ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-THPSC03

THE TUNING OF THE ACCELARATING STRUCTURE UTILIZING ELECTROSTATIC UNDULATOR

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Abstract

The accelerating structure based on an electrostatic undulator is very attractive for bunching and acceleration of ribbon beams of light ions with beam current over 1 A. It also allows simultaneously accelerate two ion beams with positive and negative charged ions. This paper is presenting the analytical model of the accelerating structure. Also the paper is presenting the results of the simulation in ANSYS HFSS and the results of the experimental study of the mock-up of this structure that demonstrate the ways of tuning of the uniform transverse electrical RF field in its accelerating channel.

INTRODUCTION

At 1972 R. B. Palmer proposed to utilize magnetic undulator for acceleration electron beams [1]. Later E. S. Masunov showed that this idea are working and for acceleration of ions [2] and even better working better for accelerating ions utilazing an electrostatic undulator [3].

The beam dynamics calculation [4] showed that combined waves composed of the field of electrostatic undulator and the first harmonic of RF field in 0 mode can accelerate ribbon ion beams. The current limit of this structure with the aperture 8 mm by 200 mm is 1 A [5]. This type of accelerating structure also allows simultaneously accelerate two beams having positive and negative ions.

This article describes the development of equivalent circuits of this structure. The study of model of this structure with the uniform accelerating channel in ANSYS HFSS and the investigation of the mock-up of this structure showed the technique of tuning of the structure.

ACCELERATING CHANNEL

The accelerating channel of the mock-up structure consists of 16 pairs of cylindrical electrodes that the same time belong to the electrostatic undulator and RF, i.e. we have the combined accelerating structure. Electrostatic potentials $+U_0$, $-U_0$ were applied to the undulator and RF potentials also were applied to the same electrodes of the undulator $+\widetilde{U}_{rf}$, $-\widetilde{U}_{rf}$ (Fig. 1).

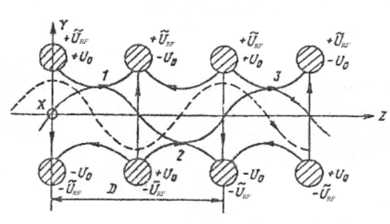

Figure 1: The accelerating channel of the accelerating structure with the electrostatic undulator.

The dash line shows the typical trajectory of the ions without FR field. The solid line shows the trajectory of the ion with RF field, if this ion injected in structure in zero phase of RF field. The deflection of beam caused by the RF field into the regions, where the combined wave of the electrostatic field and the first spatial harmonic of RF field has z-component of an electrical field makes conditions for acceleration of beam in the z-direction.

DESIGN OF MOCK-UP OF ACCELERATING STRUCTURE

The accelerating structure consist of two coupled RF subsystems A (inside green oval in the Fig. 2) and B (inside blue oval in the Fig. 2). Every of this system is DC insulated from the chamber. There is DC voltage between these two systems for the electrostatic undulator.

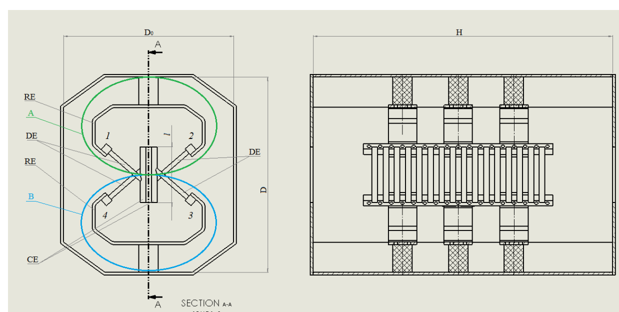

Figure 2: The design of the accelerating structure.

This mock-up has uniform accelerating channel composed of $N = 16$ pairs of cylindrical electrodes 10 mm of diameter, 100 mm of height. The aperture of the accelerating channel is 10 mm by 100 mm. The distance between centers of pair electrodes of accelerating channel in z-direction is 20 mm.

Every subsystem of structure based on three half wave of resonance elements the left ends of which and the right ends of which are joined by copper bars.

DEVELOPMENT OF EQUIVALENT CIRCUITS OF THE STRUCTURE

To minimize capacitive load of the accelerating channel the structure has used the synchronous phase type of excitation, where resonance elements excited in the half wave mode, bar 1 and bar 4 have the same potential that is opposite polarity of RF potentials of bar 2 and bar 3.

To compose equivalent circuits of structure in the synchronous and non-synchronous type of excitation, we present resonance elements as pieces of strip lines and calculate capacitance of accelerating channel. Figure 3 shows partial capacitances of the accelerating channel.

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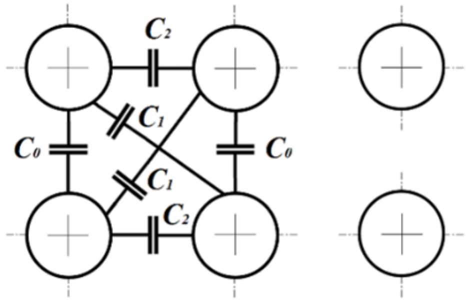

Figure 3: Capacitances of the accelerating channel.

The calculations of capacitances between bar 1 and 3 allowed calculate NC_0, capacitances between bar 1 and 2 allowed calculate $(N-1)C_1$ and capacitances between bar 1 and 4 allowed calculate $(N-1)\,C_2$. The Table 1 contains the results of calculation of capacitances, performed in COMSOL.

Table 1: Capacitances of the Accelerating Channel

C_{13}, пФ	C_{12}, пФ	C_{14}, пФ
7.7	4.2	23.0

The accelerating structure has equivalent circuits for synchronous and non-synchronous type modes that is in Fig. 4, a) and b) correspondently.

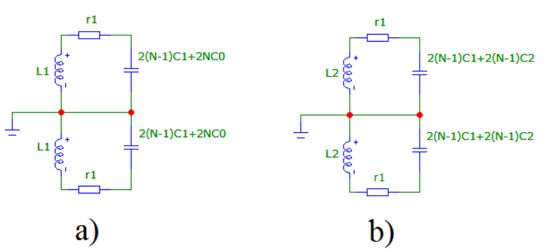

Figure 4: Equivalent circuits of the accelerating structure in synchronous and in non-synchronous modes.

Calculation of L_1, L_2 uses formulas (1) and (2) below:

$$L_1 = L_0(1+K) \quad (1)$$

$$L_2 = L_0(1-K) \quad (2)$$

Where L_0 is half of own inductance of three half wave resonance elements in the parallel connection, K is coupling coefficient between two subsystems A and B.

The presentation of three resonance elements as a strip line of three strips let the calculation of L_0. The calculation of this inductance used value of the input impedance of this line in the channel side, the line has a shorted circuit near its supports and it has the double of capacitance of the accelerating channel in the other end.

In the result of this calculations: $Z_{input} = i46\ \Omega$, $L_0 = 42\ nH$.

According to the equivalent circuits in the fig. 5 the formulas for synchronous and non-synchronous mode are below:

$$f_{syn} = \frac{1}{2\pi}\frac{1}{\sqrt{L_0(1-K)[2(N-1)C_1+2NC_0]}} \quad (3)$$

$$f_{nsy} = \frac{1}{2\pi}\frac{1}{\sqrt{L_0(1+K)[2(N-1)C_1+2(N-1)C_2]}} \quad (4)$$

The eigenmode simulation in ANSYS HFSS gave frequencies of these modes:

$f_{syn} = 174{,}19\ MHz$, $f_{nsy} = 127{,}55\ MHz$.

$$\frac{f_{syn}}{f_{nsy}} = 1{,}38 \quad (5)$$

Development of (3), (4) with the utilization of ratio (5) gives expression for coupling coefficient between subsystems A and B (Fig. 2):

$$K = \frac{1-\left\{\left(\frac{fsyn}{fnsy}\right)^2\left[\frac{2(N-1)C_1+2NC_0}{2(N-1)C_1+2(N-1)C_2}\right]\right\}}{1+\left\{\left(\frac{fsyn}{fnsy}\right)^2\left[\frac{2(N-1)C_1+2NC_0}{2(N-1)C_1+2(N-1)C_2}\right]\right\}} \quad (6)$$

In the result: $K = 0{,}10$.

SIMULATION AND EXPEREMENTAL STUDY OF TUNING OF FIELD

The specific of accelerating structure with electrostatic undulators that at the edges of these structures capacitance between electrodes of accelerating channel essentially higher than in the rest of part of accelerating channel. This causes non-uniform distribution of RF potential along bars and finally changes RF field in the nearby gaps of the accelerating channel. Figure 5 shows the distribution of capacitance between left and right rows of the cylindrical electrodes of accelerating channel without any field correction.

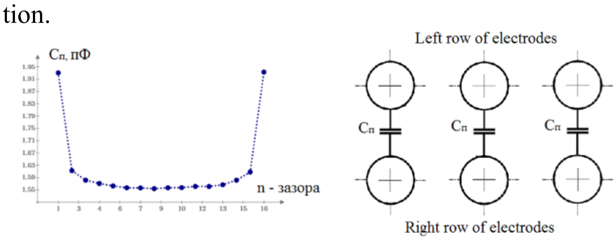

Figure 5: Capacitance distribution in the accelerating channel.

This graph shows that ratio of the capacitance between electrodes of the first or the last pair and the capacitance of between electrodes of the pair in the middle of the accelerating channel equals to 1.2. The simulation in ANSYS HFSS shows that the reduction of electrical field take place in the first pair of electrodes and in the last pair of electrodes. The fields in the second pairs and in the pair before the last pair higher than in the other pairs. The connection of the even pair of electrodes and the odd pair of electrodes to the different pair of bars makes this difference in field (Fig. 6). At the middle of the accelerating channel, the fields are almost the same.

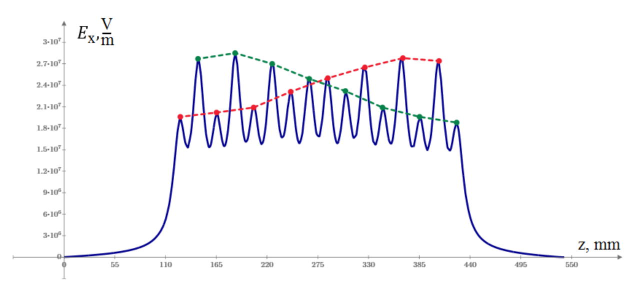

Figure 6: The transverse electrical field of accelerating structure in synchronous mode.

The investigation of the distribution of traverse electrical field in the mock-up of the structure showed the same result (Fig. 7).

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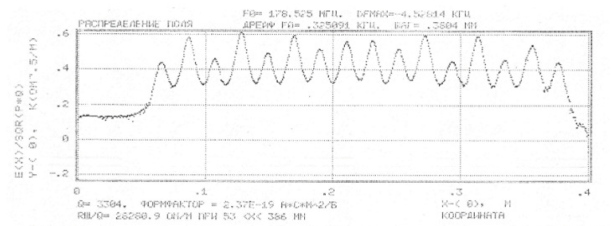

Figure 7: The result of measurements of the distribution of the RF electrical field in middle of accelerating channel of mock-up.

The installation of corrective capacitors between bar 1 and 4; and also the installation the other corrective capacitors between bar 2 and 4 made more uniform distribution of potential along these bars and such way made field uniform. The study of the model with corrective capacitors in ANSYs HFSS proved that this correction is working well. Figure 8 shows the model of the structure with installed corrective capacitors (pos. 6, 5, 7, 8).

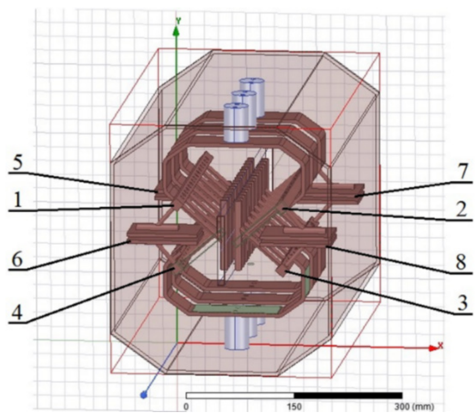

Figure 8: The HFSS model of the accelerating structure with the corrective capacitors.

The investigation of the mock-up and it tuning for the uniform fields in the accelerating structure also confirmed the results of simulations and made recommendations for the design and tuning this kind of accelerating structures. Figure 9 shows the photo of the mock-up of the structure.

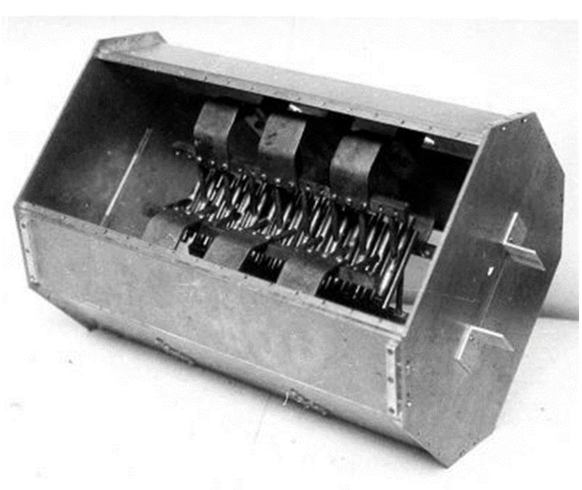

Figure 9: The mock-up of the accelerating structure with the electrostatic undulator.

Figure 10 shows the result of simulation, where uniform field distribution has been reached.

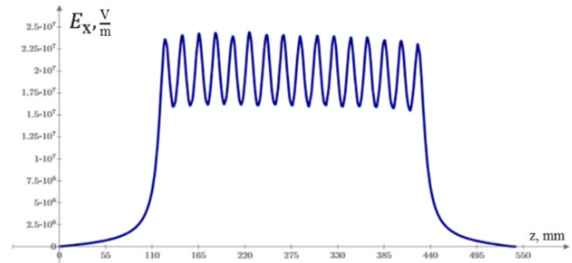

Figure 10: The distribution of the electrical component of RF field after the installation of corrective capacitors.

The utilization of the corrective capacitors in the mock-up of structure also allowed reach the uniform distribution of field. Figure 11 shows the result of the measurements of the field after tuning.

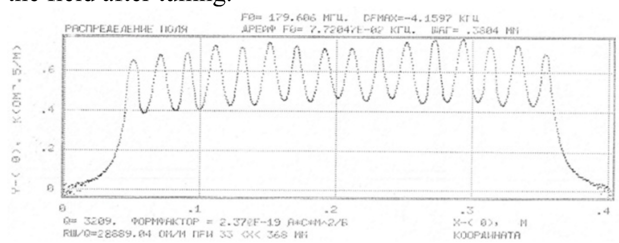

Figure 11: The field distribution after the tuning of the uniform field.

CONCLUSION

The presented data proved that the way of tuning of the uniform distribution of the traverse RF electric field in the accelerating structure allows tuning the field that is completely satisfied the beam dynamics requirements.

REFERENCES

[1] R.B. Palmer, Iteration of relativistic particles and free electromagnetic Waves in presence of a static helical magnet, J. Appl. Phys. 1972, v.43, No.7, p. 3014-3023

[2] E.S. Masunov, Transverse Focusing of a Beam in an Undulator Accelerator, Proceedings of the 10th All-Union Conference on Accelerators of Charged Particles. Dubna: JINR. 1986, v.1, p. 379-381

[3] E.S. Masunov, Focusing and Acceleration of the Beam in a Linear Undulator Accelerator. Proceedings of the 11th All-Union Meeting on Accelerators of Charged Particles. Дубна: JINR. 1988, v.2, p. 121-123.

[4] S.M. Polozov, Acceleration and Focusing of intense ion Beams in High-Frequency Structures Using Undulators, PhD thesis in physical and mathematical sciences. Moscow, 2003

[5] E.S. Masunov, V.N. Leonov, A.P. Novikov, N.V. Avreline, Ion LINAC. USSR Patent №4720655

[6] N.V. Avreline, V.N. Leonov, E.S. Masunov, A.P. Novikov, A.G. Ponomarenko. Acceleration system of ribbon ion beams in linetonutron using periodic electrostatic fields. Preprint 041-90, MEPHI, 1990, 24 pp.