DESIGN OF ACCELERATING CAVITIES FOR UNDULAC

S.M. Polozov, P.R. Safikanov, O.A. Tatsyuk
National Research Nuclear University - Moscow Engineering Physics Institute, Moscow, Russia
E-mail: smpolozov@mephi.ru

The acceleration of high intensity low beta ion beams is one of the priority tasks of applied accelerating technology. The space charge effect is a key problem appeared for high intensity ion beam acceleration. The influence of space charge can be decreased by the ribbon beam acceleration. The linear undulator accelerator (UNDULAC) was proposed by E.S. Masunov for this aim. In this paper the accelerating cavity for UNDULAC will considered, H-type and E-type cavities will studied, the electrodynamics parameters will defined and optimization of fields distribution will done. The especially designed method of drift tubes geometrical parameters synthesis will discussed and tested.

PACS: 29.17.w, 29.27.Bd

INTRODUCTION

Some different ways to increase the limit beam current in linacs are discussed now. The ribbon or hollow (tube) beam acceleration are possible.

The undulator linear accelerators with radio frequency undulator (UNDULAC-RF) [1] and with electrostatic undulator (UNDULAC-E) [2] were considered earlier for ribbon ion beam acceleration.

In a conventional RF linac the beam is accelerated by a synchronous wave of the RF field. The acceleration mechanism in UNDULAC is similar to the acceleration mechanism in an inverse free electron laser (IFEL), where the electron beam is accelerated by a ponderomotive force. In UNDULAC the beam bunching, acceleration and focusing are realized in the accelerating force which is driven by a combination of two non-synchronous waves (two undulators). As it has been shown, one of the undulators must be of the RF type, the second one being, optionally, of magnetic (UNDULAC-M), electrostatic (UNDULAC-E) or RF (UNDULAC-RF) types.

Both UNDULAC types can be realized using interdigital H-type (IH) resonator. Problems of the electrostatic potential input into resonator was discussed in [4] for UNDULAC-E. Its further design and construction of the UNDULAC-RF resonator will be discussed in this paper. It should be noted that such resonator is provided for ribbon ion beam acceleration and should has free especial characteristics:

(i) slit accelerating channel is necessary for ribbon ion beam acceleration,

(ii) ratio of base and first RF field special harmonics amplitude should be equal to 0.25…0.3 for effective beam focusing;

(iii) field amplitude should increase in the front end of structure to realize the beam bunching [1].

A number of resonator designs for low energy high intensity ribbon ion beam acceleration are discussed. Conventional IH resonator can be used for low energy high intensity ribbon beam acceleration in UNDULAC-RF and E-type resonator with DC potential input is necessary for UNDULAC-E. The operating frequency is 150 MHz and $\mu=\pi$ mode of RF field for UNDULAC-RF and $\mu=0$ mode of RF field for UNDULAC-E. These two schemes will be simulated to define electrodynamics characteristics.

1. ACCELERATING IH CAVITY FOR UNDULAC-RF

Computer simulations of RF field distribution in IH-type cavity for low energy high intensity ribbon beam acceleration (Fig.1) were done and electrodynamics characteristics of structures were calculated. Drift tubes can be placed horizontally or vertically relatively to resonator vanes [5]. The second model has the better electrodynamics characteristics: *Q*-factor and shunt impedance are Q=4100 and R_{sh}=20 MOhm/m.

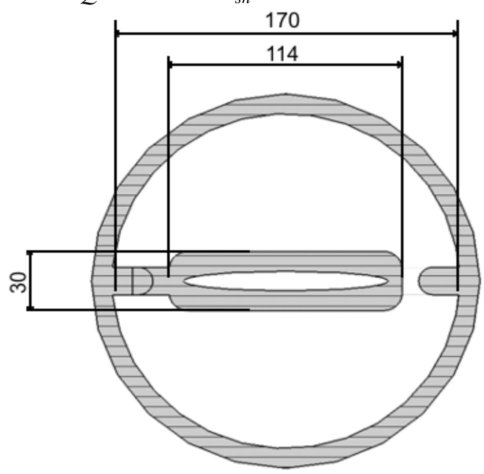

Fig.1. IH-resonator for UNDULAC-RF

The optimization of electric field longitudinal distribution in the IH-type resonator was done by cutting of the supporting vanes. It is necessary to realize the field amplitude increasing in the bunching part of the resonator and the constant amplitude value in the cavity's end. The magnetic field is pressed out due to vanes cutting. Therefore RF power will transfers from magnetic to electric field and electric field will aligns at the cavity end. A number of different variants of wanes cutting were analyzed. The top view of most effective structure variant is shown in Fig.2. The longitudinal field component on the axis of accelerating-focusing canal is shown in Fig.3 for IH-resonator with cut off vanes.

The transverse electric field distributions within drift tube for IH-type resonator are shown in Fig.4. Results obtained by simulation agree to theoretically predict. The *Ex(x)* component close to the electrode is corrupted. However, it does not matter to the process of ion beam acceleration due to the beam is accelerated near the channel axe.

ISSN 1562-6016. ВАНТ. 2012. №4(80)

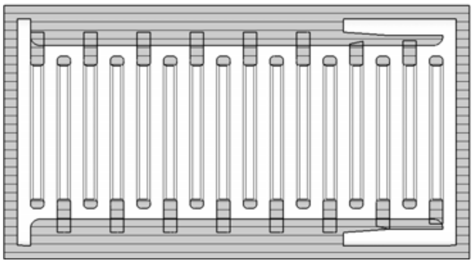

Fig.2. IH cavity with cut off planes. Top view

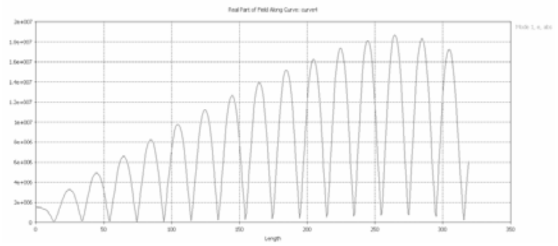

Fig.3. Electric field distribution along of the longitudinal axis in IH cavity with cut off planes

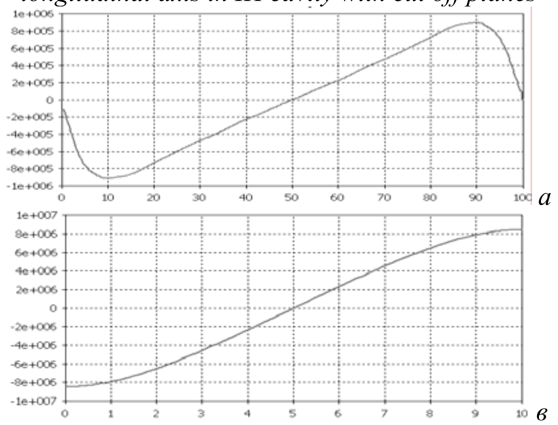

Fig.4. Electric field distribution within drift tubes of IH-cavity along of wide (a) and small (в) tube size axes

2. E TYPE CAVITY FOR UNDULAC-E

The E-type cavity design with DC potential input is necessary to realize the beam acceleration in UNDULAC-E. The various types of dc inputs into E-type resonator were studied. Most effective structure is shown in Fig.5.

The detailed views of the drift tube and dc potential input are shown in Fig.6. Aperture of the drift tubes is designed slit for ribbon beam acceleration.

The dc potential input is realized by entering of the common bus top of the cavity. The odd drift tubes are electrically contacted to the common bus with electrostatic potential, the even drift tubes are attached to the resonator’s wall. The holes in the resonator’s wall for supporting stem were chosen to solve two opposite problems: on the one hand to preserve the electric breakdown and on another hand to minimize the RF field distortion from the holes.

Q-factor and shunt impedance for E-type resonator are Q = 59500 and R_{sh}=22.3 MOhm/m. The longitudinal field component distribution on the accelerating-focusing canal axis is shown in Fig.6 for E-type resonator. Transverse electric field distributions within drift tube are shown in Fig.7. Results are better than for IH-resonator.

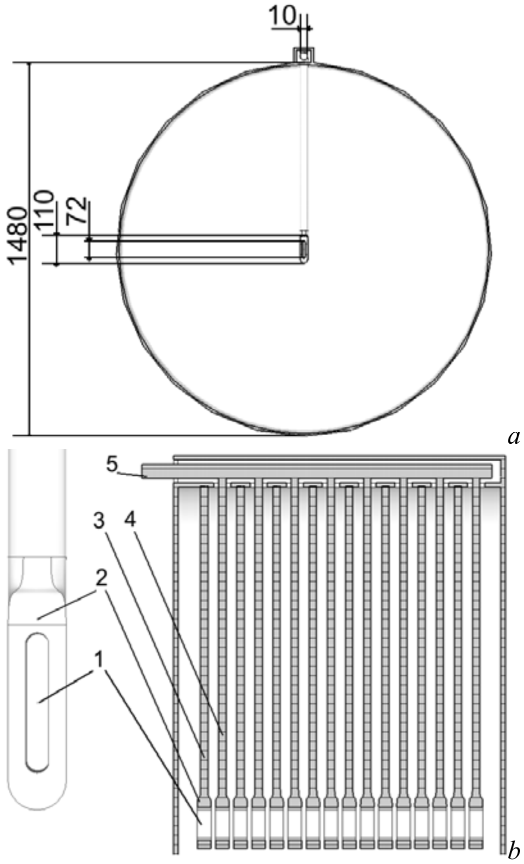

Fig.5. E-type resonator: (a) – front view; (b) – detailed view of E-type resonator drift tubes. 1 – aperture; 2 – drift tube having slit aperture; 3 – supporting stem of the drift tubes; 4 – stem of the electrode with electrostatic potential; 5 – common bus

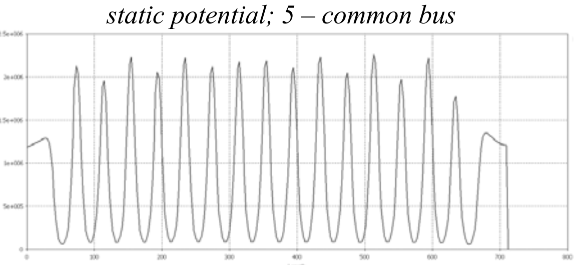

Fig.6. Electric field distribution along of the longitudinal axis in E type cavity

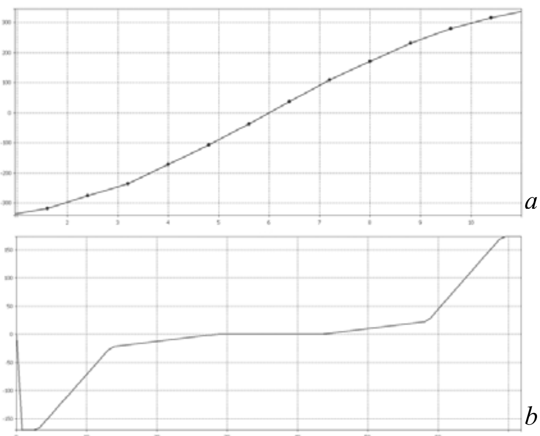

Fig.7. Electric field distribution within drift tubes of E-type cavity along of wide (a) and small(b) tube size axes

3. SYNTHESIS OF ELECTRODES

During the design of accelerator channels the important problem is to find the electrodes (for example, drift tube) shape that provides the necessary amplitudes of RF field spatial harmonics distribution (or RF potential). If the field or potential distribution is known on the accelerating channel axis the search of electrode shape cannot be done directly due to the boundary conditions indetermination. This problem can be placed to the class of incorrect one and can't be solved directly. But there is another way to do it. The electrode shape can be represented as polynomial (as in our case the power series was chosen) expansion

$$y = c_1 + c_2 x + c_3 x^2 + \dots + c_{10} x^9 \quad (1)$$

and the direct analysis of electrical field distribution could be done using the method of finite differences. The field distribution (for instance on the channel axis) is being compared to reference value. Then using the directed optimization we get the polynomial coefficients with those the calculated field distribution is as close as possible to "reference". We will consider the potential of ten equidistant points on the axis of two electrodes. Let's assume that the reference potential in these points is known and equal to $f_1, f_2, \dots, f_{10}$. It's necessary to find the coefficients $c_1, c_2, \dots, c_{10}$ calculated by numerical methods when the potentials $U_1, U_2, \dots, U_{10}$ generated by electrodes in these ten equidistant points are as close as possible to $f_1, f_2, \dots, f_{10}$. So, we have to solve the system of equations:

$$\begin{cases} U_1 - f_1 \to 0, \\ \dots\dots\dots \\ U_{10} - f_{10} \to 0. \end{cases} \quad (2)$$

The following function is defined to solve the system of equations:

$$\psi = |U_1 - f_1| + |U_2 - f_2| + \dots + |U_{10} - f_{10}|. \quad (3)$$

The solution of this equation $\psi = 0$ is equal to solution of the system of equations (2). Since the solving of $\psi \ge 0 \forall U_1, U_2, \dots, U_{10} \in R$ is the finding solution $\psi = 0$ and is equal to finding of ψ function minimum value.

The solving of minimum value of ψ function is proposed to be done by directions set method. The idea of this method is that first we are fixing the coefficients $c_1, c_2, \dots, c_{10}$ and looking for the minimum value of ψ function as a function of one variable c_1. For finding the minimum value of the function of one variable the "golden section" method is used. Then we find $c_{\min}$ when the function ψ approaches to its minimum value $\psi(c_{\min}, c_2, c_3, \dots, c_{10}) \to \min$. Then c_1 was set to $c_{\min}$. Similarly the setting of c_2 (the minimum value of ψ function was found when the coefficients $c_1, c_3, c_4, \dots, c_{10}$ are fixed and the coefficient c_2 was set to $c_{\min}$ when the function $\psi(c_1, c_{\min}, c_3, \dots, c_{10}) \to \min$) and other coefficients were done. We assume that a finding of minimum value of ψ function of one coefficient is one iteration. The number of iterations sets up within code.

To solve the problem of field distribution analyzing the difference scheme was being used, therefore convergence, and as a consequence, the accuracy of finding ψ function minimum value, depends strongly on the step of grid partition and for each case which is determined empirically.

Here are some examples of the code algorithm. Let's assume that the reference function is given by equation:

$$f(z) = -100 \sin(\pi \frac{z}{10}) . \quad (4)$$

The "reference" values $f_1, f_2, \dots, f_{10}$ and calculated potentials $U_1, U_2, \dots, U_{10}$ versus of the coordinates on the axis after twelve iterations are shown in Fig.8. The ψ function values as function of the number of iterations shown in Fig.9. We can see that the limit of convergence is achieved at the twelve's iteration.

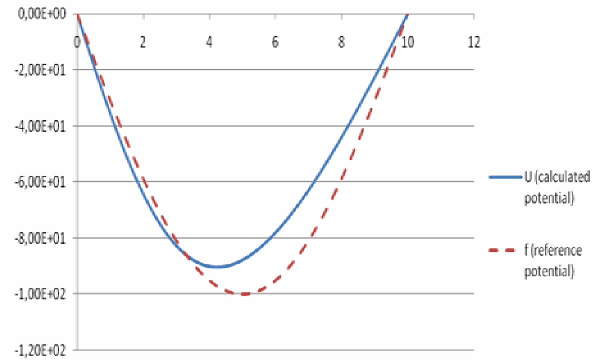

Fig.8. The "reference" and calculated RF potential values distribution in ten equidistant points on the axis

It should be noted that the limit of convergence (more precisely, how many iterations were done when the minimum value of ψ function is achieved) depends strongly on the coefficient we begin to search the minimum value of ψ function by coordinate descent method – coefficient c_1 and c_{10} have different "weight" in the formation of potential on the axis.

The boundary potential values selection for searching the minimum value of one variable by golden section method also influence to the calculation time and accuracy.

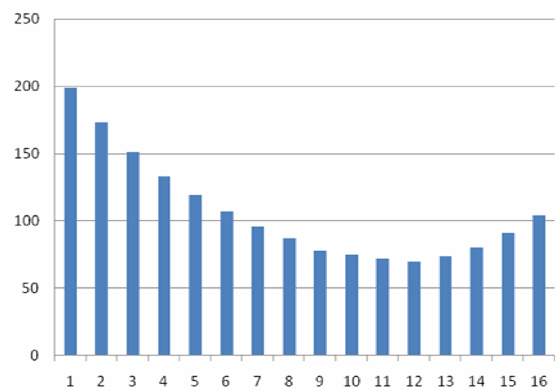

Fig.9. ψ values as a function of the number of iterations

In the example pointed above the relative error in ten equidistance points is 12 %. This error can be significantly reduced by experimental choice of the grid step for different schemes.

Let's take a look on another example. Assume that the reference function is given by the following equation:

$$f(z) = 25\sin(\pi \frac{z}{10}) . \qquad (5)$$

The "reference" $f_1, f_2, ..., f_{10}$ and calculated $U_1, U_2, ..., U_{10}$ potential values of the coordinates on the axis is shown in Fig.10. In the example pointed above the relative error of the calculations in 10 equidistance points is 12 %.

Indeed the method proposed for incorrect problem solving is useful. But simulation accuracy is not sufficient for electrode's synthesis. The choice of minimization method is very important for higher accuracy because the direct optimization method not gives necessary one.

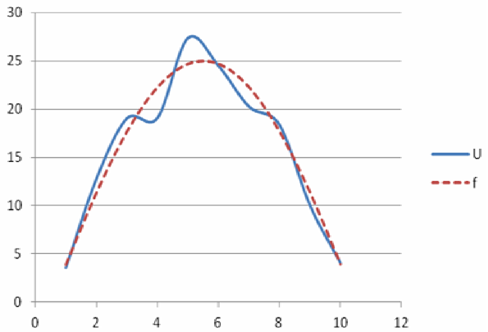

Fig.10. The "reference" and calculated potential value distribution in ten equidistant points on the axis (2nd example)

CONCLUSIONS

The cavity constructions for undulator linear accelerator with RF and electrostatic undulator were discussed. Problems of the DC potential input into E-type resonator of UNDULAC-E were studied. An especially designed simulation method was proposed to inverse Maxwell's problem solving.

REFERENCES

1. E.S. Masunov, S.M. Polozov // *Phys. Rev. ST AB,* 2008, v.11, 074201.
2. E.S. Masunov, S.M. Polozov, A.S. Roshal // *Radiation Physics and Chemistry,* 2001, v.61, p.491.
3. E.S. Masunov, S.M. Polozov // *NIM A*, 2006, v.558, p.184.
4. E.S. Masunov, et al. // *Problems of Atomic Science and Technology. Series: «Nuclear Physics Investigations».* 2010, №3 (67), p.54.
5. S.M. Polozov, et al. / *Proc. of IPAC,* 2011, MOPC039.

Статья поступила в редакцию 24.09.2011 г.

КОНСТРУКЦИИ УСКОРЯЮЩИХ РЕЗОНАТОРОВ ДЛЯ ИСПОЛЬЗОВАНИЯ В ЛИНЕЙНОМ ОНДУЛЯТОРНОМ УСКОРИТЕЛЕ

С.М. Полозов, П.Р. Сафиканов, О.А. Тацюк

Ускорение сильноточных ионных пучков при малых энергиях является одной из приоритетных задач современной прикладной ускорительной техники. Основные проблемы, возникающие при ускорении интенсивных ионных пучков, связаны с действием объемного заряда. Понизить влияние объемного заряда на поперечный размер пучка возможно при ускорении ленточных пучков. Для этих целей Э.С. Масуновым был предложен так называемый линейный ондуляторный ускоритель. В настоящей статье будут рассмотрены ускоряющие секции ВЧ-ондуляторного ускорителя, будет проведено исследование резонаторов Н-типа и Е-типа, определены электродинамические характеристики резонаторов и проведена оптимизация распределения полей. В работе описан метод синтеза геометрии трубок дрейфа по заданному распределению полей.

КОНСТРУКЦІЇ ПРИСКОРЮЮЧИХ РЕЗОНАТОРІВ ДЛЯ ВИКОРИСТАННЯ В ЛІНІЙНОМУ ОНДУЛЯТОРНОМУ ПРИСКОРЮВАЧІ

С.М. Полозов, П.Р. Сафіканов, О.О. Тацюк

Прискорення сильнострумових іонних пучків при малих енергіях є однією з пріоритетних задач сучасної прикладної прискорювальної техніки. Основні проблеми, що виникають при прискоренні інтенсивних іонних пучків, пов'язані з дією об'ємного заряду. Знизити вплив об'ємного заряду на поперечний розмір пучка можливо при прискоренні стрічкових пучків. Для цих цілей Е.С. Масуновим був запропонований так званий лінійний ондуляторний прискорювач. У цій статті будуть розглянуті прискорюючі секції ВЧ-ондуляторного прискорювача, буде проведено дослідження резонаторів Н-типу і Е-типу, визначено електродинамічні характеристики резонаторів і проведена оптимізація розподілу полів. У роботі описано метод синтезу геометрії трубок дрейфу по заданому розподілу полів.