IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

A 500 MeV LOW OPERATING COST ELECTRON LINAC

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Summary

A 500 MeV linac has been constructed and operated since Dec. 1980 at ETL in Tsukuba for the generation of high intensity photons and pions and for the electron injection to a 600 MeV storage ring and a 150 MeV beam stretcher. The linac consists of an injector with a triode type electron gun and an inflector and three kinds of twenty linearly tapered iris type accelerating sections, of which four sections are 2.3 m long and sixteen sections 3 m long. Rf power at a frequency of 2856 MHz is provided by seven 25 MW klystrons with an improved efficiency of about 50 % to save the power consumption to about 70 % of that of the ordinary linac. The maximum beam duty cycle is 0.24 %. To avoid the cumulative beam blow-up, special attention has been paid to the design of the linearly tapered iris type accelerating section and the configuration of twenty sections and eleven quadrupole doublets and a triplet. For the economical beam sharing, the beams with three different energies from low, medium and high energy sections are simultaneously provided to four experimental arears by means of the combination of three pulsed coils and four beam transport systems.

Introduction

The linac has been designed and constructed so as to provide high energy electrons in an energy range of 10 - 500 MeV at a low operating cost. The electron beams are used for the establishment of radiation standards, the studies of radiation damage, radiation chemistry and nuclear data, the electron injection to a SOR ring and a beam stretcher, and the RI production. In order to satisfy the various requirements for the characteristics of the beams, the linac has three energy sections, that is, a low-energy, a medium-energy and a high energy sections.

Another feature of the linac is of medium duty ratio and high power, not of high duty ratio and high power as the two machines operated at Saclay[1] and MIT[2] as shown in Fig. 1. The design approach to avoid the cumulative beam blow-up[3] and to achieve a reasonable peak current results in a configuration of twenty linearly tapered iris type accelerating sections whose iris diameter is linearly tapered along the axis and twelve quadrupole doublets or triplets.

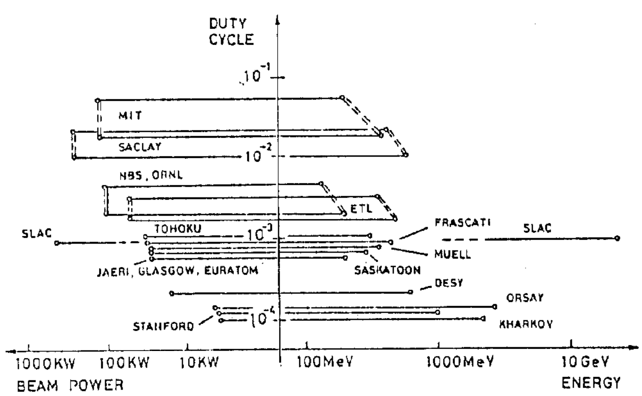

FIG. 1 Main Medium and High Energy Electron Linacs in Operation.

Accelerating Sections

The structure of the linearly tapered iris type[4] accelerating section is very simple as shown in Fig. 2 and the fabrication cost is lower than that of the constant gradient type. It is interesting to line up

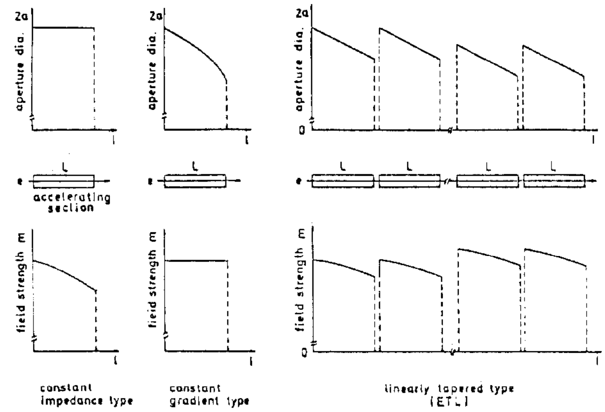

FIG. 2 Features of the Linearly Tapered Iris Type Accelerating Sections and Their Configuration.

several kinds of linearly tapered iris type accelerating sections and have common cavities as many as possible in their structures to reduce the fabrication cost.

We have designed five kinds of linearly tapered iris type accelerating sections usable for a multi-section linac providing several hundreds MeV and a hundred kW electron beams[4]. Fig. 3 shows the variation of their design parameters as a function of the iris diameter 2a (cm) of loading disk. The five kinds of the accelerating section 3 meter long are shown in the Fig. 3, in which they are designated A3 through E3.

The linac is designed to consist of three kinds of linearly tapered iris type accelerating sections, namely, the two types of C3 and D3 and the type of C2, which is the input side 2.3 m long of the type C3. The four sections of C2 type are used in the low energy section. Thr four sections of C3 type are used in the medium energy section, and the six sections of each C3 and D3 type are used in the high energy section.

The 2.5 GeV KEK linac under construction adopts the five kinds of the ETL type-linearly tapered iris type-accelerating sections as 160 accelerating sections.

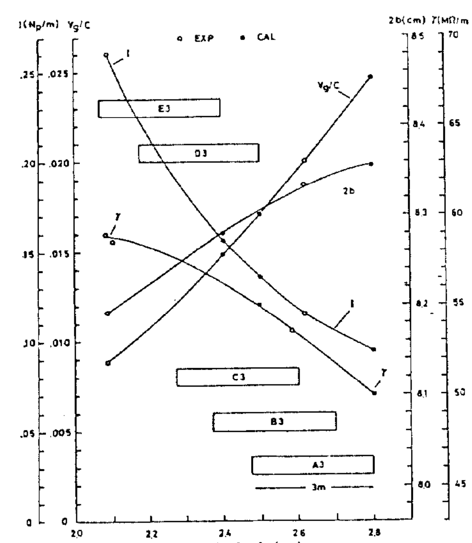

FIG. 3 Design Parameters of the Accelerating Sections against iris diameter. The Experimental Data are quoted from the Refs. [7 - 10].

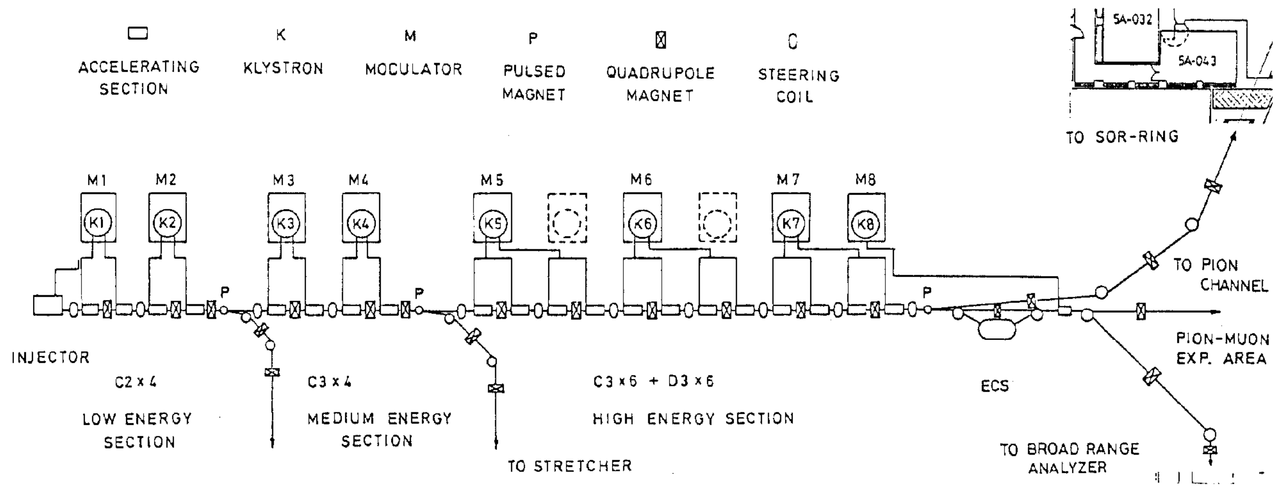

FIG. 4 Schematic Layout of the Beam Centerline, Klystrons, Modulators, and Beam Transport Systems.

Main Configuration of the Linac

Fig. 4 shows a schematic layout of the beam centerline, klystrons, modulators, and beam transport systems for the 500 MeV linac. The linac consists of an injector, the twenty accelerating sections of the three kinds mentioned above, the seven rf sources for the linac (10 rf sources in future) and an rf source for an ECS, and the beam transport systems including the twelve quadrupole doublets and the twelve steering coils along the beam centerline. To reduce the effect of terrestial magnetism, the four accelerating sections of the low energy section are covered with a sheet of a high μ metal. The main design parameters of the linac are listed below:

Total length			
Type of accelerating sections	$2\pi/3$		
	2856 MHz at 40 $\pm$ 0.1°C		
	Linearly tapered iris type		
	C2	C3	D3
No. of accelerating sections	4	10	6
Length (m)	2.3	2.93	2.93
Shunt impedance (MΩ/m)	54.1	54.5	55.6
Voltage attenuation const. (N/m)	0.140	0.148	0.170
Input peak rf power (MW)	12	12 (6)	6
Water flow (l/min)	50	50	50
Water temperature in (°C)	37.2 - 40		
Beam pulse width	5 ns - 4 us		
Pulse repetion rate	less than 600 pps		
No. of klystrons	8 (1 is for ECS); 10 in future		
Maximum peak rf power	25 MW		
Average rf power	25 kW		
Maximum duty cycle	0.0025 at 10 MW		
Efficiency	more than 50 %		
Total unloaded beam energy	520 MeV at 0 A		
Total loaded beam energy	467 MeV at 0.1 A		
Loaded beam energy at the medium energy section	208 MeV at 0.1 A		
Loaded beam energy at the low energy section	93 MeV at 0.1 A		
Construction, date	March 1980 - Sept. 1980		
First beam, date	Dec. 22, 1980		
	350 MeV, 40 mA		

Rf Power Sources

Rf power to the linac is provided by the seven high power klystrons, whose operation efficiency is about 50%. The peak rf power output of commercially available high power klystrons is of the order of 20 - 30 MW but the duty cycle is around 0.001 at S-band. The maximum peak power of the klystron used here is 25 MW at a duty cycle of 0.001. However, it is slightly modified so as to be used at duty cycles up to 0.0025 at 10 MW, keeping the average output power of 25 kW constant. The high efficiency of 50 % is an important feature demanded for this klystron to realize a low operating cost linac. This enables us to save the power consumption of the linac to about 70 % of that of the ordinary linac. Fig. 5 shows the efficiency of the commercially available pulse klystrons. Among them, the efficiency of our klystrons is the highest[5].

Each klystron is driven by a medium power klystron which, in turn, is driven by an rf oscillator system. The klystron has two output waveguide arms. Rf power emerged from each arm is fed to each accelerating section of low and medium energy sections, but to two accelerating sections of high energy section, through the pressurized SF_6 filling water cooling waveguide system. The waveguide system including rf power dividers, phase shifters and directional couplers for rf monitors is installed in the klystron gallery or the accelerator room. The rf drive system and the rf loads are cooled by a coolingwater system.

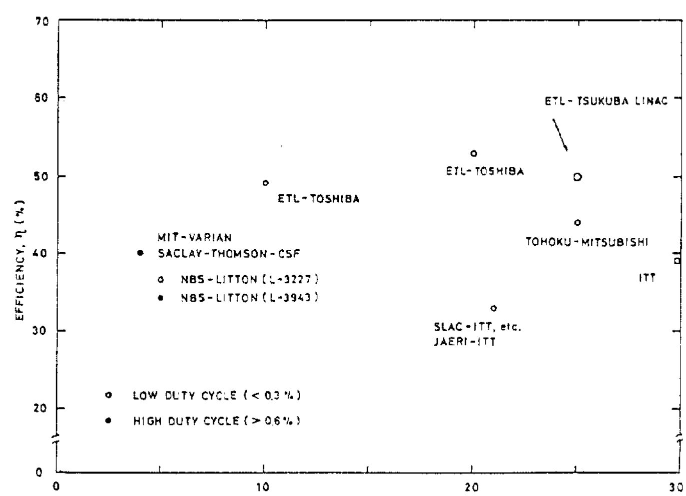

FIG. 5 The Operation Efficiency of the Commercially Available Klystrons

Injector System

The injector system consists of the following elements; in sequence from input to output, they are a 100 kV triode type electron gun, two focusing solenoids a gate valve, a beam inflector, a focusing solenoid, a collimator, a prebuncher cavity, a focusing solenoid, and a travelling wave (TW) buncher section installed in a focusing solenoid. The electron gun is turned on for 7 μs during rf pulse at repetition rate of up to 600 pps. The cathode of the gun is of an impregnated cathode type. Pulse width of 100 keV electrons emerging from the gun is determined from the width of gride pulse from 10 ns to 4 μs and the electron pulses pass through into the beam inflector; the inflector can clearly select the duration of the electron beam pulse train (50 ns to 4 μs). The electron beam, which is normally held off axis, is deflected through the collimator.

The prebuncher cavity is of a reentrant type and is nickel-plated to reduce the Q value. Microwave bunching of the electrons is achieved during their passage through the prebuncher and a 30 cm long drift space. The electrons from the gun, 100 keV in energy and $\pm$ 180° in phase spread, are velocity-modulated by the prebuncher cavity; at the entrance of the buncher, their energy and phase spread are 100 $\pm$ 7 keV and $\pm$ 30°,

The TW buncher is a 46 cm long section of constant impedance type, with disk spacing stepwise tapered so that the phase velocity of the rf wavw increases almost linearly from $v_p/c = 0.75$ at the input end, up to $v_p/c = 1$. The designed value of field strength parameter α is 1.54 over the length of the buncher section for a 2 MW input rf power to the buncher. As the electrons pass through the buncher, they are simultaneously bunched and accelerated; at the entrance of the first accelerating section, their energy and phase spread are 1.38 $\pm$ 0.2 MeV and 4° at a peak current of 0.5 A[6].

Beam Transport Systems

For the economical beam sharing, the beams with three different energies from low, medium, and high energy sections are simultaneously provided to four experimental rooms by means of the combination of three pulsed coils and four beam transport systems. Fig. 6 shows the beam sharing.

low energy section
pulse current
beams to low energy exp. room
medium energy section
pulse current
beams to medium en. exp. room
high energy section
pulse current
beams to storage ring room
beams to pion or high energy exp. room

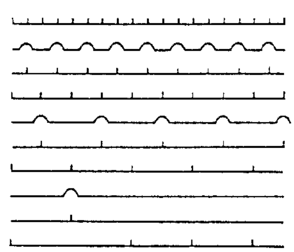

FIG. 6 Beam Sharing at Each Energy Section

Performance

The injector and the twenty accelerating sections are maintained to be their designed temperature of 40°C as shown in Fig. 7 by a closed-loop, temperature control system. Hot water of about 60°C is used as a heat source in the control system so that the total system can be warmed up to 40°C $\pm$ 0.2°C in 15 minutes and controlled in 40 $\pm$ 0.05°C in 3 hours. However, slight changes in their temperature can be seen according as the rf power consumption and the beam acceleration.

The beam acceleration through the total accelerator length has been done without trouble, adjusting the currents of the quadrupole magnets and the phase of the rf power put into each section. Some steering coils are effective since the accelerating sections of the medium and high energy sections are not covered with a sheet of a high μ metal to reduce terrestial magnetism. Because of these well settled beam handling system, the beam loss loss is so small that one can walk in the accelerator room at the acceleration of about 350 MeV electrons of 40 mA (average 4 μA). Fig. 8 shows a TV picture of Cerenkov radiation emitted from about 350 MeV, 40 mA electrons injected into a water bath. Total length of the Cerenkov radiation is about 90 cm. The 600 MeV storage ring is completed in May, 1981, and the electron injection begins in June.

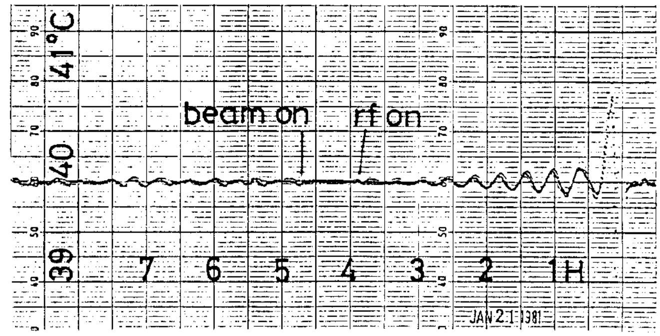

FIG. 7 Temperatures of the Accelerating Sections

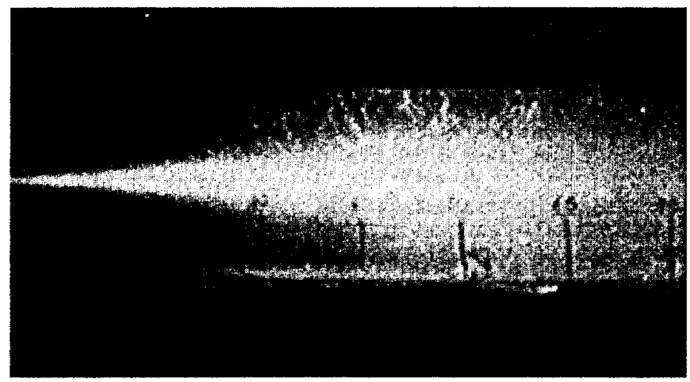

FIG. 8 TV Picture of Cerenkov Radiation Emitted from about 350 MeV, 40 mA Electrons Injected into a Water Bath. Total Length of the Radiation is about 90 cm.

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