Study of RFQ Accelerating Structures Based on Multi-conductor Resonators

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An analytical method which treats the radio-frequency quadrupole (RFQ) accelerating structures based on 4-rod configuration of electrodes has been developed. A new electric-field potential function in RFQ-channel with 4-rod configuration of the electrodes has been formulated for analytical study of effects of the intrinsic field distortion. Modifications of 4-rod RFQ structure and a new multiple-beam RFQ structure have been suggested.

Keywords : Linear accelerator (linac)/ Beam dynamics/ Resonance/ Resonator/ Multiple-beam RFQ

Radio-frequency quadrupole (RFQ) accelerating structures based on 4-rod configuration of electrodes are widely used in linear accelerators. We have developed a theoretical model of the RFQ resonators with 4-rod configurations [1-5]. It advances a conceptual design study of both beam dynamics and resonance structure in the 4-rod RFQ or multi-rod RFQ system.

The general concept of the 4-rod RFQ structures is shown in Fig.1. The 4-rod RFQ resonator consists of four longitudinal electrodes connected with a tank by transverse conducting stems. The resonator is simulated as a set of four conductor shielded transmission lines (4CSTL) connected in a cascade manner by coupling network (see Fig. 2). It was shown [1,3], that any field in a 4-rod RFQ resonator is expressed as a superposition of four normal modes propagating in the 4CSTL. Figure 3 shows the E-line patterns of four normal modes.

Qualitative analysis of 4-rod RFQ resonators has been done [3]. The examples to reconstruct the RFQ

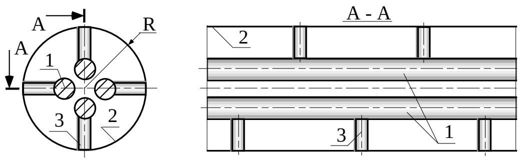

Figure 1. General concept of the 4-rod RFQ structure: 1 is a quadrupole electrode; 2 is a tank; 3 is a transverse stem.

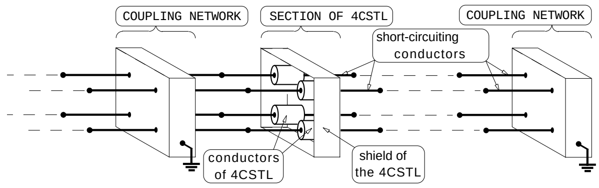

Figure 2. Block diagram of the equivalent circuit of an RFQ resonator having a 4-rod configuration of the electrodes.

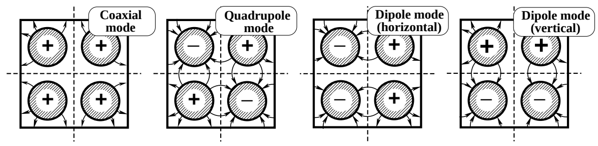

Figure 3. The E-line patterns of normal modes.

NUCLEAR SCIENCE RESEARCH FACILITY — Beams and Fundamental Reaction —

Scope of research

Particle beams, accelerators and their applications are studied. Structure and reactions of fundamental substances are investigated through the interations between beams and materials such as nuclear scattering. Tunable lasers are also applied to investigate the structure of unstable nuclei far from stability and to search for as yet unknown cosmological dark-matter particles in the Universe.

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fields from the results of the normal mode analysis have been presented in [2, 3]. They are in good agreement with numerical calculations done with MAFIA code.

Formulas for the resonance frequency, flatness of the longitudinal voltage distribution in RFQ-channel, RF power, Q-value and the specific shunt impedance have been obtained. They are in agreement with MAFIA calculations and experimental data.

A new formulation [5] for an electric-field potential function in RFQ-channel with 4-rod configuration of the electrodes has been developed for analytical study of effects of the intrinsic field distortion. The electric-field potential function is expanded into four components corresponding to four normal modes. With this function, an analytical study of beam dynamics for typical RFQ-channels with the free-space wavelength λ of 2 m has been made in case of the periodical accelerating structure (see Fig.4). Dependence of beam oscillations on the length of the resonator period l_p has been analyzed including distorted fields. At a long period of the resonator ($l_p/\lambda > 0.1$), resonances of beam oscillations have been found. It has been confirmed by numerical simulations. Under the resonance condition with the field distortion of 5%, the beam transmission degrades from 95% to 60% (see Fig.5).

Two modifications of 4-rod RFQ structure (with incorporated quarter-wavelength matching section and with frequency variation) has been proposed on the base of the normal mode technique [2].

There are applications, which require MeV-range broad beams, e.g. heating of plasmas in confinement devices and ion implantation. The broad-beams are formed as multiple-beams consisting of an array of identical beamlets. The beamlets should be packed very closely. We have concluded that a simple extention of the usual design principle from a single-channel RFQ to a multiple-beam RFQ (MB-RFQ) reduces a packing factor considerably, since adjacent RFQ electrodes can not be interconnected at any point.

To preserve a high packing of beamlets, a new MB-RFQ accelerating structure arranged as a matrix-array of the electrodes has been suggested [4] (see Fig.6). This structure is based on a new combination of normal modes and allows discrete connections of adjacent electrodes. The beam dynamics in RFQ-channels is modified. Beams perform "slalom" motions, utilizing intrinsic transverse oscillations. Figure 7 shows the example of the beam-structure and the electrode profiles in the X0Z-plane. The analysis of this system is in progress.

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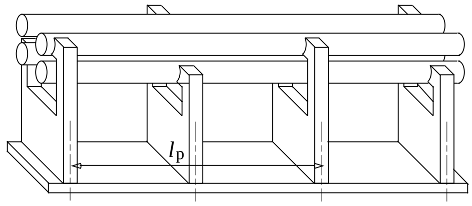

Figure 4. Schematic diagram of the periodic 4-rod RFQ.

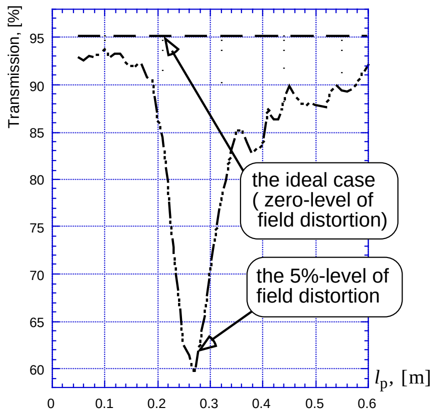

Figure 5. Transmission efficiency as a function of the structure period l_p.

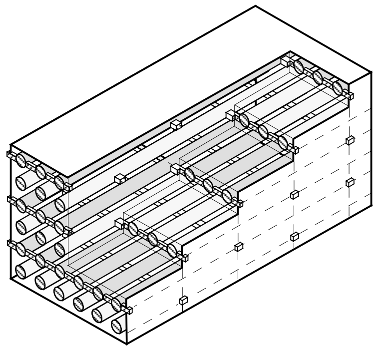

Figure 6. MB-RFQ resonator with a 6x6 matrix array of the RFQ-electrodes.

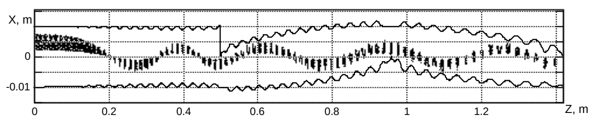

Figure 7. The cross-section of the RFQ-channel showing the beam structure and the electrode profiles.

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