Proposal of Effective Compact Accelerating Structures for Heavy Ions

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The well known interdigital IH structure is now widely used for acceleration of heavy ions in low β range. Using the main idea of the IH cavities - transformation of the transverse rf voltage into longitudinal accelerating one, but differing in realization of this principle, several rf structures are considered. In comparison with the IH cavities, the proposed versions originally have practically uniform field distribution along beam axis and no problems with end walls. With the small outer tank diameter, the effective shunt impedance is high enough. The design of the structures and preliminary results of optimization are presented.

INTRODUCTION

For acceleration of charged particles in low velocity range ($\beta \leq 0.1$) it is usually to apply InterDigital structures (ID). Let remember the main idea of the ID. There should be two conductors (electrodes) parallel to the beam axis. If one will supply rf voltage to these conductors, then rf electric field will be generated between electrodes, perpendicularly to the beam axis and no acceleration is possible. But, if drift tubes trough short stems will be connected to these conductors in turn, then rf voltage will be between drift tubes, generating longitudinal accelerating field. So, drift tubes convert 'perpendicular' rf field into 'longitudinal' one.

Let remember the idea of another classical device – Radio Frequency Quadrupol (RFQ). There should be four conductors (electrodes) parallel to the beam axis. To provide quadrupol electric field distribution, one needs to supply rf voltage with opposite signs to neighboring conductors.

In the complete device there should be not only conductors, but also the resonant system to provide rf voltage between conductors. RFQ and ID structures differ in the utilization of the rf voltage, but may be very similar in resonant system to provide it.

1. DIFFERENT RESONANT SYSTEMS

The resonant systems both with distributed electrodynamic parameters and with lumped ones may be used both for RFQ and ID realizations.

1.1. H-type cavities

H-type cavities are now well known both for RFQ and for ID (IH structure). The example of application practically the same (in design) cavity both for IH and for RFQ is given in [1].

H-cavity is the system with distributed magnetic field, instead of the electric field is strongly concentrated between conductors. The original mode can not exists without variation along the cavity length. To equalize field distribution, one should provide undercuts in vanes and girders near end plates. For short cavities, when the cavity length is comparable with the cavity diameter, additional rf losses in end plates, where magnetic flux turns, lead to the reduction in shunt impedance. Nevertheless, IH structure is good investigated, developed, there are solutions for problems and question is only price of solutions.

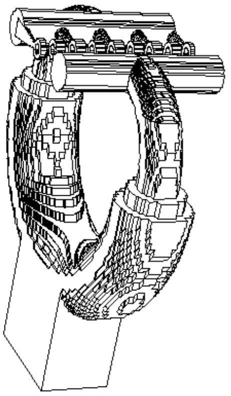

Figure 1: The Split Ring Interdigital Structure. The outer cylindrical wall is not shown.

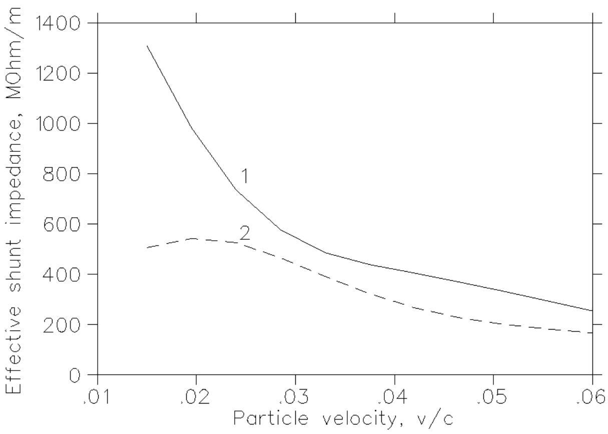

Figure 2: Z_e^r of the SRIS. 1 - for $\beta \leq 0.03,\ 2a = 1.0cm, \beta \leq 0.05,\ 2a = 1.4cm, \beta \leq 0.06,\ 2a = 1.6cm$; 2 - for $2a = 1.4cm,\ 2r_t = 3.0cm,\ 2r_c = 3.0cm$.

1.2. Split Ring Resonant System

In resonant systems, which are more close to quaterwave oscillators, both for RFQ and ID applications, conductors provide the capacitive part and one needs only add inductive part to complete the resonant circuit. Different solutions for inductive part are possible.
The Split Ring RFQ cavity is considered in [2]. We propose the Split Ring Interdigital Structure (SRIS), Fig. 1.

The length of the module L_m is the subject for choice and depends on tolerable tilt in difference of rf potential between electrodes. The potential difference between conductors is larger and the end of the module then in the middle, where conductors are connected to the ring. This tilt depends on L_m and capacitive loading due to drift tubes. The capacitive loading due to drift tubes depends on number of drift tubes per unit length and dimensions of drift tubes. The results of numerical simulations shows, that for $L_m \approx 0.06\lambda$, where λ is the operating wavelength, this tilt is less than 2% for $0.015 \leq \beta \leq 0.06$ and any reasonable tube dimensions. With increasing L_m the tilt rise very fast, especially for higher β (to $5\% \div 15\%$ for $L_m \approx 0.12\lambda$), providing upper limit for L_m.

The SRIS has high effective shunt impedance. The dependencies of Z_e^r vs β are shown in Fig. 2. All results of numerical simulation are given (if it is not defined specially) for operating frequency $f_0 = 105MHz, L_m = 0.06\lambda$, drift tube diameter $2r_t = 2a+1.0cm$, where $2a$ is aperture diameter and conductors diameter $2r_c = 3.8cm$. The SRIS cavity diameter $2R_c$ slightly rise from $2R_c = 52cm,\ \beta = 0.015$ to $2R_c = 62cm,\ \beta = 0.06$.

1.3. Post Resonant System

The Post RFQ cavity was realized [3] in Variable Energy RFQ option. With movable plate one can change effective length of the posts, changing the resonant frequency and, as the result, changing designed β for the cavity. The Post Interdigital Structure (PIS), Fig. 3, also permits such option with the same question in rf contact between the plate and the posts. At the Fig. 3 one half of the structure period (from the middle of one post to the middle of next) is shown. In comparison with SRIS, PIS has smaller cavity diameter ($2R_c = 40cm, \beta = 0.02$). Effective shunt impedance remains high ($Z_e^r = 687M\Omega/m,\ \beta = 0.02,\ 2r_a = 1.0cm$).

1.4. Spiral Resonant System

The spiral cavities for RFQ applications are considered in [4]. Following to our approach, the Spiral Interdigital Structure (SIS) may be developed. One can imagine transformation of all posts in PIS (Fig. 3) into spirals, resulting in spiral-type resonant system. This structure has smallest cavity diameter in comparison with SRIS and PIS. For operating frequency $f_0 = 105MHz$ the cavity is diameter very small, providing difficulties with placement of conductors and drift tubes. For this structure frequency range $20 \div 60MHz$ is more comfortable. In comparison with resonant systems "one turn of the spiral to one drift tube", SIS has essentially higher Z_e^r value.

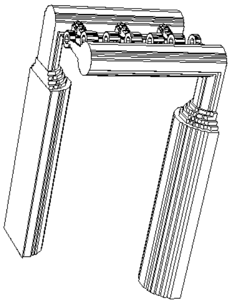

Figure 3: The Post Interdigital Structure. The outer cylindrical wall is not shown.

DISCUSSION

All stuctures considered above have very high Z_e^r (Fig. 2). To get it, one should minimize capacitive load. In all calculations simple cylindrical drift tubes were considered with gap ration $\alpha = 0.5$. In reality, the shape of the drift tube should be chosen as the compromise to minimize maximum electric field on the surface E_s, to minimize capacitance (taking into account the stem for support) and to have large transit time factor T. Diameter of conductors should be as small as possible but providing possibility for cooling chanel inside. Distribution of rf losses at elements differs no so strong for different structures. For $L_m = 0.06\lambda$ rf losses at drift tubes (including short stems) are $\approx (5\% \div 8\%)$, at conductors — $\approx (20\% \div 28\%)$, at the cylindrical wall — $\approx (14\% \div 20\%)$. Main part of rf losses takes place at the ring (SRIS), post (PIS) or spiral (SIS). It is not necessary to have complicated shape (with two radii) for ring or post.

All structures considered have their own particularities. The Split Ring Structure has very high shunt impedance. Because there no rf current along the supporting leg (Fig. 1), there are no rigid requirements for rf contact between the leg and outer cavity wall. It simplifies procedure of the structure adjustment. By using Post Structure, variable energy structure may be developed. The Spiral Structure may be used for low frequency range.

For all structures electric field is concentrated between drift tubes and magnetic field is concentrated near inductive elements. This case end walls of the cavity do not disturb strongly parameters of the structure.

Both short and long cavities may be with using SRIS. The example of short nine gap (8 total gaps and 2 reduced gaps near end walls) cavity with one ring is considered for $L_m = 0.1\lambda, \beta = 0.02, 2a = 1.0cm, 2r_c = 2.0cm, Z_e = 756M\Omega/m$. This case reduction in Z_e^r is associated mainly not with end walls, but with nonsymmetry. One conductor carries 5 drift tubes and another only 4. It provides nonsymmetry in the distribution of magnetic field and additional rf currents along the leg. The symmetrical ten gaps cavity has higher shunt impedance.

Long cavity may have several modula. Each module should be designed for his own average β, because with increasing of β capacitive load decreases and outer radius of the ring increases. Differing from RFQ cavity, it looks not reasonable to connect modula directly trough conductors. The coupling with longitudinal electric field is sufficient. Each module should be equipped with own tuner. With appropriate tuning of own frequency for each module (keeping the frequency of the cavity at the designed value), one can adjust increased rf voltage at modula with higher average β.

Conclusion

All structures considered have high shunt impedance and small transverse dimensions. For every structure there is RFQ analog. It allows to provide 'uniform' accelerating system by using RFQ initially and ID as extension with the same type of the resonant system. Such approach allows to use similar scientific, technical and technological solutions both for RFQ and for ID part, leading to reduction in total costs for development and production of the system.

References

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