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THE PROSPECTS FOR SMALL-GAP RESONATORS BASED ON COMBINED RF FOCUSING FOR USE IN PROTON LINACS

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For high-current ion linacs operating over the medium energy range, the use of an accelerating structure that implements combined rf focusing (CRFF) is suggested. Considered is the focusing provided by short IH-, CH-, and two-gap spoke cavities. The absence of external focusing elements and the structural simplicity of the proposed resonators makes them promising for use in accelerators operating in continuous or low-duty mode, which are built on superconducting cavities.

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INTRODUCTION

Nowadays, when designing a high-current ion linear accelerator, close attention has been given to small-gap resonators with focusing elements such as solenoids, magnetic quadrupole lenses, etc., placed between them (see Refs. [1, 2]). In the case of a superconducting structure, the accelerating field magnitude can reach up to 400 kV/cm, however, the presence of external focusing elements complicates the accelerator design.

To simplify the focusing system of the high-current ion linac that operates at 10…100 MeV energy range, it is proposed to use the small-gap cavities with combined rf focusing implemented. CRFF does not need any external focusing devices (see Ref. [3]). Structurally, the CRFF system is a combination of axisymmetric and quadrupole gaps. So, to implement this kind of focusing in the accelerating structure it is sufficient to introduce some extra rf quadrupole gaps into the structure. In this paper, several small-gap resonators for CRFF are considered.

MODIFICATIONS OF SMALL-GAP CAVITIES FOR CRFF

In Ref. [4], the accelerating channel of intermediate part of the high-current proton linac based on CRFF has been presented. Following are the main parameters: the energy range – 3…100 MeV, the operating frequency – 350 MHz, the acceleration rate – 5 MeV/m. The accelerating-and-focusing period has the ODDOOOFFOO lattice (with O representing the axisymmetrical gap, F is the accelerating period with the focusing quadrupole that focuses in the transverse direction (say, along the *X*-coordinate in Cartesian system with Z being the beam propagation direction), and D standing for the defocusing segment), as shown in Fig. 1,a.

The accelerator is comprised of the following parts:

– the ion source delivering a 100 keV beam energy and the beam formation system;

– the RFQ unit yielding the output energy about 3 MeV (see Ref. [5]);

– the CRFF sections based on multi-gap IH-cavities, the output energy is 20 MeV (see Ref. [6]);

– the CRFF sections based on multi-gap CH-resonators, the output energy is 100 MeV (see Ref. [7]).

When using the small-gap cavities, the accelerator structure can be presented as following:

– the ion source, the output energy is 100 keV;

– the RFQ unit yielding the output energy about 3 MeV;

– the long accelerating IH-structure with CRFF, the output energy is up to 10 MeV;

– the small-gap IH-resonators with CRFF, the output energy is about 20 MeV (Fig. 2);

– the small-gap CH-cavities with CRFF (Fig. 3) or the accelerating-and-focusing segments consisting of conventional two-gap spoke resonators and two-gap spoke resonators with quadrupole symmetry (Fig. 4).

It is suggested to use the short resonators starting from the energy 10 MeV. In this energy range, it is convenient to make use of the accelerating-and-focusing period with the OOFFOOOODDOO lattice (see Fig. 1,b).

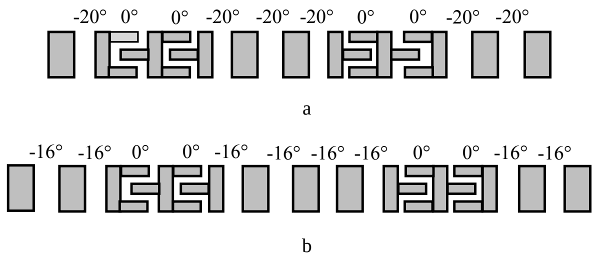

Fig. 1. Layout of the 10-gap (a) and 12-gap (b) accelerating-and-focusing period with CRFF together with the synchronous phase distribution

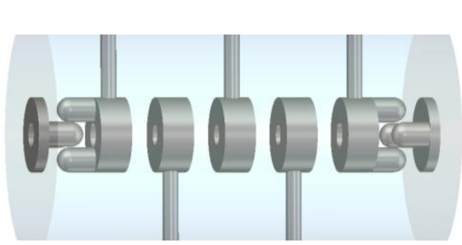

Fig. 2. Six-gap IH-cavity with CRFF

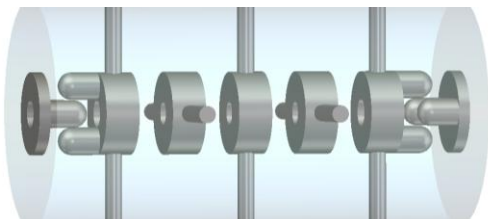

Fig. 3. Six-gap CH-resonator with CRFF

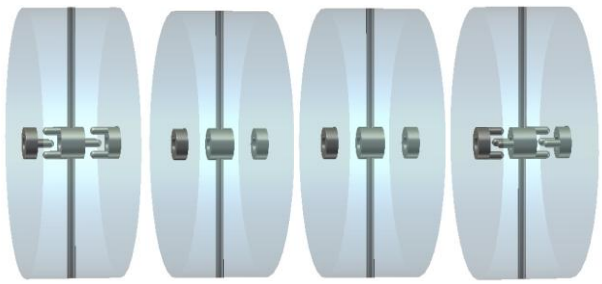

Fig. 4. The accelerating-and-focusing segment with CRFF consisting of two-gap spoke resonators

To simulate the accelerating-and-focusing channel of the accelerator intermediate part with CRFF and beam dynamics within it, the APFRFQ code was used. Following are the main parameters: the energy range is 10…100 MeV, the operating frequency is 350 MHz, the channel of 166.8 m in length is divided into 122 accelerating gaps, and the aperture radius varies from 0.8 to 1.2 cm. The channel is divided into 10 focusing segments. Fig. 1,b presents the structure of the focusing segment. Each focusing segment consists of 12 accelerating gaps, 8 of which are axisymmetrical and 4 – RFQ. The focusing segment is a dual quadrupole. The electric field maximum of 160 kV/cm is on the axisymmetrical gap axis. The average field gradient over the quadrupole gap is 165 kV/cm^2. The aperture radius of the channel is determined by the field gradient providing the necessary electrical strength of the gap. The electric field intensity maximum on the electrode surface is adopted as the criterion of electrical strength. In calculations, it is assumed to be of 366 kV/cm or 2K_p (K_p is Kilpatrick criterion) (see Ref. [8]).

To account for the space-charge effects, a macroparticle (particle – particle) method involving 10000 simulation particles was used. Fig. 5 presents the main input and output parameters calculated at 100 mA injection current. Table lists the main calculated quantities for the accelerated beam: ε_x(rms), ε_y(rms) – the normalized rms beam emittance in the XX′ and YY′ plane respectively; ε_x(97%), ε_y(97%) is the normalized beam emittance enveloping 97% of particles in the XX′ and YY′ plane respectively. The beam transmission coefficient is 100%.

Input and output beam emittances

Input (energy 10 MeV)			
ε_x(rms) mm·mrad	ε_x(97%) mm·mrad	ε_y(rms) mm·mrad	ε_y(97%) mm·mrad
0.305	1.674	0.297	1.630
Output (energy 100 MeV)			
0.355	2.346	0.351	2.107

The calculated peak pulse proton current generated in the CRFF-based accelerator is at least 300 mA (see Refs. [3, 9]). As of today, the peak current registered in the RFQ-structure is about 150 mA. Therefore, the CRFF-based accelerator is capable of capturing and accelerating with no losses almost any current generated in the initial part of any modern accelerator operating over the medium energy range.

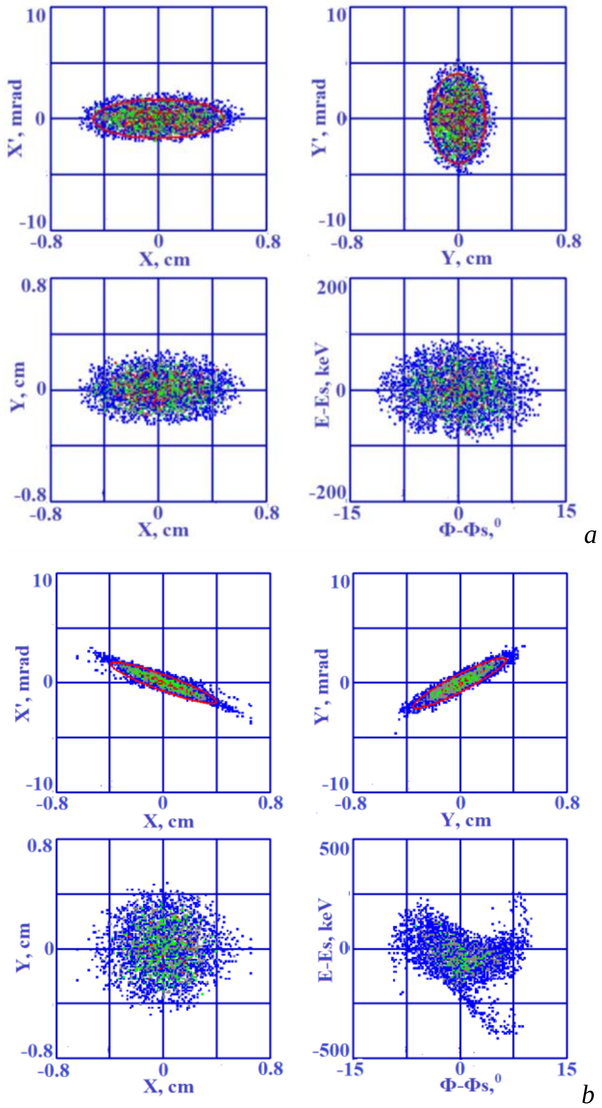

Fig. 5. Beam characteristics, output energy 100 MeV at 100 mA injection current: input (a); output (b)

CONCLUSIONS

The absence of the external focusing elements and the structural simplicity of the proposed small-gap resonators for CRFF makes them promising for use in accelerators operating in continuous or near-continuous mode over the medium energy range. In this case, to build the accelerating-and-focusing channels, a modular principle can be applied, in which the accelerator consists of several groups of the identical resonators. As for the resonators, it is convenient to realize those using already developed and studied cavities and introducing the additional gaps with the quadrupole symmetry of the accelerating-and-focusing field.

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REFERENCES

1. S.M. Polozov, A.D. Fertman. Uskoriteli protonnogo puchka bol'shoi moschnosti dlya podkritichnykh yadernykh ustanovok // *Atomnaya Energiya*. 2012, t. 113, v. 3, p. 155-163 (in Russian).
2. A.E. Aksent'ev i dr. Razrabotka kontseptsii uskoritelya-draivera protonnogo puchka na energiu 600-1000 MeV pri srednei moschnosti puchka bolee 1 MW // *Atomnaya Energiya*. 2014, t. 117, v. 4, p. 270-280 (in Russian).
3. S.S. Tishkin. Combined focusing by RF-field for ion linac accelerators // *The Journal of Kharkiv National University. Physical Series "Nuclear, Particle, Fields"*. 2008, № 808, Issue 2(38), p. 37-46.
4. S.S. Tishkin, N.G. Shulika, O.N. Shulika. An accelerating channel of intermediate part of high-current proton linac based on combined focusing by rf field // *Problems of Atomic Science and Technology. Series "Nuclear Physics Investigations"*. 2020, № 3, p. 3-6.
5. I.M. Kapchinski and V.A. Teplyakov. Lineiny uskoritel' s prostranstvenno-odnorodnoi zhestkoi fokusirovkoi // *Pribory i technika experimenta*. 1970, № 2, p. 19-20 (in Russian).
6. P.M. Zeidlits, V.A. Yamnitskii. Accelerating systems employing H-type waves // *J. Nucl. Energy, Part C*. 1962, v. 4, p. 121.
7. U. Ratzinger, R. Tiede. Status of the HIIF RF linac study based on H-mode cavities // *Nucl. Instrum. Methods Phys. Res. Sect. A*. 1998, v. 415, p. 229-235.
8. W. Kilpatrick. Criterion for vacuum sparking designed to include both RF and DC // *Rev. Sci. Instrum.* 1957, v. 28, № 10, p. 824-826.
9. S.S. Tishkin, N.G. Shulika, O.N. Shulika. Coulomb limit for accelerating current in a linac accelerating channel with combined rf focusing // *Problems of Atomic Science and Technology. Series "Nuclear Physics Investigations"*. 2020, №3, p. 94-96.

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ПЕРСПЕКТИВА ВИКОРИСТАННЯ МАЛОЗАЗОРНИХ РЕЗОНАТОРІВ З КОМБІНОВАНИМ ВЧ-ФОКУСУВАННЯМ У ЛІНІЙНИХ ПРИСКОРЮВАЧАХ ПРОТОНІВ

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Для великострумових лінійних прискорювачів у середньому діапазоні енергій запропоновано використання малопроміжкових прискорювальних структур з комбінованим ВЧ-фокусуванням. Розглянуто схему реалізації даного типу фокусування на основі коротких ІН-, СН- та 2-gap spoke резонаторів. Відсутність зовнішніх фокусувальних елементів та конструктивна простота запропонованих варіантів робить їх перспективними при використанні у прискорювачах, що працюють у неперервному режимі або режимі з малою скважністю, які побудовані на надпровідних резонаторах.

ПЕРСПЕКТИВА ИСПОЛЬЗОВАНИЯ МАЛОЗАЗОРНЫХ РЕЗОНАТОРОВ С КОМБИНИРОВАННОЙ ВЧ-ФОКУСИРОВКОЙ В ЛИНЕЙНЫХ УСКОРИТЕЛЯХ ПРОТОНОВ

С.С. Тишкин, Н.Г. Шулика, О.Н. Шулика

Для сильноточных линейных ускорителей в среднем диапазоне энергий предлагается использовать малозазорные ускоряющие структуры с комбинированной ВЧ-фокусировкой. Рассмотрена схема реализации данного типа фокусировки на базе коротких IH, CH, и 2-gap spoke резонаторов. Отсутствие внешних фокусирующих элементов и конструктивная простота предложенных вариантов делает перспективными их использование для ускорителей, работающих в непрерывном режиме или режиме с малой скважностью, построенных на основе сверхпроводящих резонаторов.