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IFMIF Accelerator RF systems Conceptual Design

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ABSTRACT

Analysis of segmented RFQ electro-dynamical properties and the conceptions of RF systems design with directional selective coupling principle for excluding different type transmission lines long feeders, undesirable modes eliminating under intense beam acceleration, matching of RF source, producing of RF control system supporting signals, accelerating structures fine tunings with electro-optical method are considered.

1 Introduction

The IFMIF [1] high duty deuteron linear accelerator specifications (40 MeV for intense 125 mA beam) cause special requirements on accelerating structures and all the RF systems design. Apart from the ordinary constructing of high power feeders, matching RF source nonreciprocal devices and coupling elements design the application of four-vane RFQ for initial acceleration sets the problem [2,3] of undesirable modes eliminating (stabilizing) and the structure precise tuning. At the advanced segmentation principle [4,5] application for relatively long RFQ structure design the operating mode special features must be also considered. Presenting RF system conception allows to obtain simultaneous solution of these problems for RFQ and for the second stage DTL accelerators instead of traditional separate consideration.

2 RFQ segmentation

According to the method of RFQ modes analysis [6] all quadrupole modes are delivered at electric (ideal metal) walls setting in Π' and Π'' symmetry planes, and the longitudinally equidistant arrangement of two identical cuts of the vanes yields the symmetry conditions for electric or magnetic walls placing in these cut's midpoint $z = z_s$, Fig. 1; operating mode is delivered at electric walls¹. The mode properties do not depend on presence of thin coupling plate (Fig. 1 in [4]) in this position, however, the second mode (magnetic walls in the midpoints)² ones will be dependent greatly. In contrast, the influence of the cut size on the mode frequencies splitting is rather weak,

¹It is indicated by [4] description of magnetic field configuration in undercuts region.

²This mode is considered as the operating one in [5].

vanishing for long segments. Radial quasi-TEM wave in four identical shortcircuited inhomogeneous coaxial (quasi-rectangular) transmission lines, loaded by electrode end – inter-wall corner capacitances, forms operating field; the voltages between the ends of the vanes in any radial cross-section do not depend on the cut size and are equal to inter-vane ones, so it is alternating signs mainly longitudinal field in the midpoint region with zero field on the axis.

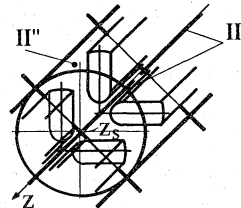


Fig. 1. Inter-segment gap in segmented RFQ.

Minimal distortion of the beam dynamics by the gap field can be obtained at the symmetrical field distribution, that leads to the gap design in electrodes without modulation region: p intervals on Fig. 2.

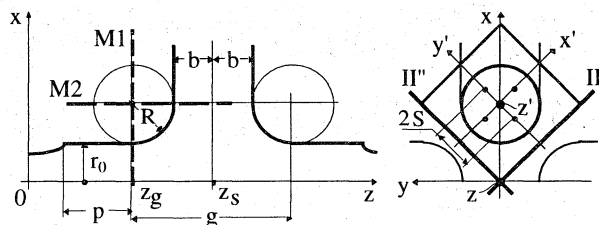


Fig. 2. Gap forming elements.

In this case the focusing quadrupoles will be added before and after the gap with alternating mainly longitudinal field in accelerating bore; p intervals can be different in the first and the second gap for the different accelerating conditions. Requirements on electric strength constrain desirable minimization of the gap size and the same strength as in the main RFQ part can be realized under spherical shape of the vane cor-

ners and rounded edges at $b = ((r_0 + R)/\sqrt{2}) - R$.

Transverse field orientation in p interval at the beam aperture bounded region consideration allow to place magnetic walls $M1$ and $M2$, Fig. 2, so the gap field is continuous extension of the sphere in cube field in $x \leq r_0 + R$, $z_g \leq z \leq z_s$ space. Mirror image's method for this electrostatic problem solution at symmetrical set - one charge in the center with six symmetrically disposed on x', y', z' axes at S distance ones - provides the desired continuation. The cube walls images potential evenness and permutative invariance refer to x', y', z' allow to use boundary conditions only in three points on the sphere surface for determination of S and charges values; with the equivalence of the sphere and uninterrupted electrode potentials condition it yields g interval field result, which is convenient for PARMTEQ code [7] modification.

3 Directional selective coupling

3.1 RF system

Four loops feeding of RFQ segments gives the possibility for the directional selective coupling principle [6] application: the RF system contains three 3 db directional couplers $D1 - D3$, equal length feeders $l_1 - l_4$ and $l_5 - l_6$ to attain equal amplitudes cophased excitation at equal coupling loops spaces in each segment; feeders-loops matching on operating mode results in full decoupling of matched loads $c1 - c3$, Fig. 3.

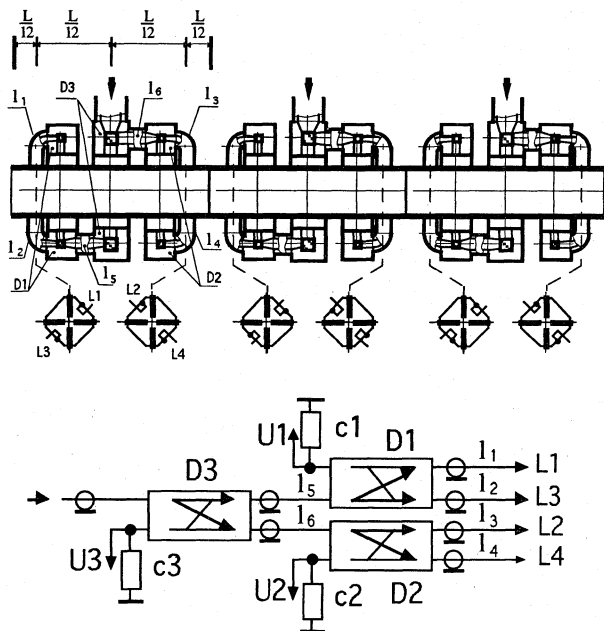


Fig. 3. RF system (not uniform longitudinal scale, L - total length).

Lowering of the undesirable modes quality factors is effective for intense beam, [6], so the dipole stabilizer rods (Fig. 1 in [4]) can be excluded. Under the ring bridges installation on each segment in three cross-sections the majority of the different types long feeders will be excluded also. Bridge's realization on square coaxial line is a simplest, central diameter will be about $0.8M$ and there will be enough space between RFQ and the bridges for the square line with accordant electric strength; l_5, l_6 feeders will be about $1M$ length, and $l_1 \dots l_4$ lengths - 20 cm, Fig. 3. At the beam excitation the loads remain decoupled at operating mode but undesirable modes are loaded on appropriate loads $c1 \dots c3$ (the maximum loading is attained just at 3 db transient attenuation of the couplers), while RF source is decoupled from these modes; the nearest nonexcluded mode will be 9 longitudinal alternation's quadrupole. In addition, the system assures RF source matching - e.g., in damage case in one of $l_1 \dots l_4$ feeders or a loop breakdown the source feeder SWR will be 1.4 for vanishing $l_1 \dots l_6$ lengths and correlation of the high level signals $U1 - U3$ determines the damaged channel; in operating conditions any deviations from amplitude's equality of these low signals detect the operating mode asymmetry.

Real system loops can not be absolutely equal, so the signals are in proportion to the resonator reflectance; $U1, U2$ and $U3$ phases form supporting for automatic control system phase-lock loop. For all that, any frequency differences between operating and eliminating modes and even their coincidences are admissible at least over the directional coupler's frequency band, the couplers central frequencies must be on the quadrupole mode resonance for additional loading minimization.

A high degree of precision is not required for the system components realization even for long $l_1 \dots l_6$ feeders case; undesirable modes levels proved to be not more than -36 db at [6] experiments. Supplementary lowering of the quality factors (10 - 20 times) is obtained at mismatched loads $c1 \dots c3$; e.g., for short $l_1 \dots l_4$ feeders the $c1, c2$ resistance must be greater than the wave impedance and usually applied circulator will assure the matching in damage cases.

3.2 RF tuning

The strong advantage of [4] principle is possibility of fabricating of relatively short segment RFQs, those can be tuned separately under the real shortcircuiting plates setting in the segment cut's midpoint $z = z_s$, Fig. 1. At accordant turn of the system Fig. 3 loops any desired well-definable mode will be excited and the segment field symmetrization can be carried out by the adjacent dipole modes degeneration features [6]; in this case decoupled tuning elements at

the vane's undercuts are to be provided.

Determination of the quadrupole field symmetry axis positions (the [6] method accuracy is about 10 mkm) gives the means for exact connection of the tuned segments; under the precise tuning method [8] application the accuracy will be about 4 mkm. The p spaces on Fig. 2 can be used for muster gauges or contact optical targets installation, which gives a convenient way for precise forming of the datum axis at RFQ segment field fine tuning and especially for the desired setting in coincidence the symmetry axes. Connected segments field symmetry can be also examined by the degeneration features and the exactness of each coupling loop tuning can be examined on quadrupole mode resonance at matched-loaded the rest eleven loops by $SWR=23$ value verification.

Electro-optical measurements for desired implementation of RFQ vane ends modulation can be combined with the axis determination procedure under equipotentials detecting principle by the means of doubled length lighted strip rotation on the round photoconductor plate, Fig. 1 in [8]. This principle at DTL tuning for precise measurements of acceleration period positions is realized by full lighting of the same round plate at minimal lighted - unlighted frequency deviation positions detecting inside the drift tubes. Autoreflexion method with [8] optical system gives several micrometer's accuracy at the tubes geometrical symmetry axis determination, and the field measurements in acceleration gaps and in ramp-field regions can be carried out by thin longitudinal photoconductor cylinder with full lighting.

4 Conclusion

Conception of directional selective coupling principle application for segmented RFQ accelerating structure has been developed. The same conception can be applied for Alvarez-type DTL feeding or especially for advantageous H-type DTL.

Analysis of segmented RFQ operating mode allowed to estimate the accelerating bore field distribution and the electrodes possible shapes in intersegment gape regions. However, it is necessary to prove the proper beam particles dynamic possibility for this quadrupole with mainly longitudinal fields in the gaps. Electrostatic approximation of these fields for computer simulation of the beam dynamics is proposed.

The devised RFQ and DTL precise tuning methods are provided by projections forming and measuring optical system under electro-optical principle application.

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