Progress in Medical and Industrial

Electron Linear Accelerator Technology

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ABSTRACT

Recent advancements in the technology of standing wave election linear accelerators, which are widely used in medical (radiation therapy) and industrial (radiography) applications, are reviewed. These include comparisons of several different structures and operating modes, in terms of performance and cost effectiveness. In addition, a new concept of a multi-energy, single-section, standing wave linear accelerator structure, which has been developed in Varian and demonstrated in commercial applications, is described.

INTRODUCTION

In recent years, electron linear accelerators have been widely used in medical and industrial applications. The ideal accelerators for commercial applications have to satisfy the following conditions, ie., 1) compact and light weight, 2) highly efficient and stable, 3) simple to fabricate and operate, 4) narrow output energy spectrum and 5) output energy variable over a wide range.

This paper reviews the recent extensive developments of electron linear accelerators operating at room temperature in terms of those conditions.

COMPARISON OF ACCELERATOR STRUCTURES

Fig. 1 shows cross sections of various high beta accelerator cavity structures. The disc loaded traveling wave guides have been commonly used in high energy physics as well as in commercial applications, in the last two decades.[1] The structure is very simple yet the shunt impedance is relatively low (about 50 MΩ/m at S-band), and at the same time, a considerable amount of RF power is wasted in the RF load at the end of the guide. The bi-periodic and tri-periodic on-axis standing wave guides are also relatively simple but have rather higher shunt impedance (about 80 MΩ/m at S-band) and coupling (about 12%).[2,3] This structure is suitable for application when the transverse space is limited, but the interaction between coupling cavities and the beam may be serious. The side-coupled standing wave guide developed at LASL has many advantages, and is consequently widely used for many applications.[4] Although the structure is rather complicated, it is much less sensitive to mechanical tolerance and beam loading than the other alternatives. Moreover, the shunt impedance can be optimized independently from the coupling cavity structure, and by choosing the accelerating cavity contour and beam hole diameter, one can obtain a shunt impedance 120 MΩ/m at S-band frequency. The interlaced side-coupled SW guide developed at Varian has several unique features.[5] The ratio of peak E field to accelerating E field can be as low as 1.3 without sacrificing the shunt impedance (90 MΩ/m at S-band). Although the structure is somewhat complicated, it is suitable for a very compact, high gradient accelerator. The disc-and-washer structure introduced by Andreev has a very high coupling factor (50%) and potentially very high shunt impedance.[6] Yet at this stage, further developments will be required for commercial applications.

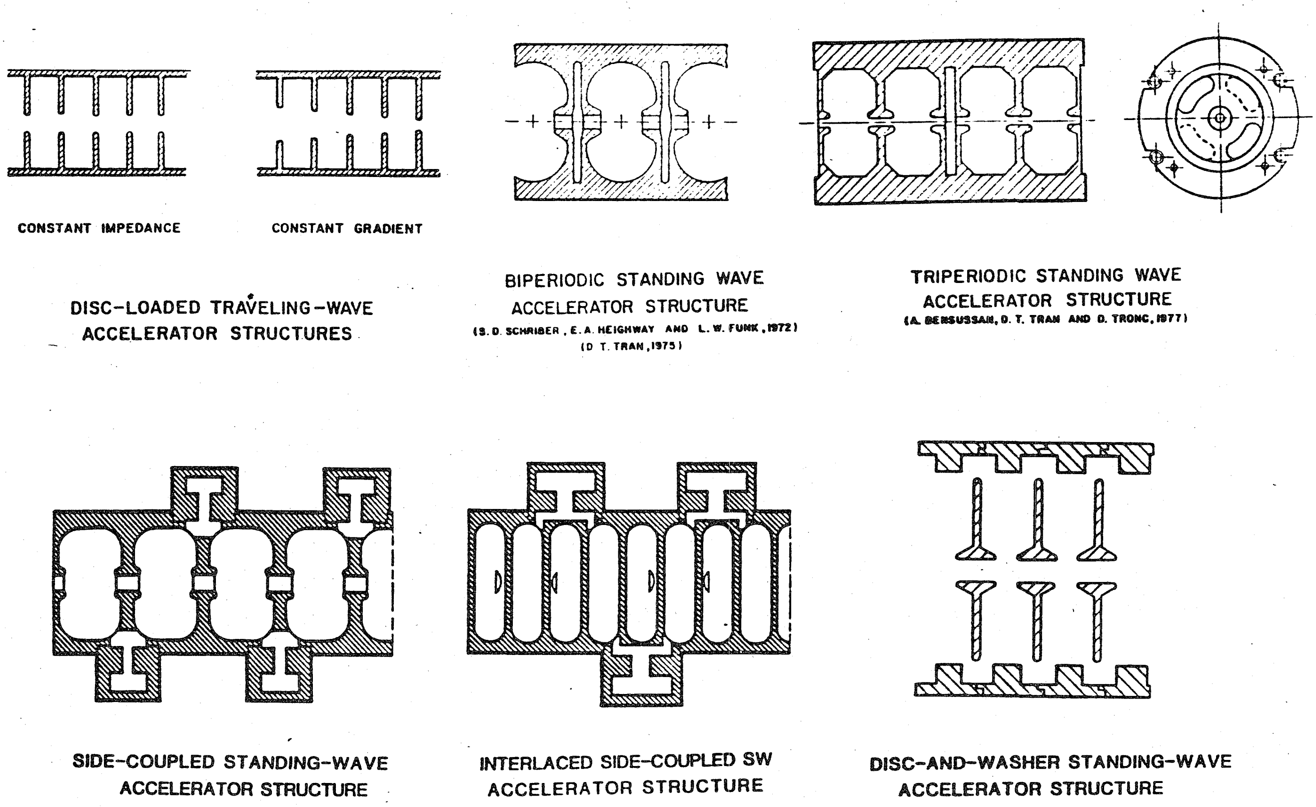

Fig. 1 Cross Sections of High Beta Accelerator Structures

VARIABLE ENERGY ACCELERATOR STRUCTURE

Radiation therapy linear accelerators typically produce X-rays in one of three energy ranges: 4-6 MeV (low energy), 8-12 MeV (medium energy) and 15-25 MeV (high energy). Depending on the location of tumors , the optimum treatment can be performed by choosing the right X-ray energy. A multi-energy accelerator would allow optimum treatment over a larger range of tumor depths with a single machine. Similarly, a multi-energy industrial linear accelerator would significantly increase the useful range of subject thickness.

Most of the single-section accelerators for medical and industrial applications are optimized for a narrow energy spectrum at a single energy, since the optimum electron "bunching" occurs at a certain level of accelerating electric field. As a result, the energy spectrum deteriorates rapidly if one tries to control output energy by changing the input RF power level.

One approach to varying the beam energy over a wide range is to cascade sections of linear accelerators which are independently excited, with independent control of accelerating field amplitude and phase.[7] Another approach is the double-path single-section linear accelerator, which uses a moveable reflecting magnet to obtain phase variation between passes.[8] However, these techniques are rather complicated and the results are often costly and less reliable.

A novel concept for varying the energy of a single-section standing-wave linear accelerator over a wide range without degrading the energy spectrum was recently developed at Varian.[9, 10,11] The technique is to utilize the unexcited coupling side-cavity to vary the relative amplitude and/or sign of the accelerating fields in adjacent centerline cavities. Technical details of this approach are given in the references.

Table I shows the basic design parameters of two classes of variable-energy standing-wave accelerators, namely Clinac 2500 for radiation therapy and Linatron 200A for radiography.

Table I. Variable Energy Accelerator Guide

Design Parameters

	Clinac 2500 Guide		Linatron 200A Guide	
Guide RF Length (m)	1.9		0.1	
No of cells	½ + 36		½ + 1 + ½	
Frequency (MHz)	2856		2997	
Effective Shunt Impedance (MΩ/m)	95		65	
Q_o	16,000		13,000	
Coupling Factor K_1	0.04		0.01	
Energy Mode	High Energy	Low Energy	High Energy	Low Energy
Energy (MeV)	24	6	2	1.2
Beam Current (mA)	50	180	200	200
Available RF Peak Power (MW)	4.5	2.0	1.6	1.6
Load Line (MeV vs A)	28.5-85i	17.0-60i	2.8-3.0i	1.4-0.9i

ACKNOWLEDGEMENT

The author wishes to express many thanks to A. McEuen who helped to prepare this manuscript.

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