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Ions Acceleration in the Synchrotrons with Constant RF of Electrical Field

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Abstract

The way of protons and heavy ions acceleration in ordinary proton synchrotrons with constant RF of an electrical field is proposed. It is carried out, if acceleration is realize with high harmonic number q, and RF voltage V is changed so, that the particles hit the new neighboring separatrix on the following turn. This way requires the application of RF systems providing the high acceleration rate 100 MeV/m, and working with the constant frequency approximately several tens of GHz.

I. ACCELERATION WITH CONSTANT RF

With protons or heavy ions accelerated in synchrotrons up to high energies, their speed varies in a wide range making it necessary to change by several fold the frequency of RF-voltage. But it is not an easy task to perform. Currently, RF-systems providing a high rate of acceleration, up to 100 MeV/m and operating at a constant frequency of about several tens of GHz are under development. Such RF-systems are supposed to be used, for example, in the project VLEPP [1]. They may be used as well, and we intend to show it, to accelerate protons and heavy ions in conventional - proton synchrotrons. We mean another alternative method, when RF - frequency may be kept constant in case the acceleration is realized at a high multiplicity q, and RF-voltage, V, is changed so that every one cycle the particles fall within a new neighboring separatrix.

Really, a gain in the ion energy with the charge Ze every one return amounts to

$$dE = eVZ\cos\phi$$

and, hence, the period of its return reduces by the value

$$\Delta T = -\frac{1}{\omega^2}\frac{\delta\omega}{\delta E}dE = \frac{K}{\omega E}eVZ\cos\phi \ ,$$

where $\omega = v/\Pi$ is the frequency of ion return with the velocity v, K is the autophasing factor, Π is the synchrotron circumference. Requiring that the beam within one return should enter the neighboring separatrix: $\Delta T = T_{ret}/q = 1/q\omega$, we find the necessary RF-field voltage per turn

$$V\cos\phi = \frac{E}{eZqK} \ . \qquad (1)$$

It depends on the autophasing properties of a synchrotron and is to vary with a change in the ion energy. The transition to the neighboring separatrix requires a high rate of energy gain and high growth rate of the leading magnetic field:

$$\frac{1}{<B>}\frac{\partial <B>}{\partial\ t} = \frac{\beta c}{\Pi q\alpha} \ . \qquad (2)$$

It follows from Eqs. (1) and (2), that the multiplicity q of the RF-field should be high enough for the voltage V and growth rate $(\frac{\partial <B>}{\partial\ t})$ to be technically realizable. But in this case the energetic size of the separatrix is decreased and, hence, the momentum spread

$$\frac{dP}{P} = \pm\frac{2}{qK\beta^2}\sqrt{\frac{\tan\phi_s - \phi_s}{2\pi}} \qquad (3)$$

will be small in the beam captured into the acceleration regime. This difficulty may be avoided by cooling down the stored beam or injecting the beam having been cooled down. Ratios (1), (2), (3) impose certain requirements for the selection of the structure of a synchrotron ring-shaped electromagnet, in particular, it can not be isochronous, the coefficient α of the orbit expansion and the perimeter Π should be as large as possible and special straight section suitable for the electron cooling-down system to be arranged are to be provided.

As an example, consider a synchrotron with a circumference $\Pi = 150m$, $\alpha = 0.5$, $B_{max} = 1.5T$, accelerating heavy ions with $A/Z = 2$ from $W = 50MeV/n$ up to $W = 2.8GeV/n$ ($\gamma = 4$). Then the parameters of the RF-systems will be the following: the RF-amplitude varies during acceleration cycle from $9.7kV$ to $0.32MV$, ($\cos\phi_s = 0.5$), $q = 10^5$, $\omega = 62GHz$, $(\frac{\partial <B>}{\partial\ t})_{max} = 58T/s$. A beam with a momentum spread of $(dP/P)_{max} = \pm 1.6\cdot 10^{-5}$ is maintained in the synchrotron. The criterion [2] of betatron oscillation stability at a high multiplicity q is satisfied.

At $W = 2.8GeV/n$ $\beta = 0.79$ and, hence, circulation frequency changes slowly with the increased particle energy. The acceleration up to higher energies is reasonable with standard RF-station at a low q within a small range of frequency changes. That is why, the acceleration method proposed may be used in proton and heavy-ion synchrotrons:

1. to obtain a practically monoenergetic beam with an energy of several GeV/n bunched into q bunches with small dimensions;

2. to pre-accelerate protons or heavy ions from a low energy to an energy of several Gev/n at a constant

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frequency of RF-voltage. In this case obtained is a higher acceleration rate, no frequency change is required, and RF-stations are small-sized and take up not much space in the ring-shaped electromagnet of the synchrotron.

II. REFERENCES

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