

HIGH-BETA LINAC ACCELERATING STRUCTURE

V.G.Andreev, G.I.Batskikh, B.I.Bondarev,
B.P.Murin

Moscow Radiotechnical Institute of Russian Academy of Sciences
Russia, 113519, Moscow, Varshavskoe shosse, 132

Introduction

At the present time the two sets of thotypical parameters of the proton high-current high-energy linac are considered. The first one with the beam energy of 1.5 GeV and average current of 0.3 A serves for the transmutation of long living radioactive wastes of atomic power engineering (ATW Program). The second one with the energy of 800 MeV and average current of 10 mA belongs to the conversion program ABC of war plutonium utilization. There are sets of parameters (for example one of Los-Alamos projects: 800 MeV, 140 mA), which occupy intermediate position within the aforementioned limits.

The basic problem for all parameter configurations is the selection of accelerating structure for high-energy linac part because this choice influence on linac manufacture, exploitation and reliability.

The D&W accelerating structure invented in MRTI was used in 100-600 Mev energy range for Moscow Meson Facility (MMF). This structure is also preferable for the above designs.

1. Comparison Between High-Beta Accelerating Structure

The main part of the burner-reactor linac used in the USA, Russia and Japan projects is based on resonators divided into sections with magnetic quadruple lenses (doublets or single) between them. Each resonator is fed from a separate generators.

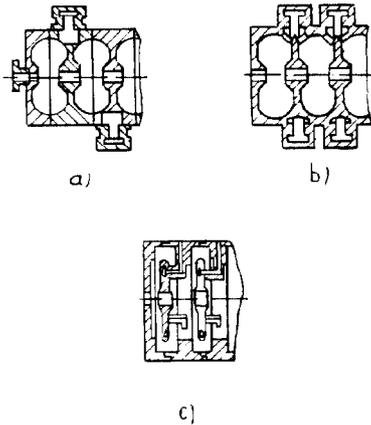


Fig.1
a) SCS b) RCS c) D&WS

In Fig.1 the three types of accelerating structures are shown: with side-coupling cells (SCS), with ring coupling cells (RCS), disk and washer structure (D&WS). All the structures operate at a $\pi/2$ wave, so that in neighboring accelerating cells RF fields have opposite signs.

These three structures have approximately the same value of shunt impedance. The disk and washer structure's effective shunt impedance as a function of beta is shown in Fig.2.

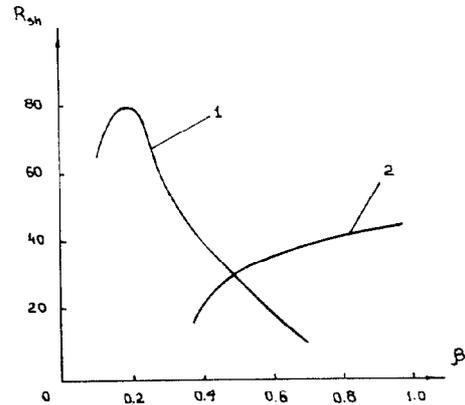


Fig.2
Shunt impedance of Alvarez (1) and D&W (2) structures as a function of beta

The coupling coefficient between the neighboring cells is an important characteristic of the accelerating structure. As it increases, sensitivity of the resonators accelerating field distribution to various perturbations (geometrical errors included) decreases. The combination of the two characteristics (shunt impedance and coupling coefficient) shows that the disk and washer structure is the most suitable for the main linac part. As it is clear from the Table 1, it has a number of advantages over other structures belonging to the same energy range [1,2].

The design of D&WS resonator is shown at Fig.3.

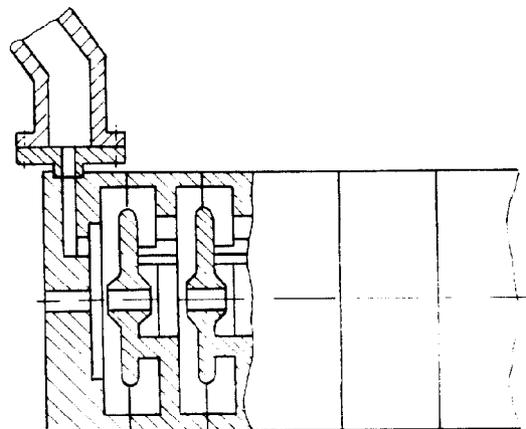


Fig.3.

Comparable Performances

Side Coupled Structure

D&W Structure

I. Coupling Coefficient

$K_c = 5\%$

$K_c = 30-50\%$

1. Highly sensitive to errors caused by manufacturing and inaccurate tuning.
2. Individual tuning of each cell ($\Delta f = \pm 30$ kHz)

The same sensitivity is less by 40-100 times.
The cavity may be tuned as a whole unit without tuning of separate cells. ($\Delta f = \pm 800$ kHz)

II. Efficiency of RF Power Use for Providing a given rate of acceleration

Approximately equivalent

III. Proximity of Parasitic modes

Parasitic modes in structure band are not available

Parasitic modes of the Moscow Meson Factory are spaced by $\pm(15-20)$ MHz out of operation frequency

IV. Bridging Devices

Mechanical rigid coupling with acceleration section: accuracy of manufacturing is about 0.01 mm.

Mechanical uncoupled with acceleration sections: accuracy of manufacturing is 2 ± 3 mm.

V. Vacuum conductance

Insufficient: Vacuum collector is required.

High: Vacuum collector isn't necessary

VI. Design and technology of manufacturing

It is complicated with regard to design and technology

Design and technology are simple.

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RCS has the same features

Besides many advantages, DaW structures in its initial variant had a defect which first seemed to be substantial and prevented its propagation. The fact is that the operational oscillations mode was surrounded with a number of parasitic modes having the azimuthal field variation. The frequency of which with the growth of b shifted, finding itself in close neighborhood or even coinciding with the operational frequency. Such neighborhood is extremely undesirable. In this case the operational mode frequency depends on the coupling with inoperational modes, the RF power losses in the structure grow, the operation of various automatic control systems is impeded, the beam stability is endangered and so on.

Shifting of inoperational oscillations frequency from the operational one was affected in a way, which did not cause field (frequency) perturbation of the operational mode, using combined slits (Fig.4), cut in washers [3].

Frequency spectra around the operational mode without slits (a) and with them (b) are shown in Fig.5.

Disk and washer resonators, consisting of four sections coupled with bridges, are used in the Moscow Meson Facility (MMF) linac. They ensure stable acceleration of the beam.

The resonators in the main part of the burner-reactor linac will consist of large number of sections coupled with bridges. For example in MRTI project the resonator consists of eight sections. Bridges are manufactured of pieces of standard waveguide with the rectangular cross-section (220×104 mm).

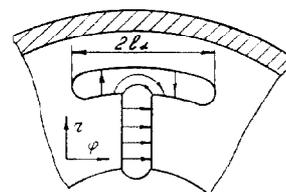
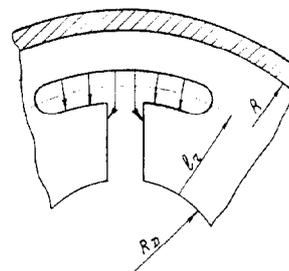


Fig.4
Excitation of combined slit electromagnetic oscillations with the help of operation wave (top) and parasitic wave (bottom)

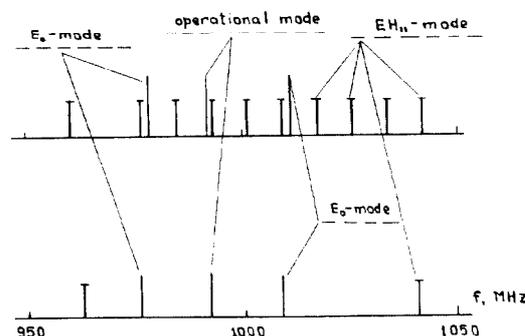


Fig.5
Resonator electromagnetic oscillation spectrum of D&WS before and after application combined slits into disk

The dispersion characteristic of a resonator (Fig.6), consisting of eight accelerating sections and seven bridges has fifteen oscillation modes, of which the two nearest to the operational one are spaced at 1 MHz from it, at a distance 8 times as large as the passband of a resonator with the lowest quality factor. It is quite enough to ensure the stable linac operation.

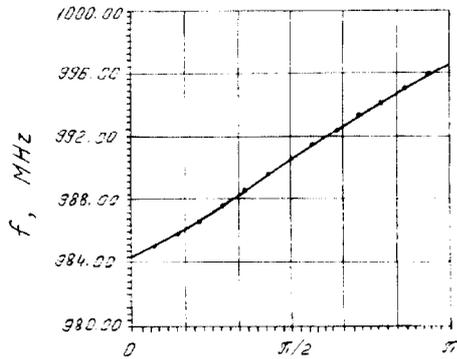


Fig. 6
Dispersion characteristic of resonator

The overall number of accelerating sections in the linac with the output energy of 1.5 GeV and acceleration rate 1 MeV/m is equal to 610, the number of resonators - 77, bridges - 540. The RF power of about 490-500 MW must be fed into resonators, of which 40-50 MW will be lost in resonators walls and 450 MW will be transferred to the beam.

For focusing in the main linac part are used 612 quadruple lenses of permanent magnets placed between resonators and their accelerating sections. Side by side with the FODO focusing structure which is taken as basis, FDO structure is considered too. Choice of the optimum structure will be made later.

Each resonator of the main linac part is fed from one regotron having seven energy outputs with the overall output power of 5 MW [3.5]. The typical linac module is shown in Fig.3 [2.3]. The module is designed to operate with energy gain of 15 MeV and cw current of 300 mA.

2. The Outlook for the Modification of the Main ATW Linac Part

Further modification of the main linac part (the increase of the focusing channel acceptance, facilitation of radiation pureness problem) may be ensured with the aid of superconducting solenoids and resonators not divided into sections.

The latest MRTI design is based on the proposals of 1972-1974 years, presented in [6.7], which show that focusing by a strong longitudinal magnetic field allows to increase the acceptance of the focusing channel with the same aperture and to reduce its sensitivity to random errors

The channel acceptance V is:

$$V = \frac{\nu_{\min} \cdot R^2}{L_f} \cdot \beta \gamma$$

where R is the channel aperture radius, ν_{\min} - minimum within the limits of a focusing period unitless transverse oscillations frequency, L_f - focusing period length, β - relative particles velocity, γ - relativistic factor.

With the strong longitudinal field focusing ν_{\min} is equal to 1.0-1.4, while with the quadrupole focusing this value does not exceed 0.6. Therefore the acceptance with the longitudinal magnetic field focusing is 1.5-2 times as large as that with the quadrupole focusing at the same channel aperture.

In the main part of the burner-reactor linac with quadrupole lenses focusing the average ν_{\min} is equal to 0.6. The transverse magnetic field focusing with the same channel

aperture ensures $\nu_{\min} = 1$. The increase of ν_{\min} by factor of 1.7 at the fixed beam emittance results in the reduction of its radius by 30%. The possibility of such a considerable decrease of the aperture radius allows either to improve radiation pureness of the main linac part or to decrease by 20% the RF power losses. With the focusing period length of 200 cm at the energy of 100 MeV and 350 cm at the energy above 600 MeV the magnetic field intensity will amount to 4-6 T. Solenoids producing such fields may be constructed only with the use of superconductivity.

The beam of particles in a channel with solenoids is less susceptible to random errors influence [5]. There are two variants of positioning superconducting solenoids:

1. Solenoids are placed between accelerating sections in the place of quadrupole doublets. The aperture of a "warm" solenoid is small and its construction is relatively simple.

2. Solenoids are ring-shaped with big "warm" aperture inside which is placed the accelerating structure. Though such a structure is unwieldy, this variant is attractive, since the accelerating focusing channel acquires a number of useful qualities:

a) Absence of coupling bridges between accelerating sections increases the coupling coefficient for DaW structure up to 50%. The nearest to the operational mode couple of side modes is shifted away from it by about ± 2 MHz (instead of 1 MHz in an 8-sectioned resonator).

b) Overall reduction of RF power losses in the accelerating structure amounts to 10% as compared with an 8-sectioned resonator having the same aperture radius.

c) Owing to the absence of spaces between accelerating sections, the main linac part length gets shorter by about 25%.

d) The focusing periods length may be chosen irrespective of the length of accelerating sections, which allows to prevent the beam radius growth caused by abrupt changes of focusing period length in those places where the accelerating field frequency or focusing channel structure are changed.

References

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