STUDY OF NON-EQUI-PARTITIONING LATTICE SETTINGS AND IBS EFFECTS FOR J-PARC LINAC UPGRADE

Y. Liu#, M. Ikegami, KEK/J-PARC, Tokai, Japan

Abstract

For the upgrade of J-PARC LINAC from 190MeV to 400MeV the annular coupled structure (ACS) was applied with frequency jump from 324MHz to 972MHz. Equi-partitioning (T=Tx/Tz=1) and envelope-keeping lattices (T=0.3) are studied for the structure and frequency transition. IBS loss rate at this ~110m part is as high as 4×10^{-5} for EP setting, which can be mitigate to 1/3 with non-EP setting with T=0.3. But at the same time obvious emittance exchange were found. The transverse emittance increases by 50%, with no particle loss found in million-macro-particle simulation. The present work is enough to show the problem and possible directions for the solutions.

INTRODUCTION

For the coming upgrade of J-PARC[1], the power of linac will be greatly increased. This may open many interesting questions. For instance, for efficient acceleration from 190MeV to 400MeV the annular coupled structure (ACS) was applied with frequency jump from 324MHz to 972MHz. Upstream part of J-PARC linac before frequency jump is set with the equi-partitioning (EP) condition [2], which prevents from the coherent resonances. If EP condition is kept for the downstream part, due to the frequency jump, the transverse focusing should also "jump" with shrink of envelop. This affects the interactions between particles, including the intra-beam stripping (IBS) effect [3] in the H- beam by increasing the loss rate.

In order to clarify the "reciprocal" relation between EP-keeping and IBS loss mitigating here, the temperature ratio between transverse and longitudinal planes, the T ratio, is used as a knob to explore the lattice parameter space.

In this paper T-ratio is defined as "Tx" over "Tz", which is convenient because the longitudinal lattice is normally already decided by the best acceleration efficiency.

Two examples are studied with T ratio of 1 and 0.3, i.e. keeping the EP condition or keeping the transverse envelop. The latter shows mitigation of IBS loss rate per unit length to 1/3, from 0.13W/m to 0.043W/m at the design duty cycle of 2.5%, while the simulation shows obvious emittance exchange from longitudinal plane to transverse ones at the upgraded peak current of 50mA.

Lattice Studies

The settings of transverse-longitudinal EP and EP-like lattice are obtained with smooth approximation with axis symmetry (2D). With given longitudinal phase advance, rms matching conditions at both planes and the given T ratio, the envelope of both planes and transverse phase advance are solved, for the 72 DTL cells (38, 21,13 for DTL 1-3), 32 SDTL cells and 42 ACS cells.

Normalized emittance ε_x=0.21, ε_z=0.30 π mm mrad, peak current of 50mA are applied in the calculation, based on the new RFQ design (J-PARC RFQ3).

The settings are done with $T=T_x/T_z$ ranged from 0.2 to 2, according to about 60% and 130% of the quadrupole gradient for T=1. The results are shown in Fig.1, on the tune diagram (Hofmann Chart) for $\varepsilon_x/\varepsilon_z$=0.7.

Settings for weaker focusing for upstream DTL and SDTL cells are not shown due to aperture limit for the practical usage.

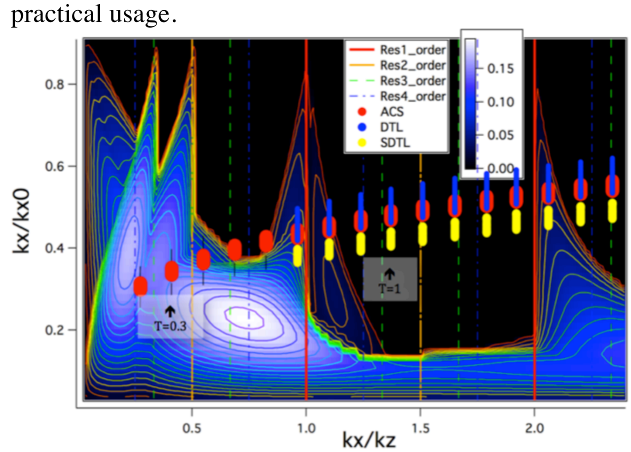

Figure 1: Analytical results of lattice exploring for J-PARC LINAC, on tune diagram for $\varepsilon_x/\varepsilon_z$ = 0.7, T-ratio ranged 0.2-2.0.

The envelope calculated for different T for ACS part is shown in Fig. 2, for choosing envelope transition for the frequency jump.

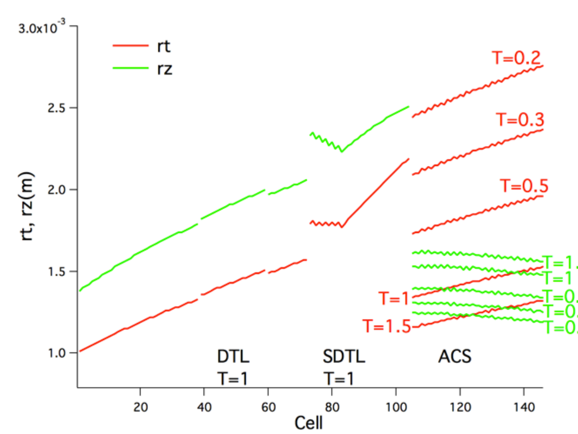

Figure 2: Transverse and longitudinal envelope for EP and EP-like settings, with smooth approximation.

The calculation for the lattice setting using smooth approximation is verified with envelope calculations with linear transfer maps with periodical matching with and

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without current using Trace3d. An example shows the qualitative consistency of smooth approximation and envelop equation calculation with linear map for 50mA, T=1, with the phase advance shown in Fig.3, used for a first benchmark.

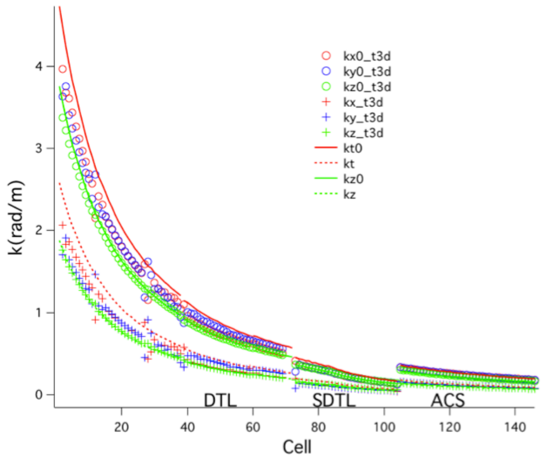

Figure 3: Qualitative consistency of smooth approximation and envelop equation calculation with linear map for 50mA, T=1.

MATCHED LATTICE FOR T=1 AND 0.3

It is found that T=0.3 is most close to the continuous connection of transverse envelope at the frequency transition, according to about 70% of quadrupole gradient of T=1. It is noticeable that the jump of longitudinal envelope cannot be mitigated due to the increase of longitudinal focusing at the frequency jump.

Matching for the transitions of lattice structure and RF frequency between SDTL and ACS is achieved at MEBT2. Preliminary matching lattices, shown using Trace3d output in Fig. 4, for T-ratio of 1 and 0.3 are to be used for IBS calculation and input of IMPACT simulations.

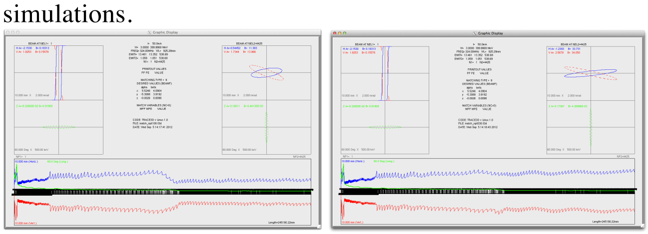

Figure 4: Matched lattice for EP or transverse envelop keeping settings for ACS, T=1(left) and T=0.3(right).

Further interesting studies and refinement works can be done at the transition section at MEBT2. For instance, for EP case there is transverse envelope transition, and T transition for the case of setting ACS cells at T=0.3.

The envelope and divergence is shown in Fig. 5 and Fig. 6, which is helpful to understand the IBS loss for the settings. IBS loss rate increases with decrease of envelope or the increase of divergence.

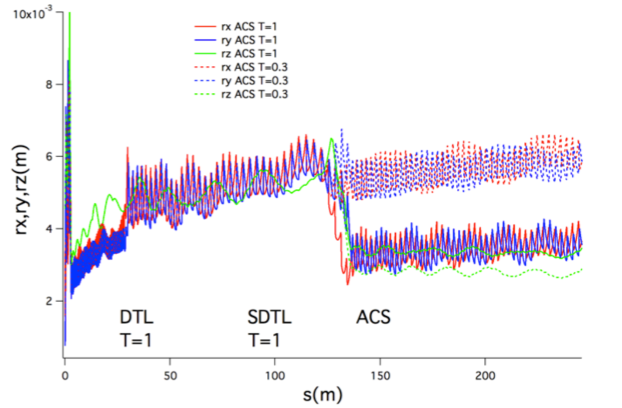

Figure 5: Comparison of envelope for ACS at T=1 and 0.3.

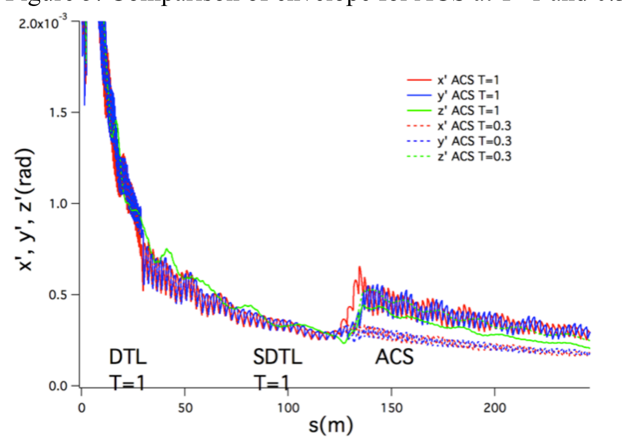

Figure 6: Comparison of divergence for ACS at T=1 and 0.3.

INTRA-BEAM STRIPPING (IBS) LOSS FOR THE SETTINGS

Particle loss and corresponding power were calculated based on the reference [3] and the above matching calculations, with peak current of 50mA at design duty of 2.5%, as shown in Fig.7 and Fig.8.

The beam loss rate per meter is more than 2×10^{-7}/m in ACS part for T=1, and reduced to 1/3 with T=0.3. The total power loss in the 110m-part can be reduced from 13.2W to 4.3W.

It is shown that for the continuous transverse envelope setting for ACS with T=0.3, compared with upstream equi-partitioned DTL and SDTL, the IBS rate is not continuous because of the decreased bunch length and increased longitudinal divergence.

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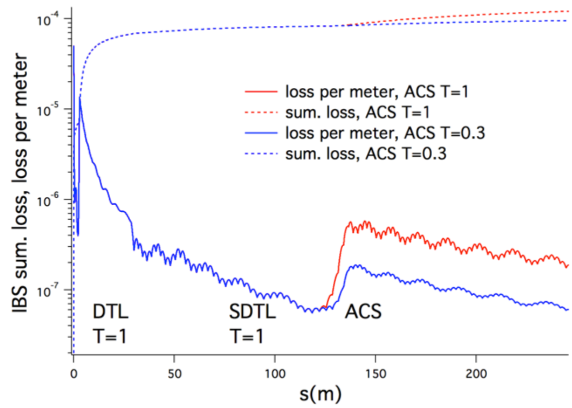

Figure 7: IBS loss rate, per meter and accumulation.

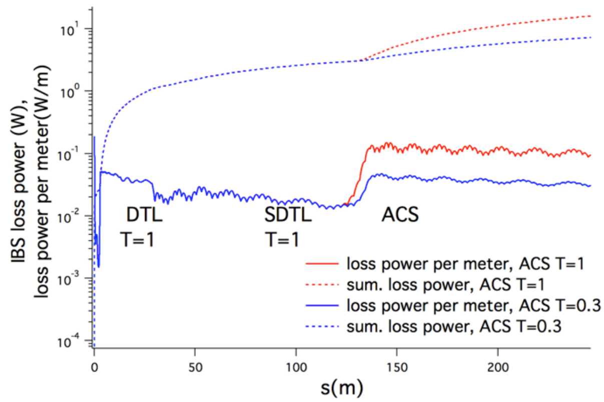

Figure 8: IBS loss power for duty cycle of 2.5%, per meter and accumulation.

The beam loss power level of 0.12-0.14W/m in the equi-partitioned ACS is very similar to the SNS IBS loss power level. So it is in the same situation that heating is not significant but radiation is considerable.

With ACS part set at T=0.3, the IBS can be mitigated to 1/3, based on the envelope calculations. But for this particular case it is in an unstable area in the Hofmann Chart. It is necessary to check the overall effects with simulation.

IMPACT SIMULATION FOR THE RESONANCE CROSSING

Simulation with IMPACT code [4] is used to check the resonance crossing for T=0.3 case compared with EP settings. Emittance exchange was found, beginning with εx=0.27, εy=0.27, εz=0.35mm mrad at MEBT2, changed to be 0.4, 0.35,0.24mm mrad at end of ACS part. The rms emittance growth in the horizontal and vertical planes are 50% and 30% respectively, with ε_z decreased by 30%. The total 6D emittance increased by 37%, as shown in Fig.9. This trend is consistent to the predictions in the Hofmann chart.

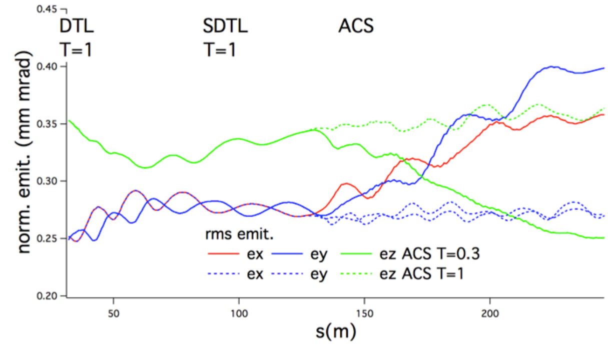

Figure 9: The rms emittance simulated with IMPACT for J-PARC LINAC, with ACS setting at T=1 and T=0.3 with initial water-bag distribution.

No particle loss is found in the simulation by applying 1 million macro particles, with initial water-bag distribution. Simulation with initial Gaussian distribution is also applied. No significant difference is found in the ACS part.

The simulation work is still very preliminary. The simulations were performed on the whole LINAC after RFQ. About 25% increase of emittance at all the planes already occurred before middle of DTL, which make much mixings for the later results and loss of information. More systematic and consistent works are planned.

CONCLUSION AND DISCUSSIONS

Equi-partitioning (T=1) and envelope keeping lattices (T=0.3) are studied for the structure and frequency transition for the J-PARC LINAC upgrade. IBS loss rate at this ~110m part is as high as 4×10^{-5} for EP setting and can be mitigate to 1/3 with non-EP setting with T=0.3. But at the same time large emittance exchange were found. The transverse emittance increases by 50% and 30%, no particle loss found by million-macro-particle simulation.

The above results show the difficulty to choose between keeping EP and other conditions like keeping relevant envelope to mitigate other beam collective effects like IBS.

The T=0.3 case might be too extreme from stability. From Fig.1, much safer settings can be chosen, but possibly with less effective mitigation against IBS. Beside pure EP-like settings with definite T-ratio, it is also possible to find an optimized path to achieve smooth transition with least emittance growth and beam halo formation. Overall considerations are necessary with re-arrangement of longitudinal focusing at the nearest cells to the frequency transition.

J-PARC LINAC is unique to cover most of the discussed range of the T-ratio at the ACS part. Yet there are many difficulties for theory and experiment studies besides other practical reasons. Normally the longitudinal information is known very little. But the longitudinal emittance is fundamental for setting the EP condition and defining the stability. During this summer shutdown 3 bunch shape monitors were installed at MEBT2. They will be promising for this issue.

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