NEW MEASUREMENTS OF PROTON BEAM EXTINCTION AT J-PARC

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Abstract

Proton beam extinction, defined as a residual to primary ratio of beam intensity, is one of the most important parameters to realize the future muon electron conversion experiment (COMET) proposed at J-PARC. To achieve the required extinction level of 10^{-9}, we started measuring extinction at main ring (MR) as its first step. According to the various measurements done at the different positions, empty RF buckets of RCS, which were considered to be swept away by the RF chopper, contained about $10^{-7} \sim 10^{-5}$ of the main beam pulse due to chopper inefficiency. We have developed a new beam monitor with improved performance for further studies at the abort line. In addition, we have started new measurements at the Hadron experimental hall by using slow-extracted beam. In this paper, we present recent results and future prospect of beam extinction measurements

INTRODUCTION

A new experimental search for coherent muon to electron transition (COMET) was proposed as an experiment using J-PARC main ring (MR) beam[1]. The experiment requires 8 GeV slow-extracted bunched beam with spacing of $\sim 1\mu$sec. To achieve required beam, the various acceleration schemes has been studied[2]. For example, Fig. 1 shows one of such schemes which could be realized in ordinary acceleration with existing J-PARC accelerator elements. The RCS is operated at harmonics 2 and only one bucket is filled by using rf chopper. Then RCS beam (including the empty bucket) is injected to the MR four times. As a result, the MR beam is filled in every other rf buckets, i.e. four out of nine buckets. It is noted that if the beam chopping is not enough, LINAC beam is injected to RCS empty bucket and then transferred into the MR empty bucket as a residual beam.

The "extinction factor", which is defined as an ratio of inter-bunch residual and the main beam, is one of the most critical requirements for the COMET experiment to reach designed sensitivity. According to the detailed background study, the required extinction factor is less than 10^{-9} so that the designed sensitivity, i.e. 10^{-16} could be achieved.

Several accelerator studies were performed at BNL/AGS for MECO experiment and their measurements showed beam leakage into adjacent empty bucket during acceleration. Since then, extensive R&D works have been done to develop sweeping devices to eliminate residual beam both in MR beam and extracted beam. The actual actions to improve extinction, however, strongly depend on the mechanism of deteriorating extinction. Therefore, we should clarify where and how proton leakage may occur by measuring extinction factor at J-PARC.

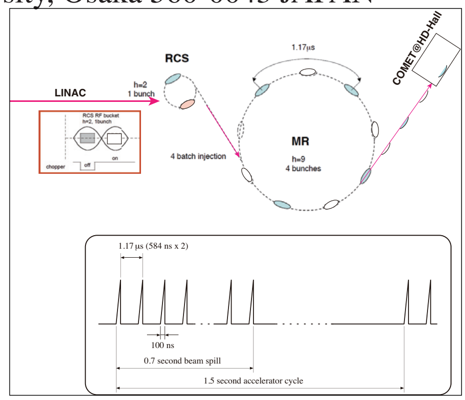

Figure 1: Simplest scheme of MR Injection for COMET experiment.

EXTINCTION MEASUREMENT AT ABORT LINE

Measurement Method

Measurement of beam extinction by level of 10^{-9} requires technical challenge to a detector which are capable of large dynamic range (10^9) and good timing resolution ($\sim$10 ns). R&D works are now in progress to develop gating device, such as gating PMT, which could screen main beam pulse within the gate window.

We alternatively use the monitor located at the abort line where MR beam is kicked out to the opposite side to the neutrino beam line by a fast-extraction kicker. The time structure of the extracted beam are analyzed as shown in Fig. 2. In the previous measurements with the prototype monitor in 2009, we obtained the following results[3]:

1. It was measured that about 10^7 protons remain in an empty RF bucket. It is considered that they remained since RF chopping of a proton beam at the J-PARC Linac was not complete.

2. By changing an RF phase of the linac chopper, we managed to minimize remaining protons in an empty bucket to about 1/3. When a proton beam loss occur in the MR, protons leak into between the RF buckets.

3. Since the prototype beam monitor system was not constructed for high vacuum, it caused a vacuum of the MR getting worse. In addition, it was exposed to a

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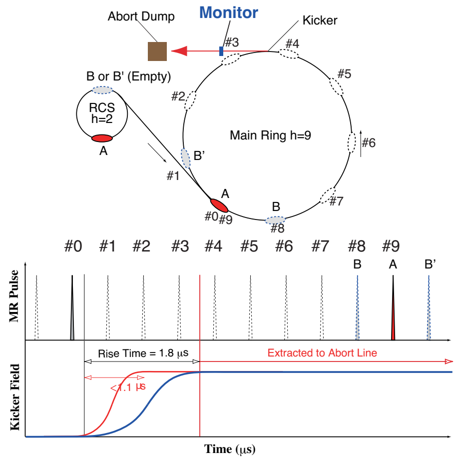


Figure 2: Beam diagnosis by using fast-extracted beam

beam when the measurement was not done. Therefore the prototype monitor was uninstalled imediately after the measurements.

New Monitor

Based on the experience in 2009, we have developed a new monitor in cooperation with the accelerator monitor group, the vacuum group and the control group at J-PARC (Fig. 3). Main improvements are:

1. Every elements in the beam monitor system have been carefully chosen for high vacuum (with no outgas) and high radiation resistance, except for scintillators and light guides.
2. We have developed a remote controlling system with a movable stage and gate valves so that they can be relocated away from the beam axis, when measurements are not done.
3. By using 4 staged optical ND Filters, plastic scintillating lights are read by PMTs. It allows us to cover a wider range of beam intensity.

MR Beam Measurements

Beam leakage from the filled bucket This new beam monitor system was installed in summer 2010. After a preliminary test, the main measurement was made in December, 2010. In this measurement, by changing the PMT gains together with a monitor of the MR beam intensity, a good sensitivity to measure a level of 2×10^7 protons per bunch has been achieved. By comparing intensities between the residual beam and the reduced intensity beam (2×10^7 protons) as shown in Fig. 4, we have determined the intensity of residual beams in the empty RF bucket as 10^5 protons, which corresponds to the extinction factor of 10^{-7}.

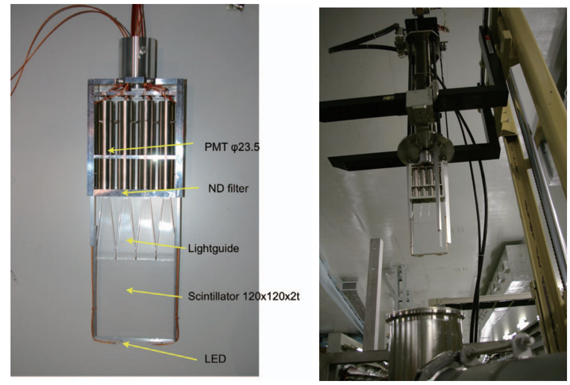


Figure 3: A New beam monitor used for the abort line measurements.

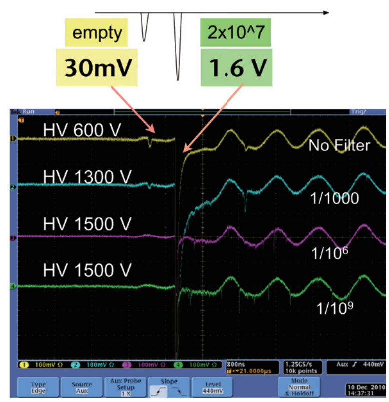
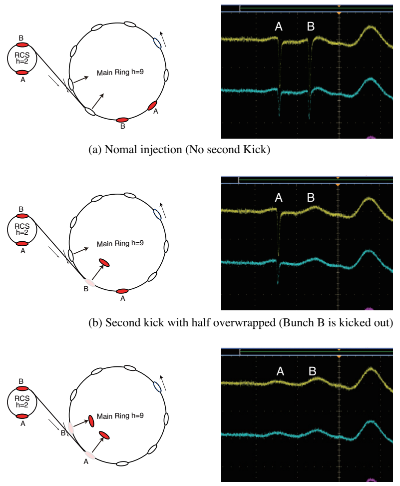


Figure 4: Residual beam in the empty buckets.

Method of double injection Kick In a normal injection scheme, two proton bunches are injected into the MR by the injection kicker magnet with its timing being shifted. The new idea is that kicking of an empty RF bucket twice by the injection kicker to sweep away the residual beams at injection. A preliminary test of this twice kicking was tried in Dec. 2010. In this test (as our first trial) two bunches of the empty buckets were used, (but contain 10^5 protons). As shown in Fig. 5, no residual protons were not observed in the double kicked buckets. From these measurements, it can be concluded that double injection kick method would improve proton beam extinction by additionally 5 order of magnitude, at least at the injection timing.

MEASUREMENTS WITH SECONDARY BEAM

The COMET experiment requires a slow extracted beam. Even if required extinction level was achieved before extraction, the bunch structure could be affected during extraction and/or transportation to the production target. So it is necessary to measure a realistic extinction using slow-extracted beam at the experimental area[4]. The measurement was performed in the Hadron experimental hall by using existing secondary beam line (K1.1BR) in Oct.



(a) Nomal injection (No second Kick)

(b) Second kick with half overwrapped (Bunch B is kicked out)

(c) Second kick at the same position (Both bunch are kicked out)

Figure 5: Residual beams with double injection kicking: (a) No double kicking, (b) with double kicking for the 2nd bucket and (c) with double-kicking for both buckets.

2010. The timing structure was monitored by measuring high momentum pions (800 MeV/c) which were transported through K1.1BR beamline. The MR was operated with the bunched slow extraction mode. Total 12 hours accelerator time was dedicated for the extinction study. The injection to the MR was done using the normal (i.e. not double-kick) injection scheme for this test. Three injections were done with one bucket filled and the other empty. The resultant timing structure is shown in the Fig. 7. It can be seen that most of the particles outside of the filled buckets are in the empty buckets. By averaging all the measurements taken in this test the extinction level is estimated to be $(5.4 \pm 0.6) \times 10^{-7}$, which is consistent with the other measurements.

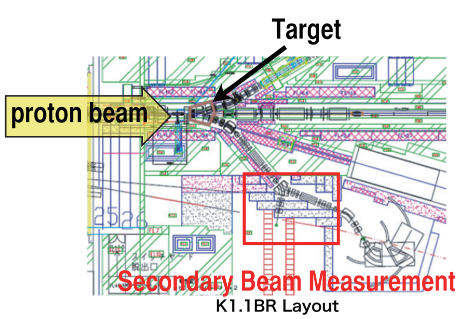


Figure 6: Experimental area (K1.1BR) for the secondary beam measurement.

SUMMARY AND FUTURE PROSPECT

We have successfully carried out the first series of the the proton beam extinction measurements at the different stage of the J-PARC accelerators. We keep improving monitor performance and continue these activities to understand and improve J-PARC accelerator performance in future.

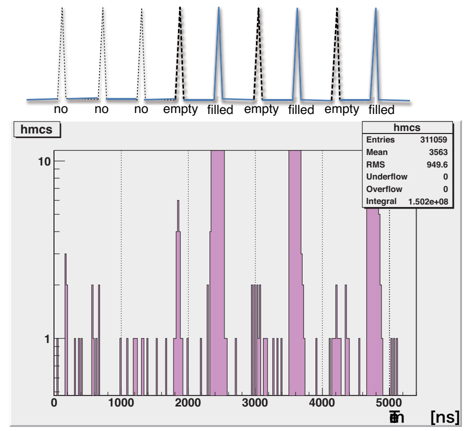


Figure 7: Timing distribution of secondary beam particles.

As a next step, we would measure extinction simultaneously with fast-extracted beam and slow-extracted beam, with and without double injection kicking. Then we would check if the new scheme shown in Fig. 8 can be used for the COMET experiment. We could also obtain useful information about at which stage the extinction would deteriorated.

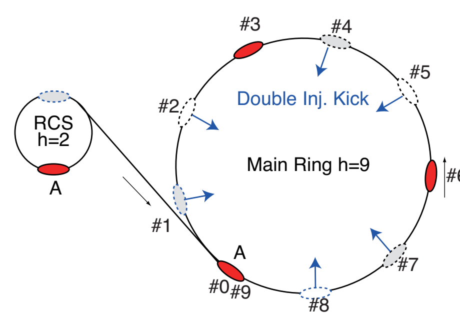


Figure 8: New scheme of MR Injection for COMET.

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