CALCULATION OF BEAN CHARACTERISTICS OF A CW ELECTRON LINAC

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Abstract

Beam characteristics of a continuous wave (CW) electron linac have been calculated. The linac operates under two conditions. One is 100% duty factor; the other is 20% duty factor. The linac is energized by two 1 MW CW L-band klystrons which is developing. The beam energy is 10 MeV and the beam current is 100 mA at 100% duty factor or 500 mA at 20% duty factor. The beam power is as high as 1 MW.

1. Design considerations

The CW linac which operates at room temperature is designed to treat waste radioactive material. It needs beam power as high as possible. At first we design a 10 MeV CW linac with 100 mA beam current and second will design a 100 MeV CW linac with 1A beam current. This linac will operate under two conditions: One is 100% duty factor, beam current is 100 mA and the RF power is 2 MW; the other is 20% duty factor, beam current is 500 mA and the RF power is 10MW, the pulse length is 5 ms with a repetition rate of 50 Hz. In both cases the beam energy is more than 10 MeV and energy spectra are less than 1%. In the case of the linac with low electric field gradient, heavy beam-loading and narrow energy spectra several special design approaches are considered: the use of short accelerator guides with traveling wave resonant rings; the use of a low gradient variable phase velocity traveling wave buncher and the use of an RF chopper and a prebuncher.

2. Description of the CW linac

Figure 1 illustrates a schematic layout of the microwave distribution system, injector and accelerator guides arrangement. Two 1 MW CW L-band klystrons energize a chopper, a prebuncher, a buncher and accelerator guides. The length of the linac is 9.6 m. It is divided into eight sections, each of which is about 1.2 m long. In the bottom of Fig.1 the wave phase velocity, electric field and phase and energy of the balance particle are listed respectively.

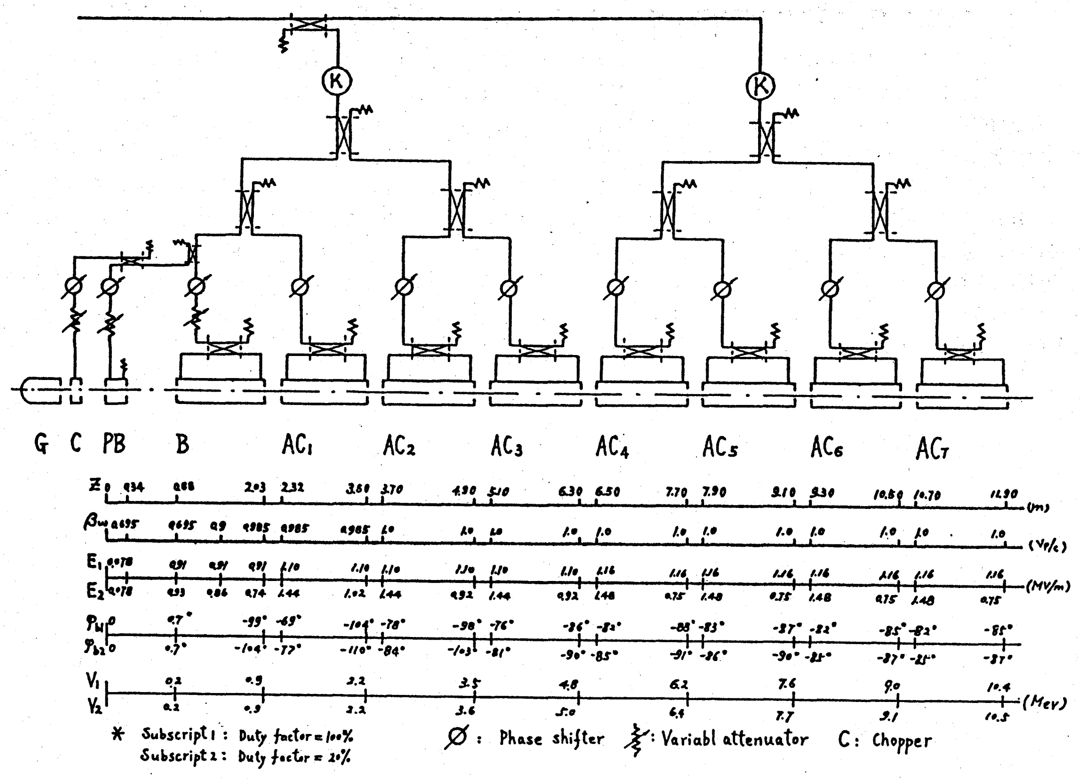

Fig.1 Schematic layout of the CW linac

3. Injector system

The injector consists of a 200 kV electron gun, a microwave chopper, a prebuncher and a buncher. The beam current available form the gun is assumed to be 200 mA in 100% duty factor and 1A in 20% duty factor. The chopper is a rectangular waveguide section with TM120 mode. It chops about 50% electrons in an RF periodic. It can reduce beam loading of the RF in accelerator. The prebuncher and buncher are designed so as to avoid phase orbit cross-overs as much as possible. The length of the buncher is 1.16m. The wave phase velocity varies linearly at first half part from 0.695c to 0.9c and in the second half part from 0.9c to 0.985c.

4. Accelerator structure

The linac consists of eight accelerator guides including one buncher. The first section is the buncher; the second is accelerating section with β=0.985c; the remainder six sections with β=1 are divided into two groups. Each accelerating section contains 15 $2\pi/3$ mode cavities and is designed such that a constant gradient condition is approached at 100 mA beam loading. The progressive stop-band technique [1] is adopted to enhance the threshold of beam breakup. The iris diameters in the initial region of accelerating sections are smaller than those in any preceding group but larger than those in subsequently located group. In order to suit for two duty factors the iris diameters are as large as possible.

5. Traveling wave resonant ring [2]-[4]

The traveling wave resonant rings are very useful to large iris diameters and short accelerator guides. They can not only enhance the linac efficiency, but also release frequency, temperature and fabrication tolerances. For f=1249 MHz, Q=18000 and τ=0.05, if the energy variation is not exceed 1% the Δf is about 0.15 MHz. The coupling coefficient of the directional couplers should be chosen so as to make the rings optimal coupling at 100 mA beam loading. It means that no power passes through to the load, i.e., the linac has the maximum efficiency. The efficiency of the CW linac is more than 50%.

6. RF system

In the linac with traveling wave resonant rings the phasing system has two parts. One of them is to adjust the RF phase of each accelerator section with respect to the beam bunch phase. The other is a phase-shifter installed in the resonant ring to satisfy the resonance condition. In this case we would rather take two spacers than a conventional phase-shifter to adjust the phase in each ring. It can reduce the RF loss in the rings to increase accelerating electric field strength. The RF power fed to the chopper is 6kW from the prebuncher waveguide through a 3dB coupler. The power energizing prebuncher is 8kW from the buncher waveguide through a 10dB coupler. The energy spectra and the bunch width change by changing the power of the prebuncher or buncher.

7.Calculation results

It is not easy to find a set of parameters such that both cases have good energy spectra. We, however, have done it by using large iris diameters, short sections and traveling wave resonant rings. A typical set of phase trajectories is shown in Fig.2. The energy spectra for both cases are shown in Fig.3. Principal design parameters of the linac are listed in Table 1.

8.Conclusion

In room temperature, a traveling-wave disk loaded accelerator structure with traveling wave resonant ring is a recommendation to design a CW linac. Of course, for high average power the cooling of the accelerator becomes a difficult problem, which is not discussed here.

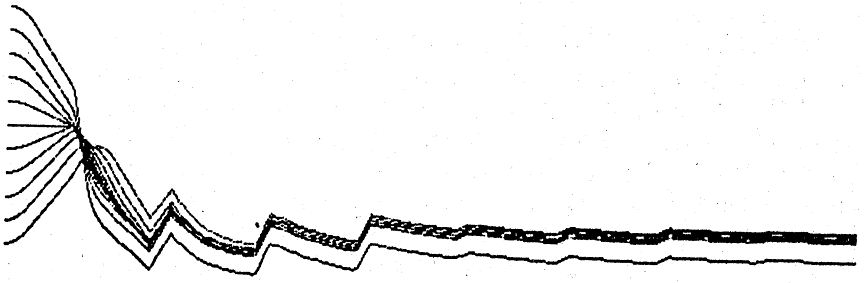

Fig.2 Calculated phase trajectories

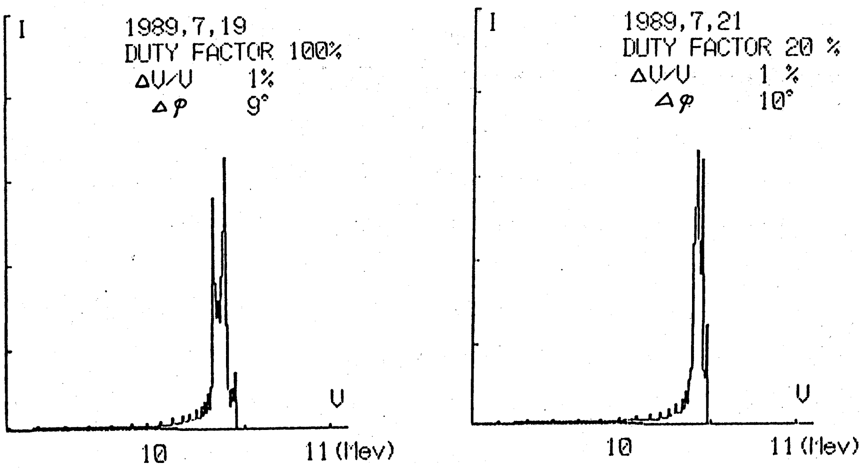

Fig.3 Calculated energy spectra of the electron beam accelerated by the CW linac

Table 1.Design parameters of the CW linac

Number of klystrons	2	Injector	
Number of accelerating sections	8	Electron gun voltage	200kV
Overall length	14.0m	Beam current (100% duty)	200mA
		(20% duty)	1A
Klystron		Chopper Rf power	6kW
Operating frequency	1249.135 MHz	Prebuncher RF power	8kW
RF power (100% duty factor)	1 MW	Prebuncher length	0.33m
(20% duty factor)	5 MW	Buncher RF power	0.18MW

Accelerator structure (constant gradient with 100 mA beam loading)

	Buncher	Accelerator 1	Accelerator 2-3	Accelerator 4-7
Length (m)	1.16	1.16	1.2	1.2
Number of cavities	17	15	15	15
Disc thickness(mm)	12.0	12.0	12.0	12.0
Iris diameters(mm)	65.0-67.0	62.0-57.0	60.0-55.0	56.6-51.6
Shunt impedance (MΩ/m)	15.2-29.3	31.5-33.3	32.9-34.8	34.2-36.1
Group velocity (Vg/C)	0.025-0.032	0.025-0.018	0.022-0.016	0.018-0.013
Attenuation (Nepers/m)	0.036-0.021	0.028-0.037	0.031-0.041	0.038-0.051
Q	14520-18910	18930-18890	19110-19080	19090-19060
Resonant ring				
Coupling coefficient C	0.4858	0.5760	0.6000	0.6400
Field multiplication factor				
M (100% duty)	2.06	1.74	1.66	1.56
M (20 % duty)	1.19	1.03	0.96	0.88

Overall performance specification

Electron energy	10 Mev
Energy spectra	1 %
Bunch phase width	9°-10°

References

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