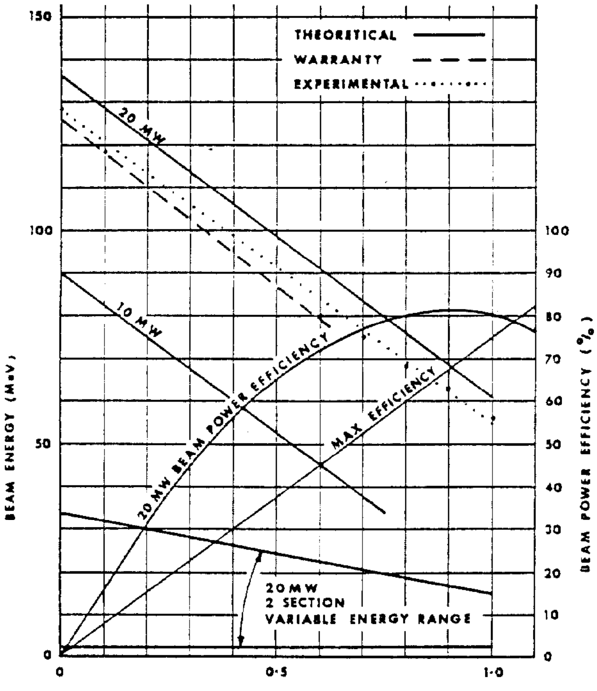

FIG 2a BEAM PULSE ENERGY & CURRENT; LONG PULSE - NORMAL MODE OPERATION

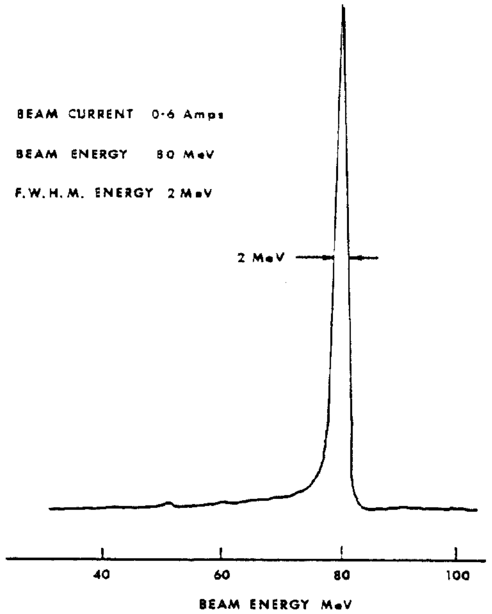

Figure 3 STEADY STATE BEAM ENERGY SPECTRUM