Study of the Painting Injection including the Space Charge Effect for the High-Intensity Proton Accelerator

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Abstract

For the hadron accelerator, the beam loss should be minimized because the beam loss causes the activation. In the high-intensity accelerator, the space charge force increases and causes the beam loss. Therefore, the Japan Proton Accelerator Research Complex (J-PARC) 3GeV rapid cycling synchrotron (RCS) is injected the beam with spreading the circulating beam size intentionally. This injection method is called “Painting Injection”. In order to optimize this method furthermore, we are studying with considering the optical parameter moderation by the space charge force.

Introduction

J-PARC 3GeV Rapid Cycling Synchrotron (RCS)

J-PARC comprises three accelerators and experimental facilities.

The accelerators play a role of source of the “high-intensity” proton beam.

Incoherent tune spread due to the space charge effect

The particles go through while oscillating.

The number of oscillation of one turn $\textbf{Betatron Tune} (v_x, v_y)$

An accelerator has the tune points where the oscillation amplitude increases immediately.

$\textbf{Resonance Points (or Lines)}$

The turn of each particle is decreased with each different decrement.

$\textbf{Incoherent Tune Spread} (v_{\text{incoh}}$ spread)

we should suppress the $v_{\text{incoh}}$ spread in order to avoid the resonance lines !!

Injection Method of RCS

To achieve “High-Intensity”...

• The beam is injected turn by turn dividing 235 pulses.

• The H- beam is injected and exchanged to proton by charge-exchange foil at Injection point.

Multi-Turn Charge-Exchange Injection has been adopted.

If the distribution is ideal “K-V distribution”, all particles receive same space charge force.

$\textbf{Anti-Corr.}$ doesn’t spread (only shift) and $\textbf{Anti-Correlate}$

Painting Injection

During injection, we change the injection beam position and angle depending on time.

in the accelerator, the particles move along the phase space oval each turn.

if position and angle is moved as follow.. $x, x' \propto \sqrt{\text{time}}$

The charge density is reduced and formed uniform.

$\textbf{The} v_{\text{incoh}} \textbf{spread is suppressed} !$

Painting Injection Modification

To realize K-V like distribution, 2 manipulations are applied as follow.

1. Applying $y'$ offset

Painting injection is performed to let Injection beam tail into same emittance area for Horizontal and Vertical.

But... Because the slope of injection beam oval is opposite from the Ring, Anti-Correlate Painting run off the ideal K-V condition (present).

$\textbf{Add offset to } y' \textbf{ (only offset)}$

2. Time function change

When the space charge force is strong... Injection beam less spread than expected on the Horizontal phase space because the oval become narrow.

To reduce the change of the oval and spread injection beam... Modify the time function as follow ($\propto \sqrt{\text{time}}$)

$\textbf{Tune shift and } v_{\text{incoh}} \textbf{ spread is reduced} !!$

Optical Parameter Moderation by the space charge force

Transverse motion including space charge force satisfy the “Envelope equation” regardless of the distribution approximately as follow...

$\frac{dx^2}{ds} + k(s) \frac{dx}{s} = \frac{1}{\chi^2 + y^2} + \frac{1}{\chi + y}$

$\textbf{Phase oval is changed.} \quad \textbf{Particular, Horizontal Phase space oval become long and narrow in RCS.}$

Summary

We are studying for the Painting Injection including the space charge force in order to reduce the beam loss as possible.

It is expected that the tune shift and the $v_{\text{incoh}}$ spread could be reduced using existing system more than ever before.