GYROMONOTRON AS AN INSTRUMENT FOR ELECTRON BEAM COOLING IN ACCELERATORS

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Abstract
A gyromonotron is based on energy transformation of the transverse motion of beam particles into electromagnetic wave radiation. This property is proposed to be used for electron beam cooling in the accelerator. The energy of the transverse beam motion is converted into stimulated oscillations of the H_{111} fundamental mode in the gyromonotron resonator. The H_{111} mode excitation is the result of simultaneous excitation of H_{111} and E_{010} modes in the resonator of the given length L, where L is determined by by the start-oscillation condition for certain values of transit angle \( \theta_0 \) in a monotron. The H_{111} mode actually determines the amplitude of the pump mode, which exists at whatever value of transverse velocities of the beam. We have determined basic gyromonotron parameters such as the radius \( R \) and length \( L \) of the resonator, and the amplitude of the guiding magnetic field \( H_z \) for intended radio frequency \( f_1 \).

INTRODUCTION
We propose here cooling of electron beams in synchrotrons [1-3] (storage rings [4, 5]) using the gyromonotron [6-9] as a device for converting transverse beam energy into the oscillation energy of electromagnetic wave. The gyromonotron is the simplest gyro-oscillator among other similar devices (gyrotron, gyromonotron, gyro-BWO) used for this purpose. The gyromonotron is a empty cylindrical resonator placed in a longitunal magnetic field of the solenoid.

We suggest effective cooling of electron beam for energy \( W_0 \) of electron beam more than some hundreds MeV, when starts action quantum fluctuations of macroscopic electron trajectories in accelerators (Ternov-Sokolov effect [10])

\[
W_0 > \frac{m c^2}{2 \pi} \left( \frac{2 \pi m e R_s}{h} \right)^{1/5}
\]

where \( h / 2 \pi \) is reduced Planck constant, \( R_s \) is synchrotron’s radius.

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

\[
W'_0 (> 151.82)(R_s)^{1/5}
\]

where synchrotron’s radius dimension is \( [R_s] = \text{meter} \).

Quantum fluctuations (recoil of electrons) lead to growth of emittance through additional particles divergence, hence, as result, growth beam dimensions.

GYROMONOTRON PARAMETERS
The energy of the transverse motion of the electron beam is converted into the electromagnetic wave energy during multiple passages of the same bunches through the gyromonotron at the given radio frequency \( f_1 \). The output window for RF power is absent in our case. Let the frequency \( f_1 \) be the minimal frequency (H_{111} mode or E_{010} mode) excited in the gyromonotron resonator. Let us consider possible gyromonotron parameters.

As is well known [11], at the given frequency \( f_1 \) (and the corresponding wavelength \( \lambda_1 \)) of H_{111} mode it is possible to determine the radius of the resonator as

\[
R_s = 1.841 \sqrt{\left( \frac{2 \pi}{\lambda_1} \right)^2 - (\pi / L)^2};
\]

where \( \lambda_1 = \pi c / \omega_1 \) is the wavelength of the oscillations by the gyromonotron requires the initial transverse velocities to be of the same order of magnitude as the longitudinal velocities are. Then, we have to provide the monotron [12] condition for simultaneous excitation of H_{111} and E_{010} modes as a result of radiative instability [13,14].

This, in turn, requires realization of the condition for excitation of the mode E_{010} with frequency \( \omega_0 \) in the monotron resonator of length \( L \).

The transition angle for the mode E_{010} in the monotron is [12-14]

\[
\theta_0 = (2n+0.5)\pi V_z / c, n=1, 2, 3...
\]

(\( n \) is the number of the generation zone , \( V_z \) is the longitudinal velocity of the beam, \( c \) is velocity light). Then the resonator length is

\[
L = (2n+0.5)\omega_0 V_z / 2c
\]

If the frequency difference \( \omega_1 - \omega_0 \) for modes H_{111} and E_{010} correspondingly is less than a linear increment of radiative instability, then simultaneous generation of modes H_{111} and E_{010} is possible. Since this instability refers to the Raman-type instability, the increment may be less than the plasma frequency or, at best, equal to the plasma frequency of electron beam \( \omega_b \) [14]; then

\[
\omega_b > \omega_1 - \omega_0
\]

Expression (4) may be rewritten as
$n_b > ((\omega_1 - \omega_0)/(5.64*10^7))^2$ \hspace{1cm} (5)

where $n_b$ is a beam density.

Another condition for excitation of the two modes with the same increment is [13]

$$\Delta \theta = 0_0 - \theta_0 < \pi$$

where $\theta_0$ is the transit angle for the $H_{111}$ mode with frequency $\omega_0$. As a result, the generation of $E_{010}$ mode is possible due to the conversion of the longitudinal motion energy into the energy of HF oscillations in the monotron. Under realization of the above conditions, the $H_{111}$ mode can be simultaneously excited as a result of mode competition. In our case, the $H_{111}$ mode is in fact a pump mode leading to electron beam cooling under coherent beam radiation. In case of necessity, we can change the amplitude of the $E_{010}$ mode through some change in the resonator length.

The condition of mode competition for simultaneous excitation of $E_{010}$ mode and an additional $H_{111}$ mode is possible due to the conversion of the longitudinal magnetic field strength of $\beta L < 1/\gamma$. The $H_{111}$ mode actually determines the amplitude of the pump mode, which exists at whatever value of transverse velocities of the beam.

Preliminary investigations of the above described device for beam cooling may be carried out using the beam from an electron linac (or an electron gun) as it passes through the gromomonotron. Computer simulation of beam cooling is needed as part of preliminary investigations.

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