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ACCELERATION OF FUSION REACTOR EXHAUST PLASMA BY LINEAR INDUCTION ACCELERATOR

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Abstract

This paper presents analytical procedure for controlled acceleration of the divertor exhaust plasma contents, using plasma core typing LINAC. Design principle for the LINAC is based on Karlovitz criterion for the developed accelerating voltage within the magnetic boundary layer.

Introduction [1,2,3,6,7]

Current design of linear induction accelerators is centered on the selection of the core material from ferromagnetic group of ferrites, as well as perfect control of the coupled pulsing network to ensure efficient performance for providing required acceleration for heavy ion beam in fusion research operation.

In previous published work by this author, modified design conventional LINAC, has been presented using a highly conducting plasma with sustained pumping velocity replacing the conventional magnet as the new core either longitudinal or radial linear induction accelerator.

The motional plasma core interacts with pulsing current establishing sustained perturbations in the applied magnetic field with subsequent rise of periodic regions of boundary layer separation. The same work revealed that while magnetic perturbation will dominate the upstream region, effective accelerating potential prevails throughout the downstreat channel.

In this paper, plasma core LINAC will be visualized to accelerate the exhaust plasma of the fusion reactor. The accelerated plasma could be reused as the recycled accelerator core and this in turn could be reaccelerated again. In other words the work in this paper points to a novel design of feedback LINAC using the divertor plasma of the fusion reactor as its core and accelerated medium in one cycle.

Divertor Plasma [1,3]

Main ions content of the fusion reactor divertor plasma are: He^{+}, He^{++}, neutrals, electrons and other impurities.

Control parameters of the divertor are:

n = total concentration of He^{+} and He^{++} = n_1+n_2

n_1, n_2 = concentration function for He^{+} and He^{++} respectively.

α_1 = rate of generation for He^{+}

α_2 = rate of transformation of He^{+} to He^{++}

β = rate of impurity removal from the main reaction zone by diffusion.

Θ = divertor effectiveness parameter
= 1 for no effect
= 0 for perfect control

In the process of performance by the accelerator characterized in this paper, the following control conditions, are analyzed:

$$\beta = 0 \tag{1}$$

$$\alpha_1 = -\alpha_2 \tag{2}$$

$$\beta = -\alpha_2 \tag{3}$$

Criteria outlining the pace of acceleration and control for He^{+}, He^{++} well as guidence for the design of a plasma core type LINAC will be presented.

Criteria of Acceleration [2,4-7]

Single dimensional acceleration of a group concentrated ions along the divertor channel is expressed by:

$$\frac{\partial^2 x}{\partial t^2} = \left[\frac{\partial n}{\partial x}\,\frac{\partial^2 n}{\partial t^2} - \frac{\partial n}{\partial t}\,\frac{\partial^2 n}{\partial x^2}\right]\left(\frac{\partial n}{\partial x}\right)^2 \tag{4}$$

Acceleration of He^{+} and He^{++} which are the main content of the divertor plasma could be secured by identifying each mathematical differential parameter according to equation 4, and to the constraints indicated in equations 1, 2 and 3.

I. $\beta = 0$

$$\frac{\partial n_1}{\partial t} = \alpha_1 n + \alpha_2 n_1$$

$$\frac{\partial n_2}{\partial t} = \alpha_2 n$$

$$\partial^2 n_1/\partial t^2 = \alpha_2^2(\alpha_2 n_1+\alpha_1 n)-\alpha_1 n$$

$$\partial^2 n_2/\partial t^2 = -\alpha_1\alpha_2 n$$

$$\partial^2 n_1/\partial x^2 = n_1\left[\alpha_1-\alpha_2 - \frac{2\alpha_1^2}{2\alpha_1+\alpha_2} - \frac{\alpha_1(\alpha_1+\alpha_2)}{2\alpha_1+\alpha_2}\right]$$

$$\partial^2 n_2/\partial x^2 \longrightarrow \infty$$

$$\partial n_1/\partial x = n_1\left(\alpha_1-\alpha_2 - \frac{2\alpha_1^2}{2\alpha_1+\alpha_2}\right)x - \frac{\alpha_1(\alpha_1+\alpha_2)}{2\alpha_1+\alpha_2}\,x - n_{1-0}$$

$$\partial n_2/\partial x \longrightarrow \infty \tag{5}$$

II. $\alpha_1 = -\alpha_2$

$$\partial n_1/\partial t = -\left(\alpha_2 n_2+\beta n_1\right)$$

$$\partial n_2/\partial t = \alpha_2 n-\beta n_2$$

$$\partial^2 n_1/\partial t^2 = -\alpha_2\frac{\partial n_2}{\partial t} - \beta\frac{\partial n_1}{\partial t}$$

$$\partial^2 n_2/\partial t^2 = \alpha_2\frac{\partial n}{\partial t} - \beta\frac{\partial n_2}{\partial t}$$

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$$\partial^2 n_1/\partial x^2 = n_1\left[\beta-2\alpha_2+ \frac{\alpha_2(2\alpha_2+\beta+\beta\Theta)}{\beta+\beta\Theta + \alpha_2}\right]$$

$$\partial^2 n_2/\partial x^2 = -\frac{1}{\beta}\left[2\alpha_2 n_2 + \beta n_1\right] \quad (6)$$

III.

$$\alpha_2 = -\beta$$

$$\partial n_1/\partial t = -2\beta n_1+\alpha_1 n$$

$$\partial n_2/\partial t = -2\beta n_1-\beta n_2$$

$$\partial^2 n_1/\partial t^2 = -2\beta(-2\beta n_1+\alpha_1 n)-\alpha_1(\alpha_1 n-\Theta\beta n)$$

$$\partial^2 n_2/\partial t^2 = n(\alpha_2^2-\alpha_1\alpha_2-\Theta\alpha_2^2)+\beta^2 n_2$$

$$\partial^2 n_1/\partial x^2 = n_1\left[\alpha_1-\frac{\alpha_1(2\alpha_1+\alpha_2+\Theta\alpha_2)}{2\alpha_1+\alpha_2(2+\Theta)} - \frac{\alpha_1(\alpha_1+\alpha_2)}{2\alpha_1+\alpha_2(2+\Theta)}\right]$$

$$\partial^2 n_2/\partial x^2 = \frac{1}{\beta}(n_1\alpha_2+2\alpha_2 n_2) \quad (7)$$

Principal Design of Plasma Core Linac [2-7]

For conventional LINAC, the accelerating voltages V_{acc} is expressed by:

$$V_{acc} = \frac{A\,\Delta B}{\tau} \quad \frac{2\sqrt{b}}{\sqrt{a}+\sqrt{b}} \quad (8)$$

where

ΔB is the net perturbation in magnetic induction
τ is the total period of pulsed acceleration
a,b is the outer and inner radius of the LINAC
A is the effective cross-section of plasma flow

The accelerating voltage established by the plasma core type LINAC is expressed according to Karlovitz criterion where by,

$$V_{acc} = -\frac{4\pi}{c}\,\frac{\partial}{\partial t}\left[\frac{AB^2}{8\pi}\right]\Big/ B \quad (9)$$

where

B is the total magnetic induction exisiting within the plasma boundary layer and is a function of axial space change.

$\therefore$ From equation (9), the accelerating field E_{acc} is secured as below,

$$E_{acc} = -\nabla V_{acc}$$

And hence the accelerating force per ion-group becomes for He^+ :

$$(E_{acc})(n_1 e) = m_{He^+}\left(n_1\ a_1\right)$$

and for He^{++}

$$E_{acc}(2n_2 e) = m_{He^{++}}\left(n_2\ a_2\right)$$

where

a_1, a_2 is the acceleration imposed on He^+ and He^{++} raspectively indentified earlier in this paper. m_{He^+}, $m_{He^{++}}$ is the mass of H_e+ and He^{++} ions respective.

Conclucions [1-7]

1. Analytical criteria have been expressed for the mode of acceleration regarding the plasma content of the fusion reactor divertor which include He^+ and He^{++}. using plasma core type LINAC

2. Design criterion has been presented for the plasma core type LINAC using Karlovitz concept on magnetic boundary layer.

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