DESIGN AND APPLICATION OF MICROWAVE STRUCTURE FOR LOW VELOCITY PARTICLES

A.V. Mishin
Schonberg Research Corporation, Santa Clara, California, USA

Abstract

A microwave structure design concept invented in 1988 has been studied and tested for a number of years. The structure employs Alvarez type resonators coupled to each other through coupling cavities to maintain satisfactory neighboring resonance separation and beam stability. This design is applicable for charged particles with velocities in a region of 0.1 c to 0.5 c. As an example, the structure was applied for various electron linacs both with on-axis electrical and off-axis magnetic coupling in a lower velocity region. Achieved accelerator performance makes the concept highly recommended for practical applications.

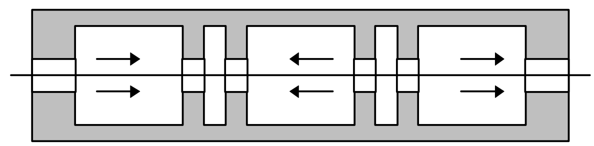
Introduction

As was described in earlier publications [1, 2, 3], the proposed concept combines the principle of standing wave coupled cavity structures with Alvarez structure, providing, therefore, a way to cover a range of charged particle relative velocity from 0.1 to 0.5, where standard coupled cavity structure is ineffective. In a period of approximately eight years from 1988 to 1996 the concept and properties of the proposed design were studied and two working electron linacs [3, 4] were developed. This concept is used to increase efficiency of particle capture and acceleration in the corresponding velocity range. In 1994, the concept and a similar structure called CCDTL was studied [5] as applied for proton and/or ion accelerator design by a group at Los Alamos National Laboratory. The concept has proved itself as vital for both electron and proton linacs and appears to be a powerful tool for microwave accelerator design.

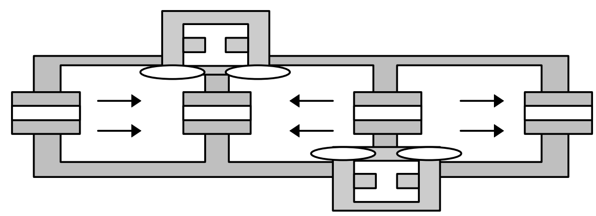
Description of Concept

The original patent [1] describes an improvement of an on-axis coupled regular or biperiodic resonant structure formed by the sequence of disk irises in a waveguide. This configuration is well known as disk loaded waveguide (DLWG). During operation in $\pi/2$ mode, every other cavity has an accelerating field component. Cavities between them play role of phase shifting, or coupling cavities.

In the case of the well-known side coupled structure, the coupling cavities are removed from the beam axis in order to increase the value of shunt impedance of the structure, as shown on Fig.1a and Fig.1b. Modification of the side coupled structure is made in a similar way [2].

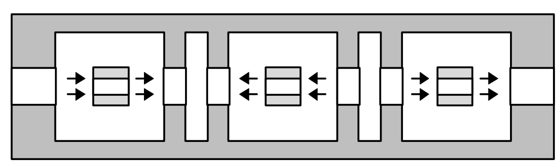


a. On-axis coupled structure

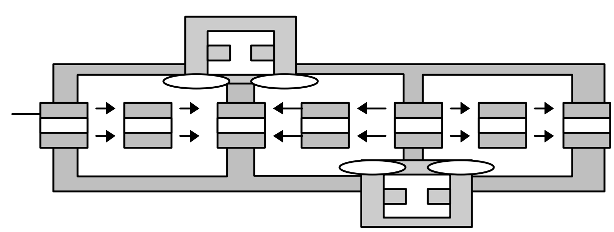


b. Side-coupled structure.

Fig. 1 Conventional biperiodic structures.



a. On-axis coupled structure



b. Side-coupled structure.

Fig. 2. Modified structures with a drift tube in the center of accelerating cavity.

An additional drift tube is introduced close to the center of an accelerating cavity, maintaining phase locked fields on both sides of the drift tube. Thus, fields on each side of the drift tube oscillate with phase shift Θ, equal to $2\pi n$, where n is integer. Coupling between the two newly formed cavities which form a single Alvarez resonator is very high to have a good mode separation. Phase shift between the neighboring Alvarez resonators remains equal to π, so that the structure conserves properties of a regular biperiodic coupled cavity structure.

This introduction, in fact, creates a sequence of Alvarez resonators, coupled to each other through the same coupling cavities, as shown on Fig. 2a and Fig.2b.

For the conventional structure, one can find the minimum theoretical particle relative velocity β_{min} when the corresponding accelerating gap, or a distance between two neighboring irises becomes equal to zero.

$$\beta_{min}=2\pi t/(\lambda\Theta), \qquad (1)$$

where λ - wavelength in free space;
t - iris thickness;
Θ - mode, or phase shift per cell, $\pi/2$ in this case.

It is assumed that when the accelerating gap is negligibly small, the period of the structure D remains constant along the central Z axis. Moreover, at particle velocities β close to β_{min} the accelerating cavities in the structures shown on Fig.1a and Fig.1b look nearly the same. The drift tube length (Fig.1b) becomes equal to the iris thickness, as for DLWG design (Fig1a). The problem of noticeable reduction of the structure efficiency in the range from 0.1c to 0.5c becomes more noticeable at a higher operating frequency, for example in X-band. Increasing the shunt impedance of the standing wave structures in the 10 GHz frequency range was one of the goals that stimulated this research.

Theoretical and experimental study of the concept

First description of the concept and study of the properties was made for the electrically on-axis coupled DLWG, shown on Fig.1a and Fig.2a in 1988. A certificate of invention [1] described the problem using a formula (1) and a concept of including a drift tube into the center of accelerating cavity creating a set of Alvarez resonators coupled to each other through coupling cavities which provide π phase shift between the neighboring accelerating resonators. Introduction of the tube permitted using the structure at the lower velocities. At the same time, quality of performance of the coupled cavity structure at $\pi/2$ mode was conserved. Therefore, it was concluded that this design provides a new, practical approach for accelerating charged particles at lower velocities from 0.1c to 0.5c. For an electron linac, it allows us to extend the practical range of injection voltages down to 2 keV and increase bunching and accelerating efficiency up to 80 keV. For a proton linac, it establishes the range of particle energy approximately from 5 to 150 MeV.

Reference to the side coupled structure shown on Fig.1b and Fig.2b, rebuilt in a similar way, was first made in 1992 [2].

As it was already mentioned above, the invention is particularly important for higher frequencies, where along with higher shunt impedance one faces the problems of higher attenuation and the difficulty of building cavities for accelerating low velocity particles.

Section with electrical on-axis coupling

The first working linac for accelerating electrons using the concept was built and tested in 1992 [2, 3]. It was designed for a 9.37 GHz magnetron. Detailed description of the studied structure and the linac was made in [2, 3], so we provide only a list of parameters.

Magnetron
Peak Power...0.5 MW
Frequency (tunable)...9368 MHz
Anode Voltage...25 kV

Section
Injection Energy...25 keV
RF Length...11.6 cm
Q...4000
Number Acc. of Cavities[1]..8

E-beam
Energy...0.7 MeV
Peak current..30 mA

A single cavity with a drift tube located in the center of the cavity formed an Alvarez resonator. A prototype of this cavity was modeled and studied before incorporating into an accelerator structure based on biperiodic DLWG design.

Because the study was made for the on-axis coupled structure shown on Fig.1a, shunt impedance was not outstandingly high, although much higher than for the conventional coupled cavity structures at the required injection energy of 25 keV, which corresponded to the magnetron anode voltage. For the chosen cavity configuration it was approximately 20 MOhm/m.

In order to provide strong coupling between the cavities on both sides of the incorporated drift tube, three kidney-shaped coupling slots were milled in the iris which supports the drift tube, leaving, therefore, three narrow stems holding the drift tube.
This mechanical interpretation was simple enough to use it in X-band and provide strong coupling and good heat

[1] - The first Alvarez-type two cell resonator is counted as a single cavity.

conduction from the central tube to the outer walls of the structure.

Section with magnetic off-axis coupling

A section using the side-coupled structure shown on Fig. 2b at 0.1c to 0.5c was built and tested for intraoperative e-beam therapy [4].

The structure has π phase shift between the accelerating cavities, provided by a side coupling cavity. The first accelerating cavity is a 3β/2, two-cell Alvarez resonator designed for 0 or 2πn (were n - integer) phase shift on two sides of a drift tube located in the center of the resonator. This drift tube separates the resonator into two accelerating cells which are very strongly coupled to each other. The drift tube is supported by three stems, formed by the borders between three kidney-shaped slots, as it was done in the structure shown on Fig.2a and tested before [3].

Even though the Alvarez resonator was not optimized, it has the shunt impedance of approximately 70 MOhm/m.

The injector voltage in this section can be regulated from 6 to 20 kV. The two-section linac (Fig. 3) is designed for energy 13 MeV and smoothly regulated from 4 to 13 MeV.

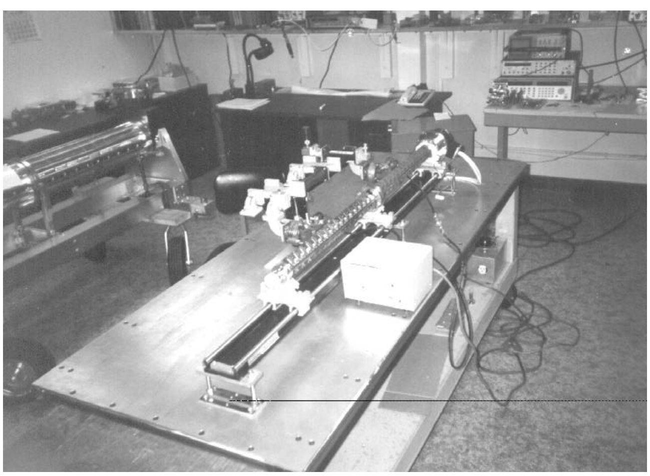


Fig. 3. Two-section linac built for intraoperative therapy. Modified side-couped structure with Alvarez resonator is incorporated into standard side-coupled structure.

Results of the low-velocity structure performance were successful. We have measured the capability of regulation of the injection energy from 6 to 13 keV with no substantial change in output beam current.

Recently, a detailed study of a similar structure using the proposed concept was made by a group at LANL . It was called CCDTL and described in application to ion linacs [5]. It was found that shunt impedance maximizes at 70 MOhm/m with average value of 50 MOhm/m in a range from 0.2c to 0.5c, measured at a frequency of 700 MHz. Converting this value of shunt impedance to X-band one can obtain approximately 150 MOhm/m.

Two stems were used to support the drift tube in the center of an accelerating cavity. This is a good decision for a lower frequency band, in particular at 700 MHz

The authors have confirmed the conclusion regarding the high potential of the concept, made in [1, 2, 3, 4]. They have made a series of calculations and measurements which are an important contribution to the concept. For example, a nice addition to the design was the introduction of a two drift tube, three- cell resonator.

Conclusion

The proposed concept [1, 2] describes a set of Alvarez resonators coupled with π phase shift through phase-shifting cavities. The concept establishes a structure which is highly efficient in the range of charged particle relative velocity from 0.1 to 0.5, where a standard coupled cavity structure is ineffective. In the period of eight years from 1988 to 1996 the concept and properties of the proposed design were studied and two working electron linacs [3, 4] were developed using this concept.

The concept raised interest in application to both electron and proton linac design. Recently, a similar structure called CCDTL was studied [5] and applied to ion accelerator design.

The author is planning to apply the structure to various linac designs [to be published].

References

1. A.V.Mishin, V.P.Komarov, Accelerating structure for a linear charged particle accelerator, Invention SU #1577678, 1990, priority from 1988.

2. A.V.Mishin, Ph.D. Thesis, Moscow Engineering Physics Institute, Moscow, 1992.

3. A.V.Mishin, Accelerator Structure for Low Energy Electron Beam, Proc. of the PAC93, Washington DC, p.p. 971-973, 1993.

4. A.V.Mishin, R.G.Schonberg, H.Deruyter, T.Roumbanis, Intraoperative X-band Accelerator Microwave Structure Design, Proc. of EPAC94, p.p. 2185-2187, London, 1994.

5. James H. Billen, Frank L. Krawczyk, Richard L. Wood, and Lloyd M.Young, A New RF Structure for Intermediate-Velocity Particles, Proc. of LINAC94, p.p. 341 - 345, 1994.