THE NEW APPROACH FOR DEFINITION OF VOLUME CONFINED BY ECR SURFACE AND ITS AREA IN ECR ION SOURCE

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The volume confined by resonance surface and its area are one of the important parameters of the balance equations model for calculation of ion charge–state distribution (CSD) in electron–cyclotron resonance (ECR) ion source. The new approach for definition of these quantities is given. This approach allows to reduce the number of parameters of balance equations model.

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1. INTRODUCTION

For some transport models [–] for calculation of ion CSD in ECR ion sources [] the values of the volume V_p confined by resonance surface and its area S_p are one of model parameters. For example in model [] these values are using in balance equation for neutrals in ECR plasma:

$$\frac{dn_{s,0}}{dt}=\frac{\bar{v}_{s,0}S_p}{V_p}\left(n_s-n_{s,0}\right)-$$
$$-\sum_{m=1}^{M}\left(\sum_{k=1}^{K}{}^{m}\nu^{\text{ion}}_{s,0\to m,k}\,n_{e,k}+\sum_{s'=1}^{S}\sum_{z=m+1}^{Z_{s'}}{}^{m}\nu^{\text{cx}}_{s',z\to z-m}\,n_{s',z}\right)n_{s,0},\qquad(1)$$

here agreed notation are: s, s' are ion species index; z, z' are ion charge state index; m is process multiplicity; k, k' are electron component index; $\bar{v}_{s,0}$ is a neutral velocity; ${}^{m}\nu^{\text{ion}}_{s,z\to z',k}$, ${}^{m}\nu^{\text{cx}}_{s,z\to z'}$ are ionization and charge exchange rates from charge state z to z'; $n_{s,z}$, $n_{e,k}$ are ions and electrons densities; $n_{s,0}$, n_s are neutral density inside and outside of the source chamber.

In this case the proper calculations of these ones important parameters are presented.

2. ECR ION SOURCE MAGNETIC MAP APPROXIMATION

The approximation of the ECR ion source magnetic map uses the next well known fact: that minimum–B field configuration created by external magnetic system of ion source segmented on two different parts. One of these parts is solenoid magnet and the other one is multipole magnet.

2.1 EXTERNAL SOLENOID FIELD

In cylindrical coordinate system we describe the external magnetic field of solenoid by $A_\theta = A_\theta(\rho, z)$ – azimuthal component of vector potential []:

$$A_\theta(\rho,z)=J_1\left(\rho\frac{d}{dz}\right)\Phi(z),$$
$$\Phi(z)=B_1+z^2B_2.\qquad(2)$$

Here $J_1\left(\rho\frac{d}{dz}\right)$ is a Bessel function of first order; $\Phi(z)$ is a magnetic field at the axis; B_1 and B_2 are numerical coefficients in Gs and Gs·cm^{-2} units correspondingly. When in use approximation only first order term was taken in decomposition (2).

2.2. EXTERNAL FIELD OF MULTIPOLE LENS

The external multipole magnet of sextupole lens we describe by $A_z = A_z(\rho,\theta)$ – longitudinal component of vector potential []:

$$A_z(\rho,\theta)=\frac{\rho^3B_0\sin 3\theta}{3R_0^2}.\qquad(3)$$

Here B_0 is a pole tip magnet field and R_0 is a lens radius. The dimension of a quantity B_0/R_0^2 is Gs·cm^{-2}.

2.3. FITTING OF TOTAL MAGNETIC FIELD

The total vector potential $\mathbf{A}=\mathbf{A}(\rho,\theta,z)$ of minimum–B configuration is on the form:

$$\mathbf{A}(\rho,\theta,z)=\begin{pmatrix}0\\A_\theta\\A_z\end{pmatrix}.\qquad(4)$$

Here A_θ, A_z defined in (2) and (3) correspondingly. The total magnetic field $\mathbf{B}=\mathbf{B}(\rho,\theta,z)$ of ECR ion source can be expressed as follow:

$$\mathbf{B}=\nabla\times\mathbf{A},\qquad(5)$$

here ∇ is gradient operator.

Fitting of the numerical coefficients in formulas (2) and (3) was performed separately for solenoid field and for sextupole magnet. These coefficients was found for magnetic field maps of the three different ECR ion sources: for INFN, LNS, SERSE ion source of two different working frequencies 14, 18 GHz and for ECR ion source with working frequency 14.4 GHz of the Frankfurt University, IKF. The results of this calculation are presented in the table 1 below.

Table 1. *Numerical coefficients*

ECR ion source	B_0/R_0^2	B_1	B_2
INFN, LNS, SERSE 14 GHz	270	4813	27
INFN, LNS, SERSE 18 GHz	334	5374	42

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Frankfurt UNI, IKF 14.4 GHz	251	4797	21

3. ECR RESONANCE SURFACE

The subsequent discussion we advance in Cartesian coordinate system. The ECR resonance surface $F = F(x, y, z)$ is determined by condition that absolute value $B = B(x, y, z)$ of total magnetic field (5) is equal to the resonance value B_{res} i.e.

$$B = B_{res}. \quad (6)$$

For absolute value of total magnetic field $B(x, y, z)$ we have:

$$\begin{gathered} B(x, y, z) = \sqrt{B_x^2(x, y, z) + B_y^2(x, y, z) + B_z^2(z)}, \\ B_x(x, y, z) = (x^2 - y^2)\, B_0 - x\, z\, B_2, \\ B_y(x, y, z) = -\, y\,(2\, x\, B_0 + z\, B_2), \\ B_z(z) = \Phi\,(z). \end{gathered} \quad (7)$$

The coefficient B_0/R_0^2 here was redefined as B_0 and therefore expression for $F(x, y, z)$ is given by:

$$\begin{gathered} F(x, y, z) = x^4 B_0^2 + y^4 B_0^2 + B_1^2 - \\ - 2x^3 z B_0 B_2 + 6x y^2 z B_0 B_2 + \\ + 2z^2 B_1 B_2 + y^2 z^2 B_2^2 + z^4 B_2^2 + \\ + x^2 (y^2 B_0^2 + z^2 B_2^2) - B_{res}^2. \end{gathered} \quad (8)$$

The equality to zero of the expression (8) defines the implicit equation of ECR surface.

On Fig.1 the ECR resonance surfaces for different ion sources are shown. The fitted numerical coefficients are taken from Table 1.

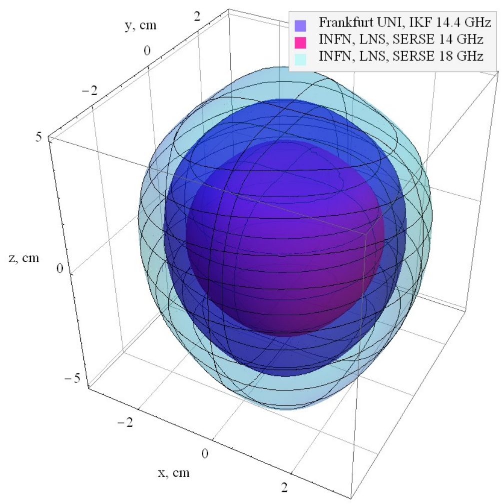

Fig.1. ECR resonance surfaces (8) for different ion sources

4. DEFINITION OF VOLUME CONFINED BY RESONANCE SURFACE AND ITS AREA

Now when the equation defines is known we can to develop the method for calculation of volume confined by resonance surface and its area. The volume can be define as

$$\begin{gathered} V_p = \iiint\limits_{\Omega} dV,\, dV = dxdydz, \\ \Omega = \{(x, y, z) : F(x, y, z) < 0\}, \end{gathered} \quad (9)$$

and for resonance surface area:

$$\begin{gathered} S_p = \oiint\limits_{S} \mathbf{n} \cdot d\mathbf{S}, \\ d\mathbf{S} = \mathbf{n} dS,\, dS = dxdy, \\ S = \{(x, y, z) : F(x, y, z) = 0\}. \end{gathered} \quad (10)$$

Using the Ostrogradsky-Gauss theorem we reduce the last expression i.e.

$$\begin{gathered} \oiint\limits_{S} \mathbf{n} \cdot d\mathbf{S} = \iiint\limits_{\Omega} \nabla \cdot \mathbf{n}\, dV, \\ S_p = \iiint\limits_{\Omega} \nabla \cdot \mathbf{n}\, dV, \\ \mathbf{n} = \mathbf{n}(x, y, z),\, \mathbf{n}(x, y, z) = \frac{\nabla B(x, y, z)}{|\nabla B(x, y, z)|}. \end{gathered} \quad (11)$$

We use the formulas (9), (11) for calculation of V_p and S_p. This calculation was produced with using Monte-Carlo method and tested for surfaces with analytical expression for volume and area i.e. sphere with given radius and ellipsoid with given semiaxis.

Table 2. *Result of calculation of V_p and S_p*

ECR ion source	Volume, cm^3	Area, cm^2
INFN, LNS, SERSE 14 GHz	64	79
INFN, LNS, SERSE 18 GHz	262	207
Frankfurt UNI, IKF 14.4 GHz	148	144

The numerical results of V_p and S_p values was found for set of numerical parameters of approximated magnetic field B_0, B_1, B_2 of the three different ECR ion sources The results of this calculation are presented in the table 2 above.

CONCLUSION

From the point of view of author the calculation problem of the volume confined by resonance surface and its area is important.

There are some works when the assumption about the ellipsoidal shape of resonance surface is given and for this case these parameters was calculated. Also in some works thus [] the numerical estimation is given:

$$\begin{gathered} V_p = 0.15\, L\, d^2, \\ S_p = 2.79\, L\, d, \end{gathered} \quad (12)$$

here L the mirror–to–mirror distance and d is a working chamber diameter and two numerical factors in (12) are for a very particular geometry of magnetic system of ion source. But all of these examples have special case. Therefore the presented above technique of calculation of volume confined by resonance surface and its area without any assumption about ECR surface shape in general allows defining these parameters using only an ion source magnetic fields map.

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НОВЫЙ ПОДХОД К ОПРЕДЕЛЕНИЮ ОБЪЁМА ОБЛАСТИ, ОГРАНИЧЕННОЙ ЭЦР-ПОВЕРХНОСТЬЮ, И ЕЁ ПЛОЩАДИ В ИОННОМ ИСТОЧНИКЕ ЭЦР-ТИПА

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В модели уравнений баланса для расчёта зарядовых распределений ионов (ЗРИ) в ионном источнике, основанном на электронно-циклотронном резонансе (ЭЦР), площадь резонансной поверхности и объём, ограниченный резонансной поверхностью, являются важными параметрами модели. В данной работе предложен новый подход по определению данных величин, позволяющий уменьшить число параметров модели.

НОВИЙ ПІДХІД ДО ВИЗНАЧЕННЯ ОБ'ЄМУ ОБЛАСТІ, ОБМЕЖЕНОЮ ЭЦР-ПОВЕРХНЕЮ, І ЇЇ ПЛОЩІ В ІОННОМУ ДЖЕРЕЛІ ЭЦР-ТИПУ

А.В. Філіппов

У моделі рівнянь балансу для розрахунку зарядових розподілів іонів (ЗРІ) в іонному джерелі, заснованому на електронно-циклотронному резонансі (ЕЦР), площа резонансної поверхні і об'єм, обмежений резонансною поверхнею, є важливими параметрами моделі. У даній роботі запропоновано новий підхід за визначенням даних величин, що дозволяє зменшити число параметрів моделі.