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DISTINCTIONS OF RF PARAMETERS TUNING FOR ACCELERATION PERIOD OF STRUCTURE WITH SPATIALLY PERIODIC RFQ FOCUSING

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Abstract

Distinctions of RF-tuning for accelerating structure with spatially periodic RFQ focusing are considered. Capacitor's method for tune of resonance frequency with minimum accelerating fields distortions presented. Experimental and theoretical results are shown.

The resonance of an intermediate electrode holder in accelerating structure with spatially periodic RFQ focusing is described. The different designs of the holder to escape the influence of this resonance on acceleration are considered. The variant of water cooling design of the holder for low relative pulse duration accelerator is offered.

INTRODUCTION

The accelerating structure with spatially periodic radio frequency quadrupole (RFQ) focusing is used for acceleration of hydrogen ions. In IHEP considerable experience of design and tuning of these structures is accumulated. There are two RFQ drift tube proton linacs, named the LU-30 and LU-30M, in the IHEP Protvino, that are presently in operation. Both accelerators are the unique machines employing high-frequency quadrupole focusing up to 30 MeV at exit. Since 1985 till now, LU-30 routinely operates as an injector to booster proton synchrotron, thus feeding the entire accelerator complex of IHEP. The LU-30M is now run in a stand-alone test operation mode.

Period of this structure consist of an axial gap (accelerating), and a quadrupole gap (focusing). These gaps are separated by intermediate electrode. Gap's electrodes and an intermediate electrode holder are installed in resonator with longitudinal magnetic field [1], [2], [3].

Work is currently under way on advancing of tuning techniques for spatially periodic RFQ focusing accelerators with attraction of modern numerical methods.

Opportunity for tuning of working frequency with minimum accelerating field distortions is shown by experimental and numerical methods. The resonance of an intermediate electrode holder also is described.

CAPACITOR TUNING OF FREQUENCY

Frequency tuning of resonators for LU-30 and LU-30M has been realized by turn of copper rings in a resonator magnetic field in vacuum. Turn of one ring changes frequency approximately on 8÷25 kHz, depending of the resonator Q-factor and the size of a ring. The method offered now allows expanding a range of tuning frequency essentially with minimum accelerating field distortions.

Offered capacitor tuning of frequency has significant feature. Tuning elements in the form of the metal flat disks located at holders are settled down in the field of low amplitude electric field of the resonator.

On Fig. 1 placing of tuning elements on an internal surface of the container of the H-resonator is shown and parameters of tuning elements - an angle of an inclination **fi** and the distance to surface of resonator **dd** are shown.

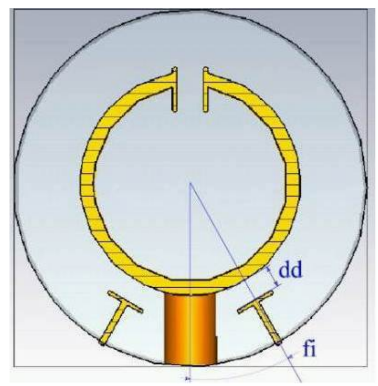

Figure 1: Cross section of H-resonator with tuning elements and dummy load.

On fig. 2 the curve of change of resonant frequency for the H-resonator for position of electrodes with the angle to a vertical fi=30 ° is shown, this frequency is a function of distance from a flat part of tuning electrodes to an external surface of the H-resonator dd.

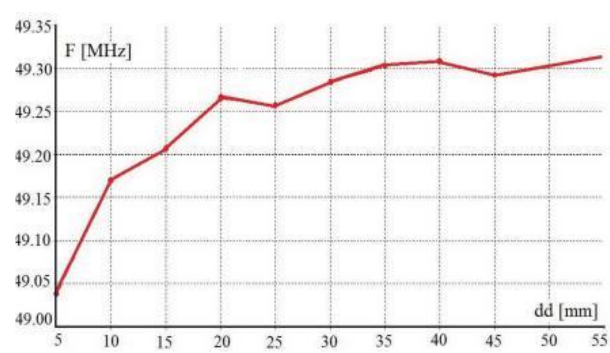

Figure 2: Frequency as a function of space dd.

From the analysis of the function represented on Fig. 2 follows, that effective tuning of frequency is possible at change dd in the range from 5 mm to 35 mm. The further increase of an interval dd not essentially influences frequency of the resonator, but too small size dd can lead to breakdown.

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Further researches of beam dynamics have been carried out taking into account distortions of electric field on the periods of acceleration due to tuning elements. Voltage applied to accelerating electrodes at any investigated positions of tuning elements does not exceed two percent from nominal voltage and decreases in process of removal from tuning elements along an accelerator. The comparative analysis of dynamics was carried out at maximum distortion in voltage on accelerating and focusing electrodes by tuning elements. It was used two pair of tuning elements in section that corresponds to the real situation on accelerator section.

The comparative analysis of phase portraits shows, that influence of tuning elements on dynamics is not so significant, but it exist and it is necessary to estimate this influence. It is important, that transverse emittance of a beam practically has not grown (a gain is less than one percent), and longitudinal emittance has increased approximately on one and a half percent, it is not so great as well.

The obtained data show stability of dynamic parameters of the accelerated beam at application of a method of capacitor tuning of resonant frequency of accelerator sections for accelerator with a longitudinal magnetic field and confirm perspective of this method.

The method of capacitor tuning of resonant frequency of sections for the basic part of the accelerator, constructed on resonators with a longitudinal magnetic field, has shown reliability and efficiency in experimental tests at accelerator LU-30 sections. Theoretical researches have confirmed possibility of a wide range of tuning of frequency for these resonators in some hundreds kHz.

RESONANCE OF THE INTERMEDIATE ELECTRODE HOLDER

Presence of the electrode holder in accelerating structure with spatially periodic RFQ focusing which set up in an H-resonator is the reason of spurious mode; it is named resonance of the intermediate electrode holder. The designs of the holder with different reactance to escape the damaging influence of this resonance on beam dynamics are considered in this text's section with the help of analytical and numerical calculations.

Distributions of magnetic fields and currents for working mode (Hw, Ia, Iq) and spurious mode (Hr, Ir) are shown on a H-resonator cross section (fig 3) in the plane of an intermediate electrode. For working mode Hw is the longitudinal magnetic field, currents Ia and Iq along the holder opposite in phase and summation current along the holder is absent. For spurious mode magnetic field Hr is the rotatable around holder, currents Ir along the holder are in phase. This causes breaking of voltage distributions in accelerating period.

The designation on Fig 3: C - interside capacitance; Ca, Cq- capacitances of axial and quadrupole gaps correspondly ; La, Lq – inductances of axial and quadrupole sectors of H-resonator cross section; z-reactance of the holder.

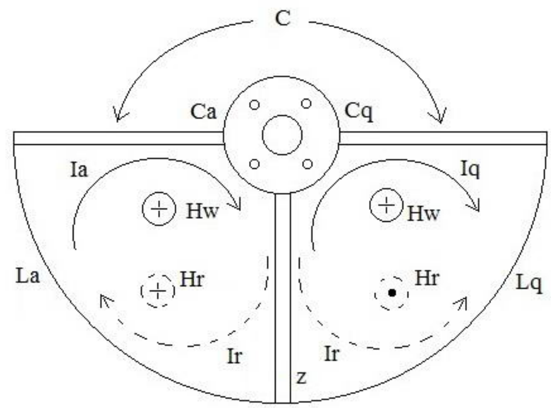

Figure 3: H and I distributions for cross section SH-resonator with electrodes.

By analytical treatment of the equivalent circuit (fig.3) expressions for resonances frequencies are found:

working frequency (ω_w)

$$\omega_w^2 = \frac{\omega_0^2}{1 + C/C_0},$$

$$\omega_0^2 = \frac{1}{C_a L_a} = \frac{1}{C_q L_q}, C_0 = \frac{C_a C_q}{C_a + C_q},$$

spurious frequency ($\omega_{r,L}$, $\omega_{r,C}$)

$$z = j\omega L_r, \omega_{r,L}^2 = \frac{\omega_0^2}{1 + L_r/L_\sigma}, L_\sigma = \frac{L_a L_q}{L_a + L_q};$$

$$z = \frac{1}{j\omega C_r}, \omega_{r,C}^2 = \omega_0^2 + \frac{1}{C_r L_\sigma}.$$

According to this expressions:

$$\omega_{r,C}^2 > \omega_w^2; \ \omega_{r,L}^2 > \omega_w^2 \text{ or } \omega_{r,L}^2 < \omega_W^2,$$

depending on character of reactance z.

Numerical calculations for different z were carried out according to model represented on Fig 4. Results of calculations for various reactance z are shown on Fig. 5.

Inductance reactance was changed by change of holder′s thickness (r_n). On Fig. 5 the results received for various holder's thickness r_n are shown. Results corresponding to the earlier conclusions are shown on the basis of analytical consideration and allow to define numerical values r_n, excluding dangerous approaching or coincidence of working and spurious frequencies.

Capacitance reactance was changed by change width of holder′s cross section (h_s). Results of calculations are shown at Fig. 5 and agree with results of analytical treatment.

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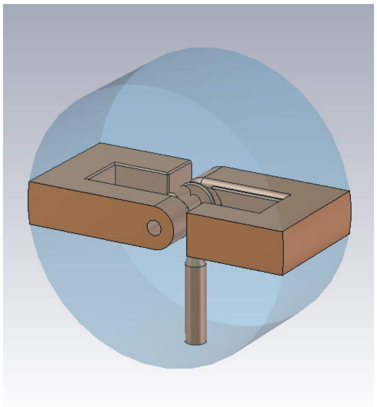

Figure 4: Model of an intermediate electrode holder in accelerating structure.

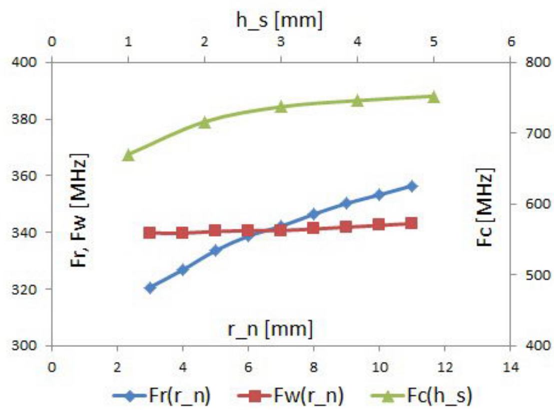

Figure 5: Calculated working F_W , spurious F_r and F_C modes as a functions holder' length.

Design of holder must not impair the resonator's RF-parameters (increase RF-losses, change geometry seriously, disturb conductive coupling). For inductive character z it can be increase in RF-losses and change of geometrical parameters of the resonator. For capacitor character z it is breakdown of galvanic communication of an intermediate electrode with the basis of resonator. Besides this design must maintain water cooling of the holder for low relative pulses duration accelerator. The cooling may be realizes by Feld's tube. . In this case RF characteristics of long line may be used. Input impedance for short circuit on the end long line has capacitance reactance for $\lambda/4 < l < \lambda/2$, where λ – length wave, l – length line. Replacement part of holder by part of this long line filled with water maintains requiring capacitance reactance. Water filler reduce length wave in line und length line l by a factor $\sqrt{\varepsilon} \approx 9$. This requirements capacitance, water cooling and conductive coupling are completed simultaneously.

Test stand tor experimental study of holder's resonance was made in IHEP (Fig 6). The stand incorporates an H-resonator with one period of accelerating structure and measuring unit.

Figure 6: Experimental stand.

Experimental possibility of management by frequency of a spurious resonance of a holder by change of length l has been tested at the stand. Experimental results are presented on Fig 7.

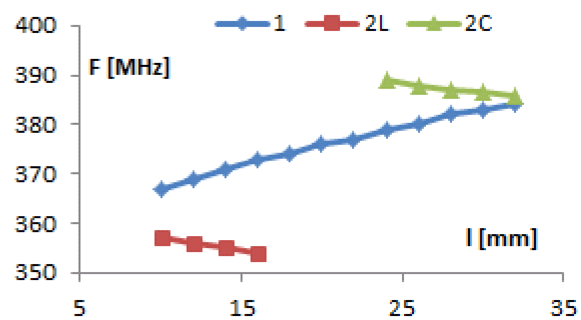

Figure 7: Experimental dates for spurious modes as a functions of reactance of holder.

On fig. 7 plot 1 corresponds to closed input of long line for simulation of inductance reactance of the holder. Plots 2L and 2C corresponds to inductance and capacitance reactances as functions of length l for open input of long line. Spurious frequency split is shown.

CONCLUSION

According to presented results opportunity for tuning of working frequency with minimum accelerating fields distortions is shown. Besides, the resonance of an intermediate electrode holder and methods to escape the influence of this resonance are described.

Received results may be useful for design of low relative pulses duration accelerator.

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