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SYNCHRONIZED SWITCHING MECHANISM FOR THE LINEAR INDUCTION ACCELERATORS

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Abstract

Feasibility study for the introduction of the saturable resistor as switching device in the network of linear induction accelerators is presented. The new accelerator can provide charging as well as accelerating beam current time duration in the order of μ sec which is desired in the utilization of heavy ion beam for inertial fusion research.

Introduction[3,4]

Developments in inertia fusion reactor research point to the need of providing bean of heavy ions characterized with relatively long pulse duration, low ion kinetic energy and several kiloamperes current. This paper presents potential design improvement in the spark gap switching mechanism for the linear induction accelerator including the core type as well as the line type (radial pulse conical, radial pulse cylindrical and the auto-coaxial). The pulse switching involves the utilization of the saturable-resistor with hard magnetic material core. Switching behavior of the saturable resistor is associated with an open-circuit impedance at synchronized inrush ac exciting current and high frequency, while its ohmic value approaches almost short-circuit just at ac. current pick-up value and beyond saturation. Calculations have been carried out with explicit results concerning design and performance parameters (spectrum of beam energy, current, pulse duration, core loss and surge impedance) as well as synchronizing switching current and frequency for various modes of linear induction accelerators synchronized with an integrated saturable resistor switching mechanism. Also the saturable-resistor impedance as well as its resistance and reactance increase exactly linearly with frequency, hence exciting beam high repetion rate is central for effective utilization of this kind of reactor.

Review of Magnetization Characteristics of the Saturable-Resistor[1,2]

a. Surface characteristic impedance Z_s

$$Z_s = E_{\text{induced-fundamental}} / H_{\text{applied}} \qquad (1)$$

$$Z_s = r + jx$$

$$r = -\sqrt{\frac{\omega B_s}{\sigma H_m}}\,(k_2 + k'_2) \qquad (2)$$

$$x = \sqrt{\frac{\omega B_s}{\sigma H_m}}\,(k_1 + k'_1)$$

H_m = amplitude of applied magnetic field.

k_1, k'_1, k_2 and k'_2 are constants dependent upon the angular phase for initial magnetization, as well as field penetration properties of the saturable-resistor, ω is the exciting beam frequency, B_s is the level of magnetic saturation and σ is the reactor electrical conductivity expressed by:

$$\sigma = 1/ai_a + b \qquad (4)$$

i_c = beam charging current a and b are constant functions in terms of max. and min. ohmic values of the switching saturable-resistor.

b. Pick-up current for magnetization or relaxation.

$$i_{rms} = \frac{2.02}{\sqrt{2}} \quad \frac{H_c \ell}{N} \qquad (5)$$

H_c = coercive force in Amp.-Turns/inch

ℓ = length of magnetic path in inches

N = number of turns

Levels of H_c for three saturistors with different ALNICO cores are listed below.

ALNICO 5-7	700	Oersted Min.
ALNICO 8	1280	Oersted Min.
ALNICO 9	1500	Oersted Min.

c. Time rate of decay of transient field:

Experimental work conducted on a saturable-resistor with ALNICO 5-7 core, revealed that the entire transient field component for an applied 60Hz source diminished within 27 msec. and its time constant at 13.5 msec. Those time durations were totally independent of pre-magnetization levels for an applied D.C. field. Also it is found that time duration for pulse front rise at 60Hz is of the order of about 3.75 msec. Therefore it is expected that the combined effects of frequency and pulse current strength will stretch the powering beam pulse duration to the order of μsec. instead of Nsec.

Switching Mechanism for Induction Accelerators

From the preceding discussion concerning the complex dependence of all ohmic values for the saturable-resistor with respect to the amplitude of the applied field as well as the linear dependence on frequency, this device can feasibly offer a real promise as an operational switch for all models of induction accelerators.

For the core model accelerator, this device acts as closing switch with almost negligible impedance for powering beam current equal to or less than the saturistor pick-up current, while throughout the duration of the exciting pulse, the saturistor impedance increases very fast such that at the peak of the pulse, the saturistor imepdance will be extremely high approaching an open-circuit and hence terminating the duration of the powering beam pulse.

Also the switching performance of the saturable-resistor could feasibly be used in a similar pattern in the process of magnetic relaxation in the core induction accelerator for resetting the core to the level of residual induction in the demagnetization period.

For the switching performance of line type induction accelerator where the principle of induction of the accelerating field is based on changing with time the cross-sectional area of enclosed magnetic flux, the saturable-resistor automatic switching on and off operation is similar to that of core type accelerator, with the added constraints on the chang-

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ing area by the saturable-resistor surge impedance, which must be compatible with that of the line accelerator, (Z_o of accelerator = Z_s of the saturable-resistor).

Revised Forms of Induction Accelerators Basic Equations[3,4,5]

The saturable resistor function as automatic switch of the powering beam current requires close and careful interconnection with the accelerator network, resulting in required modifications of the basic performance acceleration equations.

I. Core type induction accelerator:

$$i_c \text{ at saturation} = \frac{\pi d^2}{4\rho_{total}} \sqrt{ba} + b \tag{6}$$

$$\rho_{total} = \rho_{core} + \rho_{saturistor} \tag{7}$$

$$\rho_{saturistor} = \frac{A}{\ell} \frac{E_{induced\ max.}}{H_{applied\ max.}} \tag{8}$$

where,

i_c = core-current
ρ = electrical resistivity
d = magnetic core foil thickness of accelerator
b,a= inner and outer radius of accelerator core.

$$V\tau_s(\Delta B)A \frac{2\sqrt{b}}{\sqrt{a} + \sqrt{b}} \tag{9}$$

$\Delta B = B_s + B_r$ will be controlled by the magnetization and relaxation behavior of the switching pattern of the saturable resistor.

However during demagnetization resetting, forced by the saturable-resistor hysterisis loop inwhich Br is almost equal to B_s, ΔB will approach $2B_s$ resulting in a larger induced field in a similar magnetization process with a change from $-B_r$ to $+B_s$.

$$\therefore \quad V\tau_s \simeq 2B_sA \frac{2\sqrt{b}}{\sqrt{a} + \sqrt{b}} \tag{10}$$

II. Line type accelerators:

This type includes, pulse line accelerator and electron auto accelerator.

Pulse line accelerator could be either of the radial conical type or the radial cylindrical.

a. Radial conical accelerator

Its characteristic impedance Z_o is expressed by,

$$Z_o = 120 \ \ell n \cot \frac{\Theta}{2} \ \Omega \tag{11}$$

$\Theta = 90^o + \phi/2$

ϕ = angular inclination of the cone.

Again since powering beam switching on and off is feasibly expected to be carried out by the extreme change in the impedance of the saturable-resistor, the new constraint on Z_o, above is the perfect matching with the surface impedance Z_s expressed in equation 1.

Z_s is a function of the pulse line frequency as well as the saturation level of magnetization and the pattern of field penetration through the ALNIC core.

$\therefore$ from Eq. 1 and Eq. 11

$$\Theta = 2 \cot^{-1} e^{\frac{Z_s}{120}} \tag{12}$$

According to Eq. 12, Θ has to be set with respect of the total magnetization behavior of the saturable-resistor switching performance, set by the requirement of impedance matching.

b. Radial cylindrical accelerator,

Its characteristic impedance Z_o is expressed by,

$$Z_o = 60 \ \ell n \frac{c}{b} = 60 \ \ell n \frac{b}{a} \tag{13}$$

where,

a,b and c are coaxial radii of the cylindrical accelerator channels. Similarly Z_o must be perfectly matched with Z_s of the saturable-resistor inorder to avoid completely any transverse field,

$$\therefore \quad \frac{c}{b} = \frac{b}{a} = e^{\frac{4_s}{60}} \tag{14}$$

c. Electron auto-accelerator,

Its characteristic imepdance Z_o is expressed by,

$$Z_o = 60 \ \ell n \frac{a}{b} = \frac{V_a}{I_c - I_b} \tag{15}$$

where

V_a = accelerating voltage
I_c, I_b = charging current and beam current respectively
a, b = outer and inner radius of the coaxial cylinders

Similarly the constraint imposed by the saturable-resistor switching mechanism is generated by the principle of impedance matching between Z_o and Z_s,

$$\therefore \quad \frac{a}{b} = e^{\frac{Z_s}{60}} \tag{16}$$

and

$$V_a = Z_s (I_c - I_b) \tag{17}$$

for max conversion efficiency, the beam current,

$$I_b = \frac{V_a}{2Z_s} \tag{18}$$

In all types of line accelerators mentioned, the charging current I_c has a duration in the order of μsec., provided by the magnetization and relaxation characteristics of the switching function of the saturable-resistor. Spreading the pulse duration of the charging current is essential for effective inertial fusion research efforts.

Conclusions[1-5]

1. Switching performance of saturable-resistor for core-type induction accelerator provides well defined automatic closing and opening switching by virtue of the extreme change in its characteristic impedance.

2. Impedance change of this switching device in all types of induction accelerators provides a reliable stretch of charging pulse time duration

of the order of μsec. which is desired in the field of accelerating heavy ions beam in inertial fusion.

3. The principle of impedance matching is central for interconnecting the saturable-resistor in accelerator network.

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