ビームロスの KEK コンパクト ERL におけるビームハロー伝播と緩和

BEAM HALO PROPAGATION AND MITIGATION FOR BEAM LOSS STUDY AT KEK COMPACT ERL*

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Abstract

Longitudinal and transverse beam halo measurements were evaluated during recent KEK compact ERL (cERL) operation, aiming to increase the beam current up to some uA. As far, the beam current was increased; we expect some essential changes in the beam dynamics issues, such as beam halo formation and propagation. First step towards the stable and safe operation of the machine was longitudinal beam halo measurement. We investigate beam halo originated from characteristics and imperfections of an electron gun system. Then we perform the corresponding start-to-end simulation using the tracking codes GPT (General Particle Tracer) and ELEGANT to apply the beam loss distribution along the beam line. Thus, the impact of collimators was obtained. Transverse beam halo measurement allows the beam halo mitigation. Both experimental and simulation studies of the beam halo dynamics are in progress. The current results on this topic are presented in this paper.

1. INTRODUCTION

During the last cERL commissioning (January – April, 2015) a high repetition rate (162.5 MHz) electron beams of a 20 MeV energy were produced to test the Laser-Compton scattering (LCS) facility newly installed to the beam line [1] – [2]. Since the average current in the machine is significant (from some pA up to some μA), the beam halo management is extremely important topic for the successful operation.

The beam halo is known to be a collection of particles of any origin and behaviour which lies in the low density region of the beam distribution far away from the core [3]. The beam halo is a key parameter to be improved for any high intensity accelerator. Therefore, experimental measurements and analytical evaluation of the halo distribution are very important to understand the way to minimize the number of particles in the tail region of the beam distribution.

We assume the main reasons of the beam halo in cERL to be:

- Dark current from the gun and from accelerator cavities [4];
- Off-energy beam tails due to mis-steered beam;
- Scattering from residual gas, Touschek scattering [4];
- Beam line elements misalignment, kicks from the couplers, and so on.

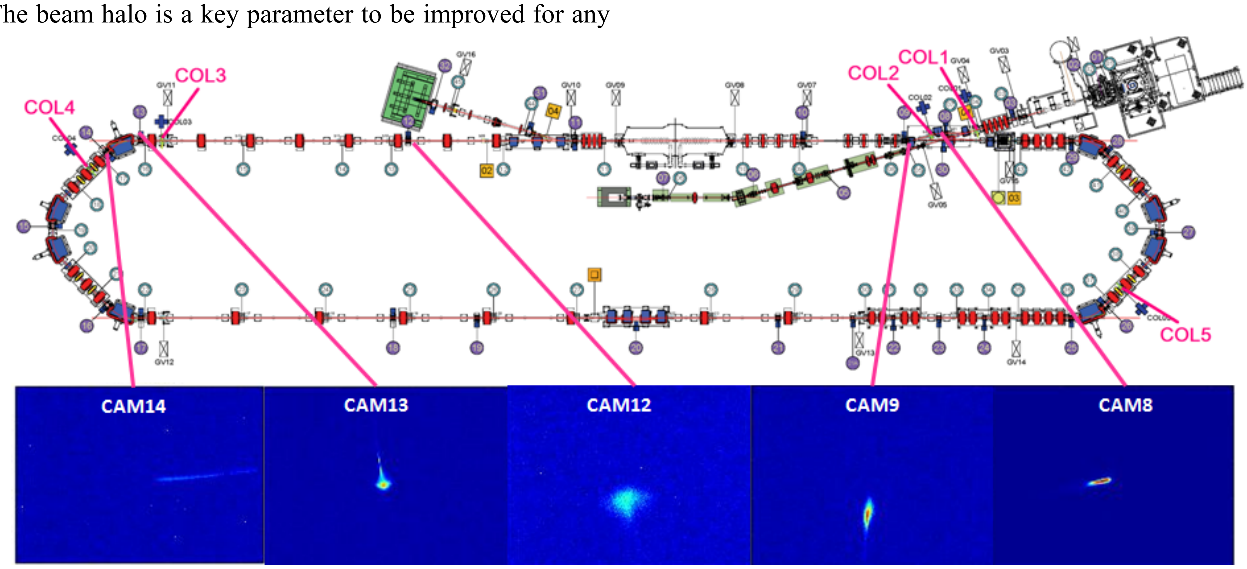

Figure 1: Layout of cERL. Collimators positions and tail profiles screen captures for laser phase +20 deg (42 ps tail).

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The main goal of our research is to understand the beam halo formation processes and to obtain beam halo and corresponding beam loss distribution. Thus, we aim to minimize the radiation damage of the accelerator elements, to avoid emission of secondary electrons, to lower the irradiation outside the machine and nuclear activation of the transport channel, to prevent cavity's quenches, to suppress noise inside detectors, and to reduce the beam loss.

2. MEASUREMENT

Last year commissioning observations demonstrated the presence of the low-dense low-energy tail in the injector line and in the straight section up to the 1st arc (see Figure 1), originated in the gun. The simple back-to-envelope estimation based on the value of the RF cavity phase shift gives the probable length of this tail from 40 ps up to 100 ps. To study the tail distribution and the tail propagation, we perform a series of measurements. The beam at the beam current of 0.5 pA was stretched using the 1.3 GHz laser phase shift from the default setting (-3.2 deg.) [5] – [6] in both directions: up to +40 deg. (84 ps tail behind the core) with the step of 10 deg., and up to -70 deg. (147 ps tail before the core) with the step of 20 deg. Then we took all screen capture of the tail profiles (see Figure 1).

Next step of the measurement was to examine the impact of collimators into the beam loss. For this purpose we used the same stretched by the laser phase shift beam. The collimators were inserted successively, while we observe the loss rate growth/decrease by the beam loss monitor. The layout of the collimation system is given at Figure 1. Collimators 1 through 5 is composed of one horizontal and one vertical pairs of cylinder collimator jaws, each independently and remotely adjustable in gap and center. The jaws made of copper. Collimators 1 – 3 have a round beam duct of 50 mm diameter, and collimators 4 – 5 have an octagonal shape beam duct 70 x 40 mm [7]. First, COL1 (before the merger section) was inserted from the top up to 0.98 mm to the beam center while the beam was stretched by the laser phase to produce the tail (the reasonable way of collimator insertion was obtained during the particular measurement [8]). No essential changes in the beam loss were observed. Then COL2 (merger section) was inserted from the right up to 0.94 mm to the beam center. This yielded 1st arc entrance loss and 1st arc loss decrease. COL3 was inserted up to 0.45 mm from the top, while COL2 was inserted from the right up to 2.4 mm from the beam center next. And again no essential changes in the beam loss were observed. Finally we inserted COL4 from the left up to 5.19 mm, while COL2 was inserted from the right up to 2.4 mm as before. Therefore the loss in the 2nd arc decreased.

We found essentially long tails on the profiles from Cam 9, Cam12 and Cam13. They became even worse when the beam was stretched by the laser phase shift. This tail seems to originate in the injector line. We assume it to be the result of the injector line element misalignment. Later we proof it by performing additional adjustment in the transverse match in the injector cavity.

3. SIMULATION

3.1 Beam Halo Tracking

To obtain the beam loss distribution and lost current values, we reproduce the measurements conditions in the simulation, using standard tracking codes.

First, to evaluate a start-to-end simulation, 100 ps tail from the gun of the specific distribution was generated using GPT (General Particle Tracer [9]) routine, creating the longitudinal distribution by convolution of cathode response function with the Gaussian (core) [10]. No SC (Space Charge) effect was included. The input parameters are listed in Table 1.

Table 1: Input Parameters

Number of particles	5000
Beam energy	2.9 – 20 MeV
Total charge	0.5 pC
RF frequency	1.3 GHz
Rms emittance	1 mm mrad
Bunch length (core, tail)	2.2 ps, 100ps

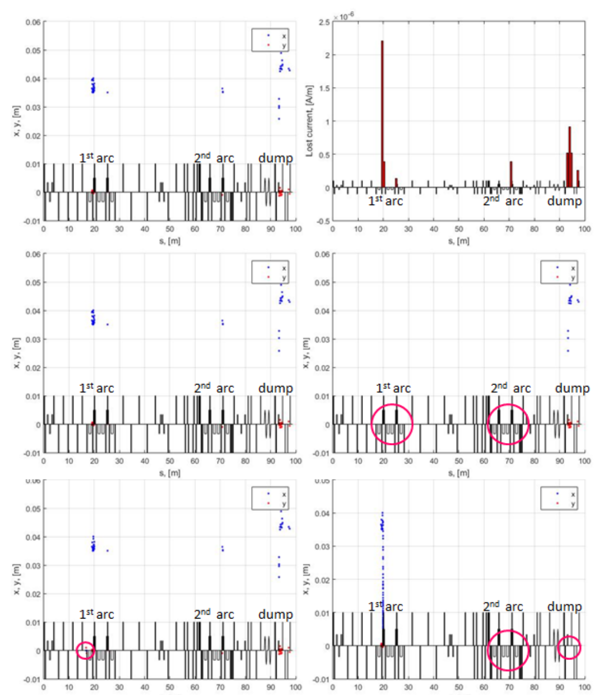

Figure 2: Loss distributions: 40 ps tail (top-left), 40 ps tail lost current (top right), tail + COL1 (middle-left), tail + COL2 (middle-right), tail + COL2 + COL3 (bottom-left), tail + COL2 + COL4 (bottom-right).

Table 2: Tail Loss Summary

Position	Peak cur., μA	Ave. cur., μA/m	% of beam
Inj. line	-	-	-
1st arc	2.21	0.16	0.42
2nd arc	0.39	0.001	0.06
Dump	0.91	0.32	0.34
Total	2.21	0.04	0.82
Impact of COL1 (up to 0.98 mm from the top)			
Inj. line	0.26	0.05	0.18
1st arc	1.95	0.14	0.38
2nd arc	0.39	0.002	0.06
Dump	0.91	0.31	0.32
Total	1.95	0.04	0.94
Impact of COL2 (up to 0.94 mm from the right)			
Inj. line	0.39	0.15	0.50
1st arc	-	-	-
2nd arc	-	-	-
Dump	0.39	0.02	0.32
Total	0.39	0.02	0.82
Impact of COL2 + COL3 (up to 2.40 mm from the right, and up to 0.45 mm from the top)			
Inj. line	0.13	0.007	0.04
1st arc	1.82	0.21	0.34
2nd arc	0.39	0.002	0.06
Dump	0.91	0.32	0.34
Total	1.82	0.05	0.78
Impact of COL2 + COL4 (up to 2.40 mm from the right, and up to 5.19 mm from the left)			
Inj. line	0.13	0.007	0.04
1st arc	5.98	0.08	1.22
2nd arc	–	–	–
Dump	–	–	–
Total	5.98	0.08	1.26

The output tail distribution (at the exit of the main cavity) has about 40 ps length due to the acceleration in the main cavity. Simulation background had been chosen to meet the measurement conditions. There is also the restriction given by the radiation background measurement [11]. Then, obtained tail distribution tracked through the accelerator matrix (from the main cavity exit to the dump) via ELEGANT tracking code [12]. Thus, we evaluated loss distribution along the beam line and lost current values to judge potentially dangerous regions of the beam line.

3.2 Collimator's Impact to the Beam Loss

Then, the collimators were involved into simulation in accordance with the measurement. This allows to judge whatever loss location is at or away from the collimators. The loss distribution results for 40 ps tail and those for the COL 1 – 4 are given at the Figure 2. Lost current calculation results are summarized in Table 2. Thus, losses due to beam tail (~40 ps) only could be up to 0.82% of the beam.

The draft collimators layout (see Figure 1) mostly effective to localize losses of beam halo away from the important parts of the machine. COL2 inserted from the low energy side is a best candidate to decrease the beam loss in 1st and 2nd arc sections of the recirculating loop. One should be careful on using COL4, because it could increase the loss in the 1st arc from 0.82% up to 1.26% of the beam. But it seems to help to get rid of the loss in the 2nd arc section and in the dump line. Insertion of COL1 slightly increasing the total loss (from 0.82% up to 0.98%) and insertion on COL3 slightly decreasing the loss (from 0.82% up to 0.78%), while the loss points stay the same.

3.3 Other Sources of Beam Halo

Not all of the beam halo profiles, obtained during the measurements, can be fully explained only by the longitudinal distribution of the bunch tail, originating in the gun. For example, vertical halo profiles at Cam9, Cam12, and Cam13 (see Figure 1) are such ones.

To find the reason of such profiles, we simulated misalignment of injector line elements in the transverse plane (buncher, injector cavity, and in addition main cavity). Such halos are explained by injector cavity kicks due to the vertical misalignment of a few tenths of mm up to 1 mm.

Other possible source of the halo could be kicks from the steering coils, and from the HOM/input couplers. To understand the halo dynamics properly, such kicks should be studied in details.

4. CONCLUSION

A series of beam halo measurements were performed to understand the halo formation and halo propagation mechanisms in cERL. The study of collimator's impact to the beam loss concludes that we can effectively protect most of the linac regions from the lost beam power with the present collimation system. A small adjustment in the injector line helps to get rid of halo in the merger section and after it. Both experimental and simulation studies of the beam halo dynamics are in progress. Thus, steps will be taken to account for the halo particles due to the mis-steered beam, focusing mis-matching, and wakefields.

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