A FUSION DEVICE OF THE CONTINUOUS ELECTRON BEAM CONFINEMENT USED BY THE ACCUMULATING RING WITH THE CONTINUOUS INJECTION

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Abstract

In this paper the design of a accumulating storage ring for the electron beam with ultra–fast automatic cooling is given.The electron beam can be continuously injected and accumulated in more than 1 MA at the enough high eneregy.It can contain deuterium and tritium about one per cent and confine them to realize the fusion.The choice of the cooling magnet and the lattice design are introduced.

1.INTRODUCTION

J.P.Schiffer proposed the possibility of achieving a condensed crystalline state in cooled particle beams.Thier calculations have shown that a plasma of one kind of particle under the influence of such a field as f=k.r can undergo a phase transition and form a crystalline aray in a certain conditions[1].In the case of the nonneutral plasma,when Budker limits are fullfilled[2]

$$\frac{1}{\gamma^2} < \frac{Z.N_i}{N_e} < 1$$

In that case,the critical intensity of the electron beam could be unlimited. The self–electric field is expressed

$$E_r = [\frac{2.I}{c.\beta_z.r_b}].\frac{r}{r_b}$$

When

$$r_b = 1\ cm, I = 1\ MA, E_r = \frac{59\ MV}{cm}$$

Such a super intense field is quite fitted to the above demand for the condensed crystalline.Of course,it can be used to the fusion.Besides,the Ultra–Fast Automatical Cooling for Beams was found out[3],which makes the accumulating ring with the continuous injection realize easily.In other words,the technically simple and remarkably feasible way has turned up.

This new idea of the fusion has such characteristics as follows:Its confinement is the super–intense static electric field produced by the intense electron beam.In the nonneutral plasma,the electron beam intensity is unlimited.Because the electron beam of any high energy can also be accumulated,the electron energy is unlimited.In general,the energy of the electron beam must be equal to or larger than 2 Mev.Because the nonneutral plasma system is self–constricted and stable,the plasma dencity can be much higher than the magnetic confinement fusion and approximating to the initial confinement fusion.It is useful to improve the action rate.Besides,the device is not only minimal and cheap,but also technically simple and remarkably feasible,it is easy to combine with the magnetic or the initial confinement.

In this paper,a minimal accumulating storage ring with the continuous injection is illustrated.Condensed plasma confined by the intense electron beam can be obtained and used to the fusion.

2. DESIGN OF THE LATTICE

As usual,the accumulating storage ring with ultra–fast automatic cooling consists of the two straight line sections and N identical periodic sections or "unit cells",which is called a lattice.There is no specific distinction from the ordinary storage ring,except that the bending magnet should play a part in the automatic cooling.In the case of the linear approximation,the current standard treatment of the betatron oscillation can be used[4],except that the edge–focusing angle of the bending magnet must be satisfied with the requirement for the automatic cooling.By other words, there is a strict constraint in the edge–focusing angle of the bending magnet. In order to simplify the structure,we had better choose a group of the double quadrupole lenses as focusing element.Then the motion of particles can be expressed in terms of the linear transformation

$$X(s) = M(s,s_i) \cdot X(s_i) \qquad (2.1)$$

$$M(s,s_i) = \begin{bmatrix} x_1(s) & x_2(s) \\ x'_1(s) & x'_2(s) \end{bmatrix}$$

$$x_1(s_i)=1, x'_1(s_i)=0$$
$$x_2(s_i)=0, x'_2(s_i)=1$$

As usual,where X stands for both horizontal and vertical direction matrices.Using the piecewise method of solution,we have

$$M = M_{s3}\cdot M_{l2}\cdot M_{s2}\cdot M_{l1}\cdot M_{s1}\cdot M_{b}\cdot M_{e} \quad (2.2)$$

Where M_e is of the matrix in the edge–focusing,so that

$$M_{ex}=\begin{bmatrix} 1 & 0 \\ k_b\cdot tan(\varphi) & 1 \end{bmatrix} \quad (2.3)$$

$$M_{ey}=\begin{bmatrix} 1 & 0 \\ -k_b\cdot tan(\varphi) & 1 \end{bmatrix}$$

$$k_b=\frac{e}{p_0}\cdot B$$

In the bending magnet region,we have

$$M_{bx}=\begin{bmatrix} Cos(k_b s) & \frac{1}{k_b}Sin(k_b s) \\ -k_b Sin(k_b s) & Cos(k_b s) \end{bmatrix}$$

$$M_{by}=\begin{bmatrix} 1 & s \\ 0 & 1 \end{bmatrix} \quad (2.4)$$

$$k_b=\frac{e}{p_0}\cdot B$$

In the conditions of the automatical coolng,we know

$$M_{bmx}=M_{bx}.M_{ex} \quad (2.5)$$

$$=\begin{bmatrix} (Cos(\varphi))^{-1} & (k_b)^{-1}\cdot Sin(\varphi) \\ 0 & Cos(\varphi) \end{bmatrix}$$

The matrix in the section of a free drift space or in the section of a quadrupole lens is the same as usual expression[4].

The optimum parameters are obtained in considering of that μ does not approach to $\frac{\pi}{2}$.The results are as follows:

$N=6;\varphi=\frac{\pi}{3};k_b=0.05;l_1=l_2=10\ Cm;l_3=35\ Cm;$

$l_l=6\ Cm;k_{l1}=0.13077;k_{l2}=0.10196;\mu_x=1.2939;$

$\mu_y=1.6624$

The envenlope can also be obtained.

3.THE NONLINEAR TRANSFORMATION OF THE TRANSVERSE EMITTANCE

In the linear approximation,as well known,the emittance is an invariant of the motion

$$\frac{\varepsilon}{\pi}=\gamma\cdot x^2+2\cdot\alpha\cdot x\cdot x'+\beta\cdot(x')^2=Const. \quad (3.1)$$

But according to the principle of ultra–fast automatic cooling,the transverse emittance of a beam with constant energy should be shrinked in the nonlinear motion.In order to prove that deduction,we must consider the nonlinear transformation of the transverse emittance.

In the region of the quadrupole lenses,we still use the exactly linear tranfer matrix.But only in the region of the bending magnet with ultra–fast automatic cooling,the formulas (2.5) in the paper [3] are used for calculation of the nonlinear transformation.

We should point out that the magnetic field in the median plane is only dependent on the transverse coordinate.Therefore it is the simplest way for the field to equal a constant.Then

$$B_\eta=B=Const.;K=\frac{e}{p_0}\cdot B;$$

$$\frac{e}{p_0}\cdot A(\xi)=-K\cdot\xi$$

Then the formulas (2.5) in the paper [3] become

$$x_k=\{\frac{x_i}{Cos(\theta_{ei})+x'_i\cdot Sin(\theta_{ei})} \quad (3.2)$$

$$+\int_{\xi_i}^{\xi_k}[\frac{f}{\sqrt{1-f^2}}-\frac{f_e}{\sqrt{1-f_e^2}}]\cdot d\xi\}$$

$$\cdot[Cos(\theta_{ek})+x'_k\cdot Sin(\theta_{ek})]$$

$$x'_k=-\frac{Sin(\delta\theta_k)}{\sqrt{1-Sin^2(\delta\theta_k)}}$$

$$f=Sin(\theta_{ei}+\delta\theta_i)+K\cdot\xi$$

$$f_e=Sin(\theta_{ei})+K\cdot\xi$$

$$Sin(\delta\theta_k)=[C_i+Sin(\theta_{ek})]\cdot Cos(\theta_{ek})$$
$$-Sin(\theta_{ek})\cdot\sqrt{1-(C_i+Sin(\theta_{ek}))^2}$$

$$C_i=\frac{Sin(\theta_{ei})}{\sqrt{1+(x'_i)^2}}-Cos(\theta_{ei})\cdot\frac{x'_i}{\sqrt{1+(x'_i)^2}}$$
$$-Sin(\theta_{ei})$$

That can be considered as the analytical solution of the nonlinear equation of motion in the natural coordinate system. can be used for calculation of the nonlinear transformation.

We have taken two groups of the initial conditions

$x_i=0;\ x'_i=0.1\ Radian$

$x_i=0;\ x'_i=0.05\ Radian$

Then the calculations follow the tracks of the emittance phase points in the 360 periodicities or 60 turns.The corresponding emittance phase diagrams are illustrated in firgure 1 and 2,from which we can get some inspirations

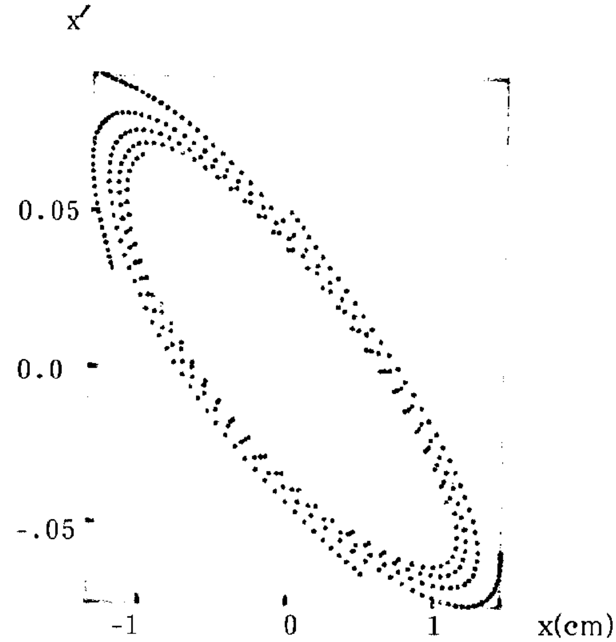

Fig.1,the phase diagram in small amplitude

1.The emittance phase trajectory is devided into five curves,which is not a closed ellipse any longer.The emittance phase points always approach to the center $x = 0, x' = 0$.That is a typical damping diagram.In the case of both larger and smaller amplitudes,there is the steady damping in the phase diagram in the stable regioin.The results show that the deduction from the principle of ultra–fast automatic cooling for beams is true indeed.

2.When the amplitude of the betatron oscillation is larger,there is obvious distortion in the emittance phase diagram.From the figure 2 we knom,it takes 15 turns or about 0.3 μs that the first phase point on each curve reach thefinal one.The phase area has contracted by a factor of $1/e$ in 15 turns or 0.3 μs.Therefore the corresponding cooling rate is much more rapid than the stochastic or the fast electron cooling by six or seven orders of magnitude. It is useful to realize continuous injection.

3.When the amplitude of the betatron oscillation is smaller,the emittance phase trajectory is quite similar to a ellipse,while there is obvious damping.Therefore it is not true that the emittance is an invariant in the

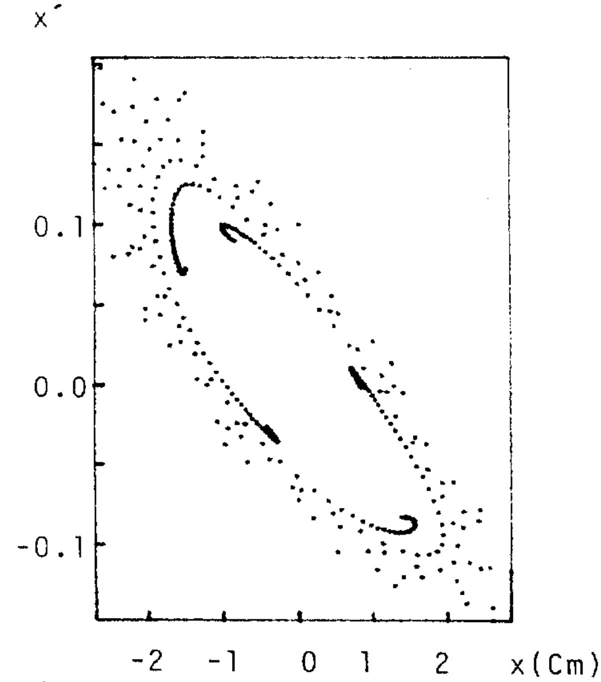

Fig.2,the phase diagram in large amplitude

tranditional theory.If only the emittance entirely is equal to zero,it really becomes an invariant.

4.The bending magnet as a cooling element may be got widespread use in various storage rings,because only the proper edge–focusing angle is need.Therefore the reliability and feseability are very clear.

5.In the case of the larger amplitude,the phase area is shrinked so fast that the continuous injection can be realized.

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