R&D on the gas injection system of Beam Induced Fluorescence Monitor toward MW beam power at the J-PARC Neutrino Beam-line

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Abstract. A Beam Induced Fluorescence (BIF) monitor is being developed as an essential part of the monitor update toward MW beam power operation at the J-PARC neutrino beam line, where a 30 GeV proton beam is extracted, bent and struck onto a 90-cm-long graphite target to produce an intense and nearly pure muon (anti-)neutrino beam for the Tokai-to-Kamioka (T2K) experiment. A BIF monitor can measure the proton beam profile non-destructively and continuously spill-by-spill with fluorescence light produced by proton-$N_2$ interactions. In order to generate enough light to measure the profile precisely, it is necessary to temporarily increase the vacuum pressure near the BIF interaction point up to $10^{-2}$ Pa during each beam spill while keeping the average pressure low ($10^{-5}$ to $10^{-6}$ Pa) at other locations to protect vacuum equipment. Therefore, R&D of a pulsed gas injection system satisfying these requirements is in progress. We will report the recent R&D status of the gas injection system and prospects toward operation of a prototype monitor which we plan to install this fall 2019.

1. Introduction of J-PARC Beam-line
1.1. J-PARC proton beam-line
J-PARC supplies a 30 GeV proton beam accelerated by a 400 MeV Linac, 3 GeV Rapid Cycling Synchrotron and 30 GeV Main Ring (MR) to the Primary Beam-line of the T2K experiment[1]. The primary beam line is constructed of Super Conducting (SC) section to bend to toward the Super-Kamiokande detector and Final Focus section (FF) to focus currently 485 kW beam. Proton beam monitors in the J-PARC Neutrino Beam-line are used to profile the beam and contribute to safe operation of the T2K Experiment[1]. Increasing the proton beam intensity (485 kW $\rightarrow$ 1.3 MW) in the future can cause degradation or damage of destructive monitors, for example, the Ti-based Segmented Secondary Emission Monitors which are currently used in T2K. Non-destructive monitor called a Beam Induced Fluorescence (BIF) Monitor is studying now. BIF requires that the pressure rise up to $10^{-2}$ Pa from $10^{-5}$ Pa to detect enough photon for profiling the beam. However, other

Figure 1. Schematic figure of BIF.
vacuum systems, especially on the upstream side of the BIF, restrict increasing pressure. We aim to construct pulsed injection system which satisfies BIF optical and vacuum system.

1.2. Beam Induced Fluorescence Monitor
A Beam Induced Fluorescence Monitor(Fig.1) has very low beam loss due to using photon produced by interaction between proton and nitrogen in the beam-line[2]. 1000 photons which provide accuracy the same as SSEMs require $10^{-2}$ Pa pressure to monitor the beam. However, continuous gas injection to increase the pressure level can cause non-acceptable pressure increase in other of the vacuum system, especially SC section. Therefore, we are aiming to construct a pulsed gas injection system to restrict the mean pressure increase in other parts of the beam-line and make the required pressure in the profile section.

2. Beam-line Experiment
2.1. Gas Injection Set-up
The FF section where the BIF is installed has a 36 m length from the end of the SC section and 200 mm diameter. The z coordinate is set to the beam direction. A schematic figure and photograph of the constructed injection part at $z=11.8$ m from the SC section exit is shown in Fig.3 and Fig.2 respectively, which consist of 5 valves and 1 small chamber.

2.2. Equilibrium state experiment
Continuous flow injection is performed to measure the equilibrium pressure ($P_{eq}$) in the beam-line with Variable Leak Valve. Equilibrium pressure is described by $P_{eq} = \frac{Q}{S_{eff}}$, where Q and $S_{eff}$ are flow rate and effective pumping speed. $S_{eff}$ is determined by the pumping speed of the pumps and their shape of the vacuum chamber. The variable Leak Valve can control the continuous flow rate by rotation of a hand-controlled knob, therefore a known Q was used to measure $P_{eq}$ corresponding $Q/S_{eff}$. Q was measured with a small test chamber attached Variable Leak Valve by build-up method which is measurement of flow rate by increasing of the pressure in the closed vacuum space. Then, making $P_{eq}$ VS Q plots, experimental $S_{eff}$ can be decided from the slope of fit result.

2.3. Pulsed injection experiment
Pulsed flow injection is done in 4 sets of valve open duration (300, 390, 400 and 500 $\mu$s) using a pulse valve. The interval of the pulse is 30 sec.

2.4. Simulation of equilibrium
Equilibrium and pulsed pressure can be simulated by Molflow Monte-Carlo software which is developed by CERN. The modeled chamber of the FF section has a 200 mm diameter and 36 m length. The end of SC side absorbs all MC particle. 4 pumps with 500 L/s pumping speed
attach to the x>0 side of the main chamber. The center of the injection surface is located at z=11.8 m on the x<0 side of the main chamber.

3. Results of Experiments

3.1. Equilibrium State Experiment

Flow rates(Q) of continuous gas were measured by the build-up method with cold cathode gauge in a small test chamber (21.8 L vacuum volume). Experimental results of $P_{eq}$ VS Q plots show that measured equilibrium pressures are almost consistent with simulation. Although the small difference is under investigation now, the effect of this discrepancy can be ignored for the BIF pressure system and beam-line. Fig.4 shows that data is almost consistent to the simulation.

![Figure 4. Result of equilibrium state experiment at z=12.5 m](image)

![Figure 5. Measured pressure pulse at down stream side(z=12.5 m) pressure gauge.](image)

3.2. Pulsed injection experiment

Pressure pulses from a cold cathode gauge are shown in Fig.5. Measured pressure pulses didn’t indicate abnormal pressure increasing during injection although the gauges have slow response time. An analysis with convolution by the gauge response is under study.

4. Conclusion

BIF R&D in J-PARC Neutrino Beam-line is ongoing now. In particular, the pressure system of BIF requires ingenuities to restrict amount of gas used while pressure to monitor the beam profile. Therefore, constructing a pulsed pressure system requires understanding of the BIF vacuum system and the FF section. So, a test experiment and simulation of the equilibrium state in the FF Section are performed.

5. acknowledgements

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Reference

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