Measurements of Proton Beam Extinction at J-PARC

K. Yoshimura*, Y. Hashimoto, Y. Hori, Y. Sato, M. Shimamoto, Y. Takeda, M. Uota,
Y. Igarashi, H. Nishiguchi, S. Mihara, KEK, Ibaraki 305-0801 JAPAN
M. Aoki, N. Nakadozono, T. Tachimoto, Osaka University, Osaka 560-0043 JAPAN

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 beam extinction at main ring (MR) as the first step. The newly developed beam monitor was installed into the abort beam line and the first measurement was successfully performed by using the fast-extracted MR beam. We found that empty RF buckets of RCS, which were considered to be swept away by the RF chopper, contained about 10^{-5} of the main beam pulse due to chopper inefficiency. We are now developing a new beam monitor with improved performance for further studies at the abort line. In addition, we have started new measurements at the different stage of proton acceleration, i.e. at Linac, 3-50 BT line, and the main ring. 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

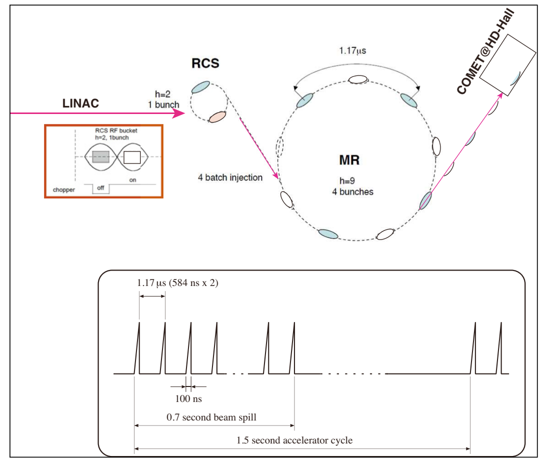

Figure 1: Simplest scheme of MR Injection for COMET experiment.

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.

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 discuss the following method which can be realized with existing detector techniques as follows:

MR beam is fast-extracted and analyzed with the external beam monitor. Separation of main pulse and inter-bunch beam can be done by adjusting kicker timing. This method can probe RCS bunch structure, beam leakage during acceleration and extraction.

When main pulse is extracted (#0,#9), the detector would be saturated and become insensitive due to the beam related secondary or scattered particles from the beam pipe and the abort dump. So we could only investigate the beam structure from #4 through #8. If a faster-rise time kicker could be available in future,beam at #1 could be analyzed.

In the measurement, position #8 is especially important. As shown in Fig. 2, we can change the order of injection,

* koji.yoshimura@kek.jp

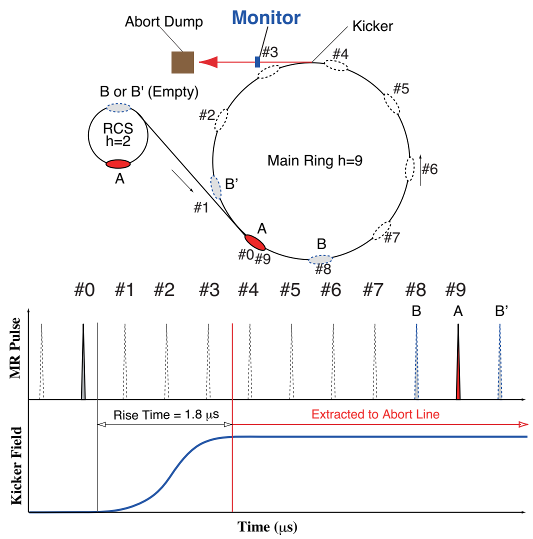

Figure 2: Beam diagnosis by using fast-extracted beam

i.e. which bucket of RCS is injected first. If empty bucket is injected first (B $\rightarrow$ A), empty bucket is located at position #8. In this case, empty bucket is extracted and analyzed before main pulse, which gives the information about proton leakage at RCS. On the other hand, if filled bucket is injected first ($A rightarrow$B), then we could investigate the bucket which was not injected from RCS, which gives the information about leakage during acceleration inside the MR.

Experimental Setup

Measurements were carried out at the abort line where beam was kicked out of the MR in the direction to the opposite side of the "neutrino line" as shown in Fig. 3[3]. The detector is two layer of 8 segmented hodoscope which comprise with thin scintillators and quartz bars, each paddle of which has 18(w)x2(t)x144(l) mm^3. Besides an additional scintillation counter was placed outside the beam pipe. This counter was used to monitor secondary beam particles which are scattered in the beam monitor.

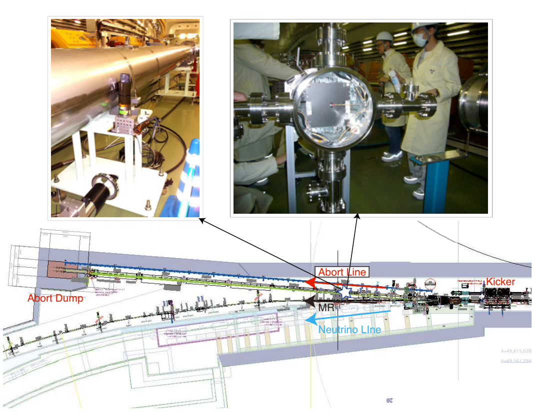

Figure 3: Beam monitors used for abort line measurements.

MR Beam Measurements

The first series of measurements were performed in the RUN #25(2009/6/11$\sim$6/22) . Beam intensity was changed from 4×10^{11} to 1×10^9 pps. Various number of RCS bunches (0, 1, 2) were injected into the different position of the MR buckets. We also studied rf chopper efficiency by changing chopper phase.

Residual beam in the empty buckets We first found that (supposed to be) empty bucket contains 10^{-5} level of the main pulse as shown in Fig. 4. Any existing beam monitor could not detect this level of the beam. After several measurements, the signal was identified as a residual beam in the empty RCS bucket, which was injecting into the MR and finally extracted into the abort line. Surprisingly, it is accelerated both in the RCS and the MR without any monitor signal as a invisible beam.

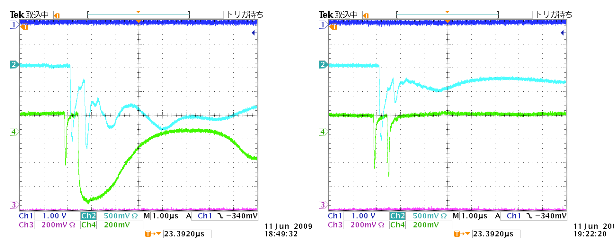

Figure 4: Residual beam in the empty buckets (Left:empty+filled, Right: both empty)

Beam leakage from the filled bucket We have studied beam leakage from the filled bucket during acceleration. By using high gain mode, we observed leakage in the several occasions as shown in Fig 5. The leaked beam was not confined in the empty bucket but rather spreaded across the whole ring. It was also found that level of leakage was strongly correlated with the beam loss level. The maximum level of leakage was observed when we inserted the flying wire monitor in the beam pipe.

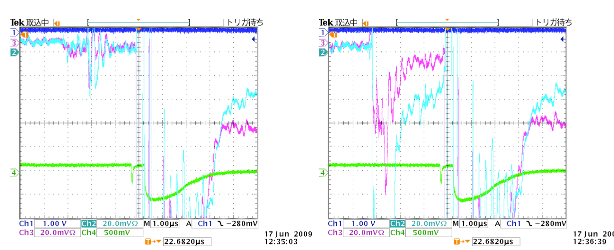

Figure 5: Beam leakage observed in the flying wire measurement. (Left:FWPM OFF, Right:FWPM ON)

Chopper inefficiency vs. Phase We have studied chopper inefficiency by changing the phase while monitoring the beam intensity in the empty bucket. We found that if we optimize chopper phase (to $\sim$16 degree) we could improve the chopper efficiency by a factor of 3 (Fig. 6). This result was confirmed in the different measurements below.

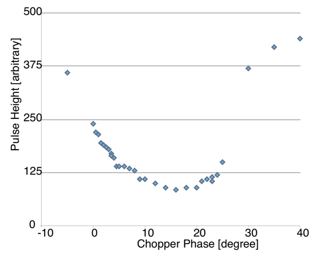

Figure 6: Chopper inefficiency vs. Phase

MEASUREMENT AT VARIOUS STAGES OF ACCELERATION

Linac

The plastic scintillator and cherenkov counter were placed behind a wire scan monitor to investigate chopper performance. The first measurement (Fig. 7:Left) showed similar sensitivity to the wire scan monitor and consistent result to the previous one. We are now developing the new monitor with improved sensitivity.

MLF

TOF measurement was performed in MLF BL-10 by using ^{3}He detector(Fig. 7:Right). Extinction factor was obtained by comparing between the number of delayed neutron with rf chopper ON and OFF. The resultant extinction factor was 1.2×10^{-5} under 5mA of Linac beam, which was consistent to MR measurement. In case of 15 mA beam current, extinction was improved to be 1×10^{-7}. The cause of this improvement is now under investigation.

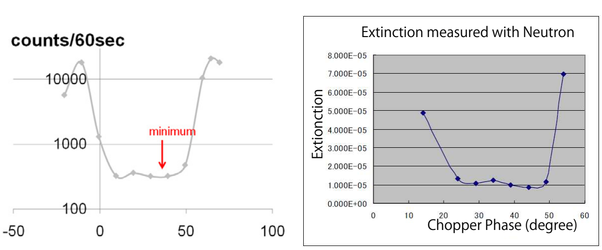

Figure 7: Residual beam intensity vs. chopper phase (Left: Linac, Right: MLF)

FUTURE PROSPECT

New Monitor

We are now developing the next version of the extinction monitor which will be installed into the abort line this summer (Fig.8). Main features are:

- Moving stage with the gate valve is equipped to remove the monitor off the beam and close off the MR vacuum system.
- Wide dynamic range (10^8) with combination of ND filters and PMT gain adjustment.
- Outgassing is improved by selecting materials.

This monitor will be used as a standing beam monitor for the future beam study.

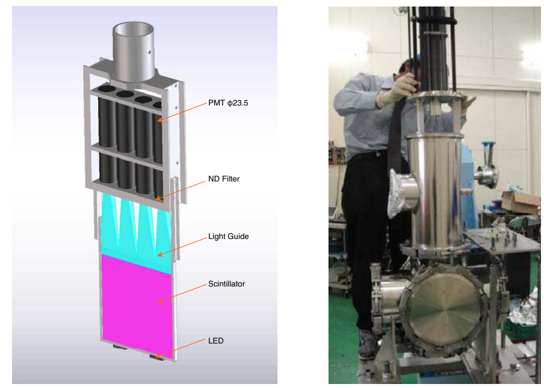

Figure 8: New extinction monitor.

ADDITIONAL MEASUREMENT

We proposed to perform a new measurement using slow-extracted beam. The measurement will be performed in the Hadron experimental hall by using the existing secondary beam line. We requested bunched proton pulse with 8 GeV. Together with the beam counter, tof counter will identify 1.0 GeV/c pion and one day data taking could achieve the sensitivity level of 10^{-9}. We will also improve the performance of the above monitors and develop additional monitors to measure beam at the different places.

SUMMARY

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 in the future.

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