BEAM DYNAMICS STUDIES IN THE MOSCOW MESON FACTORY STORAGE RING

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Abstract

The proton storage ring, which is under construction in the Moscow Meson Factory, differs from known magnetic lattice by operation close to transition energy. Therefore it is important to study particle motion in condition of high circulating current which is equal to 11.5 A. During the injection the space charge effects predominate and result to the essential evolution of momentum distribution. In order to ascertain the stability conditions the dispersion integral are investigated both longitudinal and transverse motion. Some results of the numerical simulation of the longitudinal motion are presented.

Introduction

The general functions and basic parameters of the Moscow Meson Factory Proton Storage Ring (PSR) have been presented elsewhere [1]. There are two modes in order to transform the linac beam time structure :

1. Fast extraction mode (FEM) converses of every linac macropulse into a single short bunch of 50-350 ns duration.
2. Slow extraction mode (SEM) provides the stretching of linac macropulse with duty factor up to 100% .

Special feature of the PSR is a isochronous mode of operation in order to keep the bunch structure in FEM. It means that the parameter $\eta=1/\gamma^2-1/\gamma_T^2$ is relatively close to zero. There is a number of effects disturbing the isochronous beam circulation. Particularly, the nonlinear effects have been studied in detail [2,3]. In both modes of storage ring operation the high stored current ($I \simeq 11.3$ A) and relatively low energy result in a strong space charge influence which have been studied recently for transverse motion [3].

In the following we will report on some features of injection as well as longitudinal and transverse instability problems.

Injection

The $H^- \to H^+$ charge exchange injection is planed to use in PSR. As target the carbon foil with 300 μg/cm^2 thickness is considered. 99% charge exchange efficiency is expected. Main problem of azimuthal painting is a formation of uniform longitudinal distribution along the ring for SEM. To do it the following relation is realized: $T = n\tau + \Delta\tau$, where T is the circulating period, $\tau = 5.045$ ns is rf period, $\Delta\tau$ is a small addition, $\Delta\tau \ll \tau$, $n=69$ is integer part of ratio T/τ. In order to study of longitudinal painting under strong space charge influence the computer code has been developed. Space charge forces are calculated in one dimensional model. Mainly the space charge forces change of momentum distribution of circulating beam. In more detail this effect is discussed in other paper of this conference [4].

The beam chopper located on 750 KeV transport channel will be used to create according pulse macrostructure for FEM. Again, space charge essentially effects on particle momentum especially on bunch edges that can excite transverse betatron oscillations. To avoid it the smooth bunch density distribution on the bunch edges must be realized during the injection. Proper azimuthal particle distribution can be created by chopper.

Uniform distribution of the circulating beam on the transverse phase space is important on a lot of reasons. Therefore the field in the injection bump magnets is changed in according with the law shown in Fig. 1. Vertical phase space is painted by the displacement of beam on the injection transport line by using of bump - magnets with the changing of field ~ $\sqrt{t}$ (t is an injection time). In Fig. 2 the location of phase ellipse centres of the injected beam and the contour of the circulating beam phase area are shown. Average number of foil passages per proton during the injection is ~ 30 for both modes. The calculations show that both transverse emittances and momentum distribution do not destroy essentially.

Longitudinal instability

In order to estimate an increment of longitudinal instability in FEM we consider continuous beam in the hydrodynamical approach of this problem. If $|\mathrm{Im}\ Z_1| \gg |\mathrm{Re}\ Z_1|$ the instability growth time is determined by

$$\tau_0 = \frac{4\pi}{n} \left[\frac{m_0\ \gamma\ R^2}{\bar{\omega}\ N\ e^2 |\eta|}\right]^{1/2} \frac{|\mathrm{Im}\ Z_1/n|^{1/2}}{\mathrm{Re}\ Z_1/n} \qquad (1)$$

Where m_0, e are the rest mass and charge of proton, $\bar{\omega}$ is the revolution frequency, N is number of particles, R is the ring radius. In our case the imaginary part of impedance is capacitive and determined by space charge mainly. The real part of impedance is caused by broadband impedance of vacuum chamber components. For estimation goals we consider the impedance at the cut-off frequency $\omega_c = n\ \bar{\omega}$ (n=280): $Z_1/n = (5-j\cdot 370)\Omega$. Then from (1) one follows $\tau_0 \simeq 1.9$ ms which is essentially larger than circulating time ~ 0.1 ms. In order to study the longitudinal painting and stability in condition of space charge effect and beam - environment interaction the computer code was developed. The simulation shows there is no instability in FEM with the real part of broadband impedance up to $\mathrm{Re}\ Z_1/n = 50\Omega$.

In the SEM the beam is stored up to 10 ms (but the current drops linearly with time). Therefore Landau damping of longitudinal coherent oscillations must be provided by momentum spread. By using the one dimensional computer simulation of injection process the final momentum distribution of circulating beam was found (Fig. 3). The initial Gaussian - like momentum distribution cutted on 3σ level and with 0.065% rms value has been took. For momentum distribution presented in Fig.3 the dispersion equation has been solved numerically. In Fig. 4 the curve corresponding to the growth time of 25 ms is shown on the plane ($\mathrm{Re}\ Z_1/n$, $\mathrm{Im}\ Z_1/n$). The operating point of storage ring is inside of this curve. Because of the momentum aperture of PSR is ±0.7% there is a big spare to realize more wider momentum distribution in SEM if it is necessary. The adjustment of momentum distribution of coming beam can be done by debuncher which will be installed downstream linac. For PSR conditions the longitudinal stability is provided by low energy tail of energy distribution. Therefore the beam extraction can be done by the movement of high energy tail into the internal target [5].

Transverse instability

The slow extraction in PSR is created by using the interaction of small fraction of circulating beam with thin internal target [5] therefore the coherent transverse oscillations can result to intensity modulation of extracted beam. The transverse impedance is created mainly by kicker-magnets, beam space charge and resistive walls. In the SEM the fast ferrite kicker-magnet, which is used in FEM only, can be removed and electrically shielded. By using the known expression [6,7] it is possible to calculate the impedance of PSR. In Fig. 5 the total real part of impedance vs mode number is shown. Required threshold impedance for the instability avoiding is determined by

$$|Z_\perp|_{th} \le \frac{\pi\ m_0 c^2 \beta\gamma}{e\ I\ \bar{\beta}}\ \frac{\Delta p}{p} \left[\ (n-\nu)\eta + \nu\xi\ \right] \qquad (2)$$

where ν is a betatron tune, ξ is a chromaticity, $\bar{\beta}$ is a average value of β-function. For PSR parameters $|Z_\perp|_{th} \ll |Z_{s.c.}|$, therefore there are transverse instabilities for a lot number of modes. Landau damping does not change increments essentially if $n \le 10$. To suppress the transverse instabilities a feedback damper is under development now. The maximum value of inserted decrement will be $\tau^{-1} = 10^4\ c^{-1}$ and the frequency bandwidth is 0.1 - 25 MHz to suppress the instability on modes as high as n=15.

References

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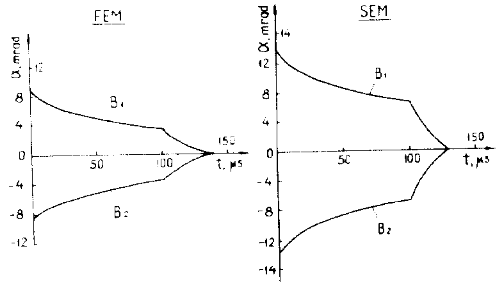

Fig. 1. Beam deviation angle created by injection bump-magnets vs injection time.

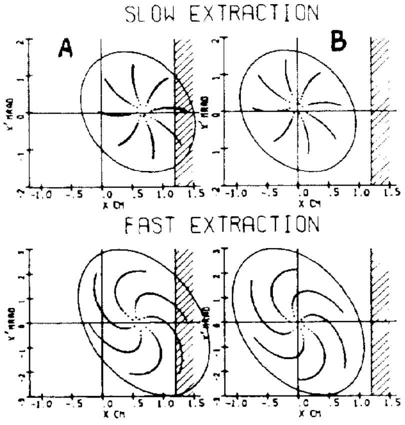

Fig. 2. The location of phase ellipse centres of injected beam just after injection completion (A) and after the bump-magnets switching off (B). Solid line is a beam contour. The target image is shaded.

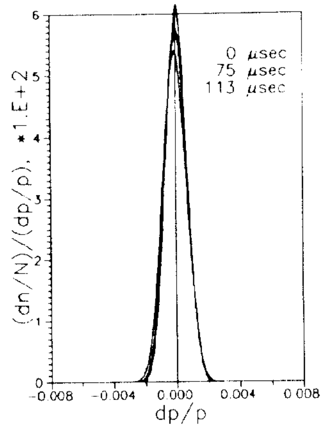

Fig. 3. The change of momentum distribution during injection.

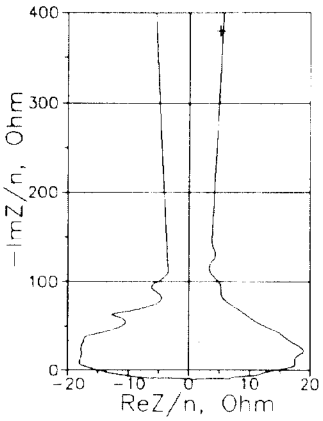

Fig. 4. Stability diagram.

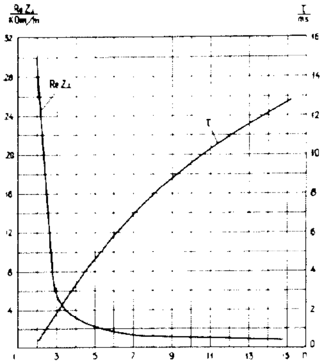

Fig. 5. The change of Re $Z_{\perp}$ and growth time vs mode number.