COOLING OF ELECTRON BEAMS

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Abstract

We considered cooling of electron beams in synchrotrons (storage rings) using gyro-oscillator by the example of gyromonotron as part of cyclic accelerator at straight-line portion. Gyromonotron is a simplest gyro-oscillator for converting energy of transversal beam energy to oscillation of electromagnetic energy. Cooling of electron beams due to synchrotron radiation (radiative “cooling”) is ineffective not only for energy W<50 MeV (low level of synchrotron radiation), but for high relativistic energies too, when positive radiative losses for cooling of a beam were prevailed by another increasing negative force named as Ternov-Sokolov effect (beam radius and emittance growth take place as result of quantum fluctuations of electron trajectories in accelerators). Hence, under high energies (starting from some hundreds MeV) synchrotron radiation is source not only focusing radiative cooling force, but defocusing force too due to recoil effect of electrons under radiation high energy quantum. Using gyromonotrons give possibility to increase maximal beam energy in synchrotrons through cooling of electron beam for prevention beam particles losses due to Ternov-Sokolov effect.

INTRODUCTION

We proposed cooling of electron beams in synchrotrons [1-3] (storage rings [4, 5]) using gyromonotron [6-12] for converting energy of transversal beam energy to oscillation of electromagnetic energy. A gyromonotron is a simplest gyro-device from possible variants (gyrotron, gyromonotron, gyro_BWO) for this purpose. A gyromonotron is cylindrical resonator placed into solenoid’s longitudinal magnetic field. We suggest effective cooling of electron beam for energy of one less 50MeV (low level of synchrotron radiation [13, 14]) and especially for energy W of electron beam more than some hundreds MeV, when starts action quantum fluctuations of macroscopic electron trajectories in accelerators (Ternov-Sokolov effect[15-17]). Analytical expression for Ternov-Sokolov effect is

$$W_0 > mc^2 (2\pi mcR / h)^{1/5}$$

where $h/2\pi$ is reduced Planck constant, R is synchrotron’s radius.

Expression for W_0 can be rewritten in a more convenient form for electrons

$$W_0(MeV) > 151.82(R)^{1/5}$$

where radius dimension is [R]=meter.

Quantum fluctuations (recoil of electrons) lead to growth of emittance through additional particles divergence, hence, as result, growth beam dimensions. As result, high energy electron beams have upper limit for synchrotrons energy despite all efforts for focusing one. For former LEP collider maximal beam energy was achieved approximately 100GeV for each beam (electron and positron). We proposed cooling of electron (positron) beams in synchrotrons by gyromonotron as part of cyclic accelerator (storage ring) at straight-line portion for multiple passing the same bunches. Gyromonotron converts energy of transversal movement electrons (positrons) into RF oscillation under corresponding longitudinal magnetic field for constancy of cyclotron frequency. Relativistic cyclotron frequency approximately has to equal RF frequency in synchrotron during accelerating process.

BASIC EXPRESSIONS

The gyromonotron is a HF oscillator for cm and mm band of wavelength. Electron (positron) beams with nonzero transversal velocities are used for excitation electromagnetic wave in resonator nearly cut off frequency. No transversal velocities mean no exciting of electromagnetic waves at all (in gyromonotron). Energy of transversal motion of electron beam converts into energy of electromagnetic wave during multiple passing the same bunches with synchrotron’s RF frequency f_0 through gyromonotron nearly cut off frequency $f_{cut\ off.}$ ($f_0 - f_{cut\ off.} > 0$). Output window is absent. We choose frequency $f_{cut\ off.}$ (and corresponding wavelength λ) as minimal frequency (H_{111} mode) for gyromonotron's resonator with length *L*. As well known [18], frequency $f_{cut\ off.}$ of H_{111} mode provides possibility to determine radius of the resonator

$$R = 1.841 / \sqrt{(2*\pi/\lambda)^2 - (\pi/L)^2};$$

$$R \approx \lambda/(2*1.71) \quad for \quad L^2 >> (\lambda/2)^2$$

We assumed above that resonator's length is

$$L/(2*R) > 1$$

for exciting of H_{111} mode.

Then it is possible for gyromonotron's solenoid to determine longitudinal magnetic field

$$H_{Z0}(kOe) \simeq 10.7 * f_0 / c$$

for low relativistic beam's energy (dimension $[c/f_0] = cm$).

For gyromonotron's operation at given frequency f_0 its needed realization of condition for relativistic cyclotron frequency

$$n * \Omega_{c.rel} / (2*\pi) \approx f_0; \ n = 1, 2...$$

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For phase focusing is needed

$$f_0 - n * \Omega_{c.rel} / (2 * \pi) > 0 .$$

A value n>1 is applicable under high energy beam.

For effective operation of installation is needed for H_{111} mode frequency of gyromonotron's oscillation have to be nearly cut off frequency approximately, for example, $f_{cut\,off} \approx 0.975 f_0$ .We consider radio frequency f_0=350MGHz (former LEP collider), cut off frequency $f_{cut\,off}$ =340MHz, wavelength $\lambda = 88.2\,cm$. Then, for sufficiently long resonator, gyromonotrn's radius is R=25.8cm, length of resonator for H_{111} mode is L>51.6cm and strength of nonrelativistic longitudinal magnetic field is $H_{Z0} \simeq 0.125\ kOe$. Conservation relativistic cyclotron frequency takes place under $H_{Z,REL} = \gamma H_{Z0} / n$, where γ is beam relativistic factor. Under $\gamma >> 1$ we have possibility to reduce longitudinal magnetic field using harmonics of cyclotron frequency n>1. Superconducting (SC) gyromonotron's solenoid in stored rings may be used for Top Up operation with constant stored beam current and energy [19].

CONCLUSIONS

Cooling of electron beams in synchrotrons (storage rings) using gyromonotron as device for converting energy of transversal motion of a beam into oscillation of electromagnetic energy is additional device for reducing transversal velocities of beam particles together with synchrotron radiation (radiative losses) for beam energies W> W_0. We suppose dominant role of beam cooling due to gyromonotron under high energies will cause neutralization of essential increasing of beam divergence due to quantum fluctuations of macroscopic electron trajectories. That emittance growth problem is main restriction of synchrotron for further growth of beam energy $W \geq 100\,GeV$ for future, for example, electron-positron collider.

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