STUDY FOR BEAM LOSS EVALUATION AT J-PARC LINAC

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Abstract

Since November 2007, the J-PARC (Japan Proton Accelerator Research Complex) linac has been operated at 7.2 kW. In ACS (Annular-Coupled Structure linac) section we observed high beam loss. A major source of the beam loss is considered to be H^0 produced from electron stripping of H^- beam with remnant gas. In this work, we investigate how to evaluate absolute beam loss magnitude by measuring primary protons originating from the H^- beam. The beam loss of the linac has been measured with $Ar-CO_2$ proportional counters. However, since they are sensitive to the background X-ray produced from RF cavities in SDTL (Separated-type Drift-Tube Linac) section, it is hard to measure low signal of real beam loss. We installed fast-response plastic scintillation counters in SDTL, ACS, and L3BT (Linac-to-3 GeV Rapid-Cycling Synchrotron Beam Transport) sections. With the counters, we measured signals with good signal-to-noise ratios in these sections. Especially in SDTL section, we clearly observed beam loss signal with almost no sensitivity to X-ray. We plan to install hodoscopes of plastic scintillation fibers to measure transverse distributions and reconstruct particle tracks systematically with possible primary proton identification.

INTRODUCTION

Since November 2007, we have been operating J-PARC linac at 7.2 kW. The highest residual radiation was observed at the bending magnet in the first arc section. This beam loss was found to be caused by H^+ produced with H- interacted with H_2 in LEBT [1]. The loss was suppressed by separating them from H^- with dipole magnets and removed by a scraper in MEBT1.

After suppressing the beam loss in the first arc section, the highest beam loss and residual radiation is shifted to the ACS section. The highest radiation level of 600 μSv/h after a 7.2 kW operation was observed before the second debuncher with a narrower aperture. Weaker radiation level of 100 to 300 μSv/h was observed in other parts of ACS.

Beam studies suggest that the main source of the beam loss in ACS section is H^0 generated by electron-stripping of H^- beam with remnant gas [2]. The beam loss was insensitive to changes of beam positions or beam widths. The profiles of neutral particles (mainly H^0) were measured with a wire scanner monitor at the 0-degree dump with the first bending magnet turned on [3]. With the bending magnet on, only neutral particles can go

straight to the beam dump. We also observed a factor of a few increase of beam loss by turning off ion pumps in SDTL and ACS sections [2].

BEAM LOSS MEASUREMENT WITH SCINTILLATION COUNTERS

In SDTL section we have not successfully measured beam loss with $Ar-CO_2$ proportional counters, due to high background of X-ray emitted from RF cavities. Therefore we measured beam loss with a plastic scintillation counter as shown in Fig. 1. A good signal to noise ratio is observed for the plastic scintillation counter, with almost no sensitivity to the background X-ray. On the other hand, the proportional counter has high level noise and we cannot observe signals. In ACS and L3BT, the signal-to-noise ratios of plastic scintillation counters are much better compared to the proportional counters.

Figure 1: Signals from a plastic scintillation counter (magenta) and a $Ar-CO_2$ proportional counter (green) at SDTL13 section. The beam current signal with a current transformer is also shown (yellow).

We measured beam loss in the downstream part of SDTL section (SDTL13 and SDTL16), the upstream part of ACS section (ACS03), and around the first arc in L3BT section (L3BT21). We used photo-multipliers of Hamamatsu H3164-10 with the gain of 1.1×10^6, the peak wavelength of 420 nm, and the rise time of 0.8 nsec. The plastic scintillator is Saint-Gobain BC-408 with the peak emission wavelength of 425 nm and rise time of 0.9 nsec, which matches the photomultiplier.

We operated the photomultipliers with the high voltage at -600 ~ -700 V. The raw signal is amplified by 1~10 times with a pre-amplifier (Giga G5106). We measured

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the counts of particles which deposit high energy loss in the scintillators. We collected waveform data of macro pulses using a 12.5-GHz Tektronix oscilloscope DPO71254-R3. The number of H⁻ per macro pulse for the measured beam condition with the macro pulse width of 200 µsec, the chopper-on-duty ratio of 0.6, and the peak current of 15 mA was 1.13×10^{13}.

The pulses with the amplitude more than a threshold value were counted. The thresholds were determined as the boundary between the signal peak and noise peak as shown in Fig. 2.
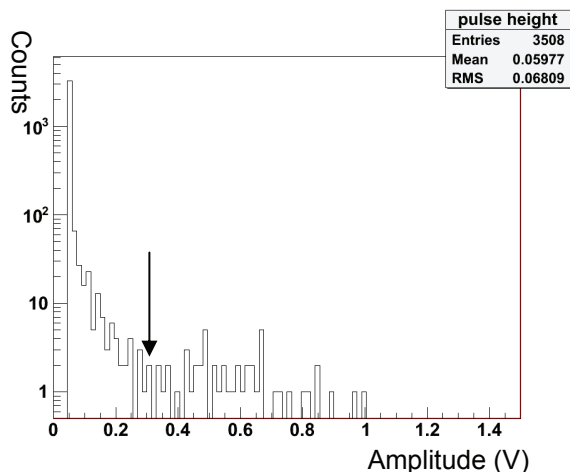

Figure 2: The amplitude distribution of a scintillation counter in ACS section. The threshold is shown as the arrow.

The measured signal counts of scintillation counters in SDTL, ACS, and L3BT sections are summarized in Table 1. The measured particle counting rates depend on the dimension of the sensitive volume of the counter, and the distance and orientation of the counter with respect to the beam axis. To correct for these effects, we need to measure the dependence of the counts on the azimuthal (ϕ) angle, and the polar angle (θ) in the cylindrical coordinate system with the z-axis of the beam.

BEAM LOSS TRACKER

We plan to develop a new beam loss monitor, a beam loss tracker. The features of this system are summarized as follows.

- Measurements of transverse particle distributions around a beam duct
- Primary proton identification with particle tracking
- Primary proton identification with the velocity measurement with the time-of-flight method
- High-rate capability (1 MHz at maximum)

The schematic view of the planned beam loss tracker is shown in Fig. 3. We are going to construct and install it in ACS section for beam operations in autumn of 2010. Since we had good signal-to-noise ratios of beam loss measurements with plastic scintillation counters, the

tracker is based on plastic scintillator. For particle position measurement and track reconstruction, we adopt scintillation fibers of Saint-Gobain BCF-10 which has a 4 mm x 4 mm square cross section. We form a 64 mm x 64 mm hodoscope of 16 fibers as shown as one of four squares in Fig. 4. Four of such hodoscope are connected to a 64-channel Multi-Anode PMT (MAPMT) Hamamatsu H8500C via optical fibers of BCF-98 with the same cross section as BCF-10. We are going to construct 4 hodocopes with two MAPMTs due to limited readout channels. The hodoscopes are installed in the linac tunnel, while the high-voltage supply of MAPMTs and signal processing, readout modules, and Data Acquisition (DAQ) system are placed in the ground level (called "Klystron Gallery"), which is about 20 m above the tunnel. We measure both energy loss and timing of a particle. The raw signals from MAPMTs are sent to a NIM crate in the ground level. For energy loss measurements, the signals are amplified with amplifiers and then sent to Analog-to-Digital Converters (ADCs) housed in a VME crate. For timing measurements, the amplified signals are converted to a rectangular pulse with discriminators and sent to Time-to-Digital Converters (TDCs) in the VME crate through NIM-to-ECL level converters. The gate signals for the ADCs and common start or stop signals for the TDCs are created with dynode signals of the MAPMTs. The ADCs and TDCs are read out with a Linux based on-board VME controller which is operated by a PC through Ethernet.
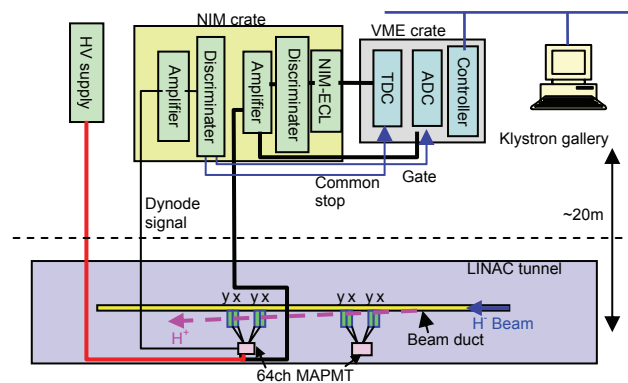

Figure 3: The schematic view of the beam loss tracker system.

We consider the following two hodoscope configurations.

For measurements of transverse particle distributions, we use the configuration in Fig. 4. In this configuration the 4 hodoscopes, two of which are to measure horizontal distribution (labelled as "x hodoscope") are and the rest are to measure vertical distributions ("y hodoscope") are placed nearly around the beam duct at the same location along the beam line.

For track reconstruction, we arrange four hodoscope along the beam line as shown in Fig. 5. We may either use the combination of two x hodoscopes and two y

hodoscopes as shown in the figure, or four of x hodoscopes or y hodoscopes. If the hit positions in the hodoscopes are aligned, they are identified as a particle track. With this configuration, if we take the distance between hodoscopes long enough (one or a few meters), we may be able to distinguish primary H^+ (proton) from other secondary low energy particles. It may also be possible to identify it with amplitudes of the signals.

Table 1: Particle counts measured with scintillation counters. "Count" shows the counting rates per macro pulse. "Orientation" denotes the orientation of the counter is perpendicular to the beam line "trans." or along the beam line "long." The "ρ" and "ρ_{duct}" denote the distance of the counter to the center of the beam duct, and the outer radius of the beam duct, respectively.

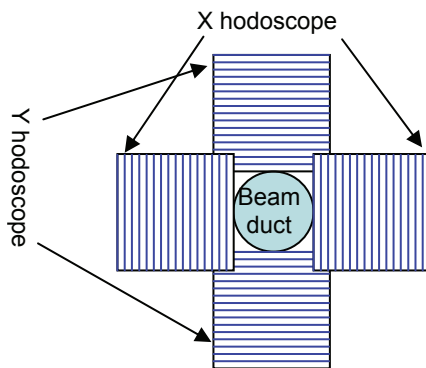| Section	Orientation	Length (mm)	ρ	ρ_{duct}	Count
SDTL13	trans.	200	315	20	13
SDTL16	trans.	200	20	20	1622
ACS03	trans.	500	165	22	51
ACS03	long.	500	265	22	35
L3BT21	trans.	500	120	37	544

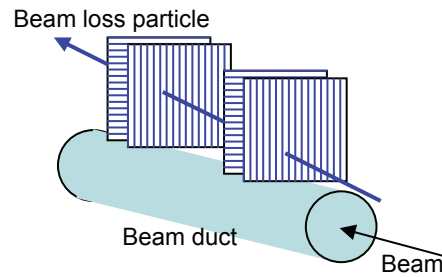Figure 4: A hodoscope configuration for transverse distribution measurements.

Figure 5: A hodoscope configuration for particle tracking

CONCLUSIONS

In 7.2 kW beam operations of the J-PARC linac since Nov. 2007, we have observed high beam loss in ACS section. There is also a problem that signal-to-noise ratios of beam loss signals with Ar-CO_2 proportional counters are not good especially in SDTL section due to large X-ray background. In test measurements with plastic scintillation counters, we successfully measured clear beam loss signals with low noise. We plan to construct a beam loss tracker system which is made of hodoscopes of plastic scintillation fibers and install it in ACS section. The tracker system is used to measure systematic transverse beam loss distributions and to reconstruct particle tracks in order to identify and evaluate the absolute rates of primary protons lost from the H$^-$ beam.

REFERENCES

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