LONGITUDINAL AND RADIAL MOD. LINEAR INDUCTION ACCELERATOR WITH HOT CONDUCTING PLASMA CORE

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Abstract

Conceptual design of linear induction accelerator is presented using for the core continuum a highly conductive plasma with sustained pumping velocity. Karlovitz criterion of boundary theory is employed in the process of design.

Introduction

Development of heavy ions beam in fusion research characterized with pulse width of the order of nanoseconds, several kamps-current and energy content of the order of 20 Gev, is centered in the present modes of research, on the optimum design of core-type linear induction accelerators including the longitudinal and the radial types of core stacking.

However reliance on the characterization of ferromagnetic behavior of the solid core material for the culmination of maximum time rate in magnetic induction, requires the selection of magnetic core material of relatively high level magnetic saturation as well as large order of residual magnetization.

The utilization of solid soft magnetic core for the LINAC, introduced the unavoidable implication of providing highly effective and perfectly moreadequate pulsing network to tackle the functions of providing uniform pulsing, compensation for the significant uniform pulsing, compensation for the significant hysteresis and the eddy-current losses incurred by the cycle of magnetization and demagnetization and the function of exact magnetic resetting. Effective and reliable acceleration of heavy ions beam requires highly sensitive pulsing network to control the pulse duration, energy content as well as the bulk of the electric current carried out by the beam.

Besides the sensitive requirements, put on the pulsing network for effective performance of the linear induction accelerator, the presence of magnetic cores will add to the total mechanical weight of the entire accelerator. Also the magnetization properties of ferromagnetic material are subject to aging effects with adverse impacts on the uniformity of pulsing as well as on the pattern of resetting and the substantial iron losses incurred unless a shift is moved to use ferrites as core material.

Moderately Conducting Plasma Core

In this paper a principal change in the design of LINACs is introduced involving total departure from the use of ferromagnetic core material, which is the utilization of moderately conducting plasma as the core continuum at longitudinal and radial linear induction accelerators.

The geometrical design configuration could be visualized the same as the conventional core type LINACS with the moderately conducting moving plasma replacing the iron cores.

The properties of the conducting plasma proposed in this conceptual design is similar to the exhaust plasma of the Tokamak Fusion Reactor Divertor. Such plasma is characterized at low pressured temperature is of the order of $10^6 \text{K}$ with charge carriers of $\text{He}^+$ and $\text{He}^{++}$ ions, electrons and neutrals. The non-fossil moderately conducting plasma will move in the core continuum with continuous pumping velocity in the vicinity of sonic level.

Accelerating Voltage Build-Up

General equation for the LINAC:

$$V(t) = AB \left[ \frac{2 - \sqrt{2}}{\sqrt{2} - 1} \right] \text{volts-seconds}$$

where

$A$ = core cross-sectional area
$B$ = total perturbation in magnetic induction
$\tau$ = time duration for maximum magnetic induction
$a, b$ = outer and inner radius of accelerator core respectively.
$V$ = accelerating voltage induced/turn.

Voltage induced per turn for the conducting plasma core LINAC will derive from the principle of dynamic behavior within the magnetic boundary layer for the moderately conducting fusion plasma through the interaction with the charging plasma generated by the magnetic field.

The accelerating potential $V$ could be controlled by two modes

1. Karlovitz Criterion

This criterion is centered on the notion that voltage induced per-turn of coil surrounding the outer plasma boundary layer is proportional to the time rate of change of the ordered energy stored within the magnetic boundary layer and inversely responding with respect to the total magnetic induction prevailing in that region, i.e.,

$$V = \frac{\Delta F}{C} = \frac{\Delta U_m}{C} \frac{1}{\Delta B}$$

where

$F = \text{the induced accelerating electric field}$
$C = \text{velocity of light}$
$B = \text{total magnetic induction in tesla}$
$U_m = \text{ordered magnetic energy stored within the magnetic boundary layer}$

2. Pressure Control

This mode refers to the plasma pressure gradient developed across the continuum magnetic boundary layer, i.e.,

$$V = K \frac{C_p T_0}{B} \left[ 1 - \left( \frac{F_o}{F_1} \right)^{\gamma - 1} \right]$$

where

$K, C_p, T_0 = \text{constants}$
$F_o, F_1 = \text{field strengths}$
$\gamma = \text{adiabatic index}$

Abstract review of plasma physics and behavior and its utilization as core continuum for the heavy ions beam induced accelerator is presented using for the core continuum a highly conductive plasma with sustained pumping velocity. Karlovitz criterion of boundary theory is employed in the process of design.

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where

\[ B = \text{total magnetic induction within the magnetic boundary layer} \]
\[ G = \text{conducting plasma mass flow rate/unit length of the longitudinal or radial channel flow of the accelerator} \]
\[ \gamma = \frac{C_p}{C_v}, \text{ratio of the plasma specific heat at constant pressure with respect to that at constant volume.} \]
\[ P_o = \text{Plasma hydrodynamic pressure at the } (r=a) \text{ outer sheet of the magnetic boundary layer} \]
\[ P_i = \text{Plasma hydrodynamic pressure at the inner by sheet } (r=b) \text{ of the magnetic boundary layer.} \]

Example \((1-3,7,8)\)

For a longitudinal accelerator channel whose width is ten times the reference length, with ten per-cent for the magnetic Reynolds number and a unit impulse for the exciting current generating the state of magnetic induction, calculation for the induced magnetic induction within the magnetic boundary layer had been carried out followed by computation of the accelerating voltage per-turn of coil surrounding the longitudinal conducting plasma channel. Those computations are reflected in figures 1 and 2 respectively.

Fig. 1. Total magnetic induction within boundary layer.

Conclusions \((1-3,7,8)\)

1. Linear induction accelerator whether longitudinal or radial model, could be structured on a cored moving moderately conducting plasma with variable degree of ionization interacting with a magnetic pulsed field produced by a singularity current.

2. Accelerating voltage induced could be produced by the control of total magnetic induction prevailing within the magnetic boundary layer and the time rate of change of the ordered stored magnetic energy that is under expansion (known as the Karlovitz criterion).

3. Accelerating voltage per LINAC stage \((1-11)\) could be controlled by the total pressure gradient across the magnetic boundary layer due to magneto-fluid interaction between the pulsing current produced magnetic field and the moving conducting plasma in the region.

4. Build-up of the total accelerating voltage \((9,10)\) could be build by increasing the number of LINAC stages radially or longitudinally as well as pressure control of the plasma continuum flow.

5. Moving conducting, non-fossil plasma \((9,10)\) as the core continuum for LINACS will relieve the accelerator from eddy-current and hysteresis losses, the need for the compensating network required for pulse uniformity and pulse resetting required in the conventional iron-cored LINACS.

6. Increasing the plasma degree of ionization and ultimately the magnetic Reynolds number will lead to amplification in the induced magnetic field and eventually the accelerating voltage \((1-5,6,9,10)\).

7. Optimized control of the plasma continuum cross-section and time duration for max magnetic induction could be accommodated in the LINAC by simultaneous increase in the total magnetic induction and the generated accelerating voltage \((5,7,8)\).

8. LINAC using the exhaust plasma of the Tokamak fusion reactor for core continuum could be coupled to the same reactor, thereby producing the necessary accelerating high voltage ions beam for the process of fusion \((1-11)\).

9. Actual calculation for the accelerating potential has been carried out for helical-longitudinal channel through which moderately conducting plasma pumped with the order velocity of sonic level, resulted in identification of the total induction within the magnetic boundary layer and consequently the illustration of the accelerating potential which is concentrated in the upstream region and very close to the exciting source. These are shown in Figs. 1 and 2.

References


