BWLAP - BACKWARD WAVE LINEAR ACCELERATOR OF PROTONS

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Abstract

The present paper is based upon the successful tests of the first models of a Backward Wave Linear Accelerator of Protons (BWLAP), using untraditionally high frequency - 1.8 GHz - and upon the computer simulations of the principal features of several options for the BWLAP application.

The BWLAP scheme is the ALVAREZ DTL-scheme turned inside out.

The zones of the accelerating and magnetic focusing fields of these accelerators are interexchanged, so DTL and BWLAP are mutual dual schemes.

The tests have been carried out in Siberia in 1982 (for the first model) and in 1987 (for the second one).

The accelerating structure (AS) used is called Sickle Stem Structure (SSS) due to its shape.

These LAs were the first full-scale realization of the original approach to the acceleration of nonrelativistic particles with a backward (BW) spatial harmonic of a traveling electromagnetic field (TW - e.m.f.), in which the RF- flux was directed against the accelerated protons. In this case, an injector and RF supply are connected to the opposite ends of AS.

Introduction

Recent LAPs for proton energy below 200 MeV were designed according to the Alvarez drift-tube linac (DTL) scheme. 45 years of effort to improve the Alvarez linac have made it possible to increase the RF supply to 450 MHz and to reach an energy gradient for protons of ~ 5 MeV/m.

Changing from electrically powered magnets to CoSm-permanent magnets is more a technological advantage than a new principal: the CoSm-magnets make it possible to increase the frequency of the r.f. supply of LAPs from 150 MHz up to 450 MHz, which in turn increases Z_{sh}- shunt impedance, creating the effective conversion of RF power (i.e. money) to particle kinetic energy (from 30-40 MOhm/m up to 60-70 MOhm/m). This increase of frequency directly results in the increase of the average rate to over 5 MeV/m. The same scheme is also considered to be the most advanced for the high current accelerators of the future.

BWLAP

The new approach proposed in 1968 allows the acceleration of heavy particles by the longitudinal electric component (E_z) of a backward (BW) harmonic, where the flux of electromagnetic energy is directed opposite the accelerated particles; the accelerator, being a realization of this method, was called BWLAP.

In 1987, after 20-years of research and development, the theory became reality with the construction and testing two models of the first 400-cell BWLAP, thus permitting the comparison of these two approaches.

The BWLAP scheme is the ALVAREZ DTL-scheme turned inside out, and suggests new bases and features.

The arrangement of the accelerating (e.m.f.) and magnetic focusing fields (m.f.f.) is cardinally changed and dual (Fig.1).

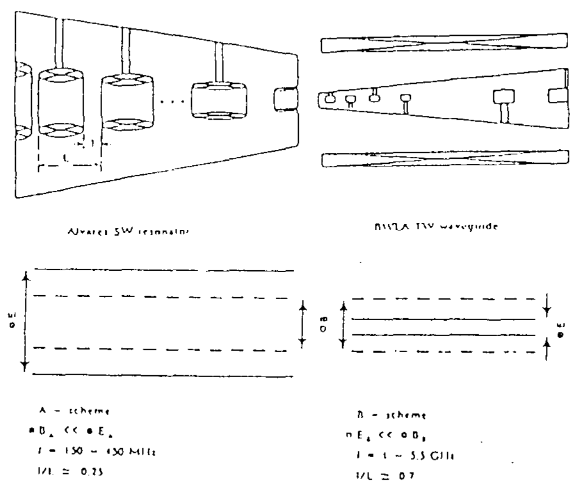


Fig.1. The arrangement of the e.m.f. and m.f.f. in DTL and BWLAP.

The frequency source used is four times higher (1.82 GHz) in the first experimental backward wave linear accelerator of protons (BWLAP - 400-cell 5π/6-TW-mode LAP), than for the Alvarez.

The unique properties of this concept, developed during the last 25 years in Novosibirsk, are given.

Potential applications of this new approach will also be discussed.

The tests have been carried out in Siberia in 1982 (for the first model) and in 1987 (for the second one). The main parameters of the investigated BWLAP-II are shown in Table1

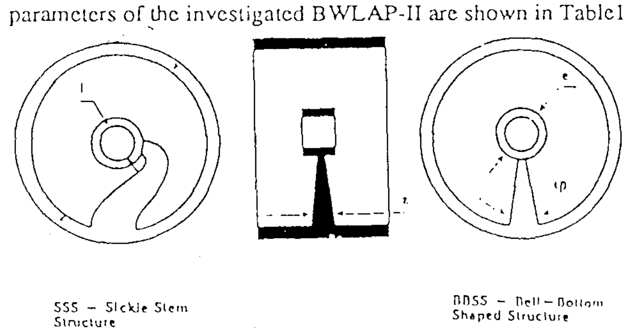


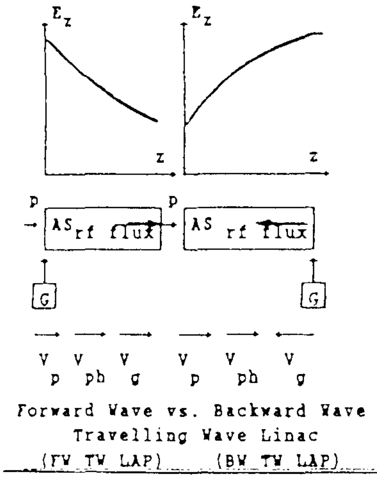
Fig. 2. Sickle Stem Structure & Bell-Bottom Shape Structure

AS I SEE IT

This study is designed to compare, in detail, the properties of the BWLAP with those of other kinds of accelerators, as well as with other devices which have similar arrangements and processes, i.e. BW-tube (BWT) and BW-accelerator (BWA).

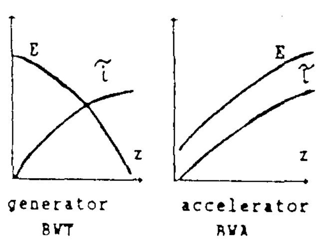
An attempt is made to show the results caused by these changes, when applied to conventional linear accelerators.

What has already been done	Results caused by structural changes
The direction of the e.m. f. flux which accelerates the particles by TW-regime is inverted. The RF generator is carried over from the entrance-injector-end of the AS to the exit-end.	A longitudinal instability problem is solved. An unrelativistic particle motion in a decreasing field is unstable. The great amplitude of E_z-field accumulates the high electrostatic energy in the forming bunch. If the latter moves in a decreasing field, as in the case of FW TW LAP, then the accumulated energy "pulverizes" the bunch. The motion is obviously stable in BW TW LAP.

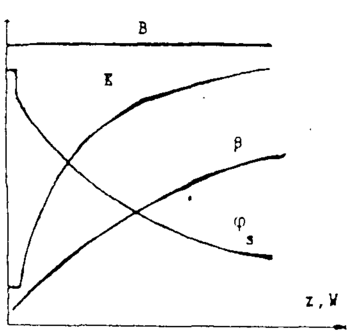


Forward Wave vs. Backward Wave Travelling Wave Linac
(FW TW LAP) (BW TW LAP)

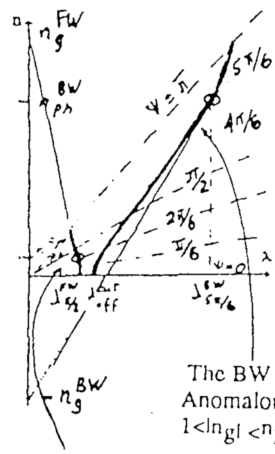
What has already been done	Results caused by structural changes
The amplitude distribution of the E_z-field is inverted relative to $\tilde{i}$.	The conversion efficiency η (RF power to kinetic power or vice versa) is about ten times higher, due to increasing $\int E_z \tilde{i}\, dz$. A perfect "harmony" in BWLAP is observed here.



What has already been done	Results caused by structural changes
If small dia. AS is put into a SC small dia. solenoid	Only in the BWLAP is the increase of β: accompanied by an increase of E. If B field remains constant or decreases only slightly, then: $B^2 \sim E \sin\varphi_s/\beta\lambda$. In BWLAP, extremely high B-field, therefore high RF possible: $\left(f_{BW} \sim B^2\right)$; In Alvarez RF limited by $\left(f_{Alv}^2 \sim \nabla B\right)$.

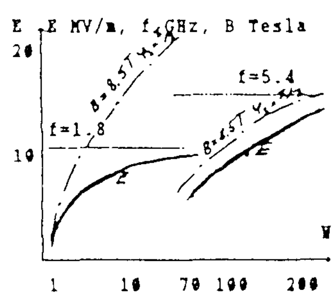


What has already been done	Results caused by structural changes
The anomalous dispersion structures (BW-type) are used.	Use of BW AS naturally leads to the largest n_{ph}. BW ASs, when operating close to π-mode, have small dia/λ because the stubs(or slots) are resonant elements and the pieces of cut-off waveguide, being non-resonant coupling elements, are used. The decrease S of AS leads to an increase of the E^2/P parameter. A small n_g in BW AS give: a small time-filling $t \sim n_g L_{AS}$. There is an opportunity to use μ-sec. RF pulses. In BW ASs the influence of the instabilities of the RF supply is weak.



The BW branch of curve. Anomalous dispersion. $1<|n_g|<n_{ph}$

The FW branch of curve. Normal dispersion. $n_{ph}<n_g$.



Use of a typical high frequencies of the BWLAP (1.8 & 5.4 GHz here) compatible with the m.f.f. by SC-solenoids makes possible the design of efficient, practical, high energy gradient LAPs with a very "moderate Kilpatrik"(i.e. K=1.6 as used here).

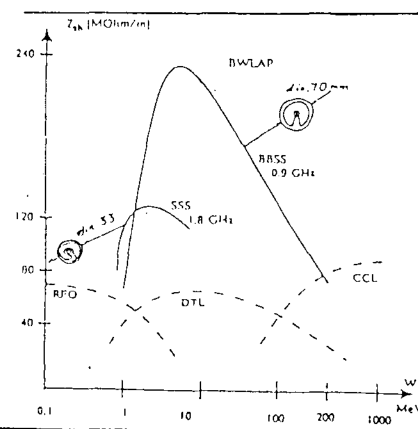


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TABLE 1

Energy	-injection	0.38 MeV
	-final	2.25 MeV
Beam current:		
average over pulse :		30 mA
	-pulse	2 & 6.5 μs
	-dia.	< 3 mm
RF frequency		1.82 GHz
	-power-input	260 kW
	-output	55 kW
Number of cells		400
Electrical length		166 ·βλ
Accel. structure:		SSS
-length		950 mm
-dia.-outer		46 mm
-inner		28-32 mm
-aperture		2.8-3.2 mm
-mode		5π/6
Focus.system-SCsolenoid:		
-length		1350 mm
-bore-warm		53 mm
-cold		85 mm
-strength		8.5 (9.07)T

The accelerating structure (AS) used is called Sickle Stem Structure (SSS) due to its form, as evidenced by Fig.2. Next Fig.3 permits to compare Z_{sh} parameter of the DTL and BWLAP.

BWLAP ARE USEFUL FOR OTHER PROJECTS BASED ON SYNCHROTRONS.

This section is a short commentary on the designing of injectors for PSs:

Several options are displayed in the Table 3.

These may be used as high energy injectors for Proton Synchrotrons (PSs) just like a "breeder" which makes a lot of short-time lived isotopes.

The injectors will produce up to 6E10 P/pulse (0.3 μs=300 ns) for a one turn injection, 6-meter diameter PS or 1.2E11 H^-/pulse (600 ns) for a 12 m-diameter one, cycling at 1 - 50 Hz.

In the case of the 10-12 MeV-energy injection, the number of protons per pulse will be increased to 1.0E11 and 1.8E11, respectively.

A wavelength of 16.5 cm is used for all these injectors as well as the first stage of the designed PTF-accelerator - for a 20 MeV proton linac. The AS is 4.2 m long, about 300 βλ electrical length, containing about 700 cells .

CONCLUSION

Hence, it becomes clear that the new generation of high technology proton linear accelerators offers the following distinct advantages over present-day system:

- lower initial investment in expensive materials; - time- , labor-, and space-saving;
- staged construction of accelerator "section by section";
- operation with beams at interim energies before the completion of the accelerator;
- adaptation of current radiation planning systems for electron linacs.

These features have significant practical advantages in comparison to conventional RFQ+DTL+CCL schemes of linacs.

I consider that none of these changes alone cardinally influence the conventional paradigm of the design of the new generation of linacs.

Nevertheless, I do think this new approach has definite advantages in the acceleration of heavy particles, and I believe that these changes, when considered as a whole, open new horizons.

TABLE 3

Option	1	2	3	4
	for injection		to produce radioisotopes	
Particle	protons	H^-	protons	H/D
Energy, MeV	20	20	12-20	20/40
Beam Current:				
- aver.over pulse, mA	30	10/30	100	100/200
- pulse, mms	0.1-6.5	0.1-6.5	6-8	6-8
- dia., mm	3	3	5	5
R.F.:				
- frequency, GHz	1.8	1.8	0.9/1.8	0.9/1.8
- imp power, MW	6	4/6	15/18	30/36
- aver. power, kW	0.1	0.1	5/10	5/40
Acceler. Structure:				
- type	SSS	SSS	BBSS	BBSS
	Sickle Stems Structure/Bell-Bottom Shape Str.			
- length, m	4.2	4.2	5	5
- dia. waveguide, mm	28-36	28-36	~ 60	~ 60
Focusing System:				
- type	SuperConducting Solenoids (SCS)			
- material	NbTi	NbTi	NbTi	NbTi/Nb_3Sn
- m.f.strength, T	8.5	8.5	7.5	7.5/15
- "hot" dia., mm	55	55	100	100
Delivery dates, months	15	18	30	30/36
Nominal cost, M$US	1.5	2.2	~ 4	~ 10