THE DEVELOPMENT OF 16-ELECTRODE MONITOR FOR MEASUREMENT OF THE MULTIPOLE-MOMENT

Y.Nakanishi†, K.Nakamura , T.Nakaya , A.Ichikawa , A.Minamino , Kyoto University, Japan
T.Toyama[1] , T.Koseki , H.Kuboki , KEK , Japan

Abstract

In J-PARC, the intensity will be increasing from 380 kW to 1.3 MW. According to this, the beam loss is the most major concern. One of the cause is the injection mismatch, so we are developing a 16-electrode pick up monitor in order to measure the beam oscillation, in particular the higher order moment. This paper describes the status of the development of the 16-electrodes monitor.

INTRODUCTION

J-PARC, Japan Proton Accelerator Research Complex, has a high intensity accelerator. J-PARC accelerator consists of 3 parts, LINAC (Linear accelerator), RCS (3 GeV Synchrotron) and Main Ring (30 GeV Synchrotron). The proton beam is used to a high intensity neutrino beam for the accelerator-based long-baseline neutrino oscillation experiment, T2K. It is essential for the experiment to get the higher intensity of J-PARC MR.

It is important to consider the beam loss upon increasing the beam power. The beam loss is caused by the coherent motion and the incoherent motion. The coherent motion is induced by the wake field, the error of magnetic field. In addition, the injection mismatch gives rise to the coherent motion. Injection mismatch from RCS to MR has been tried to measure by Ionization Profile Monitor [1] and flying wire monitor [2]. It is difficult to use the flying wire monitor because the wire cannot withstand the beam more than 2.2×10^{13} protons. IPM is now using on MR, and can measure small oscillation.

Another monitor which is non-destructive, can withstand up to the high intensity beam and can reduce the systematic error is required for observing the 2nd and 4th moment of the beam. We are now developing the 16-electrode monitor to meet this request.

QUADRUPOLE MOMENT

When the beam pass through the beam pipe, the charge is induced on the wall of the pipe. In case that the beam density is $\lambda(r, \phi)$, the charge can describe as Eq. (1) [3].

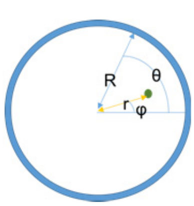

Figure 1: The position of the beam and the point on the wall.

Figure 1 shows the geometry of the beam and wall so that:

$$\hat{\sigma}(R,\theta) = -\int_0^R \int_0^{2\pi} r dr d\phi \frac{\lambda(r,\phi)}{2\pi R}(1 + 2\sum_{n=1}^{\infty}(\frac{r}{R})^n \cos n(\theta-\phi)) \quad (1)$$

If the density λ is Gaussian distribution, it can transform to Eq. (2).

$$\hat{\sigma}(R,\theta) = -\frac{I}{2\pi R}[1 + \frac{2}{R}(x_0 cos\theta + y_0 sin\theta) + \frac{2}{R^2}\{(x_0^2 - y_0^2 + \sigma_x^2 - \sigma_y^2)cos2\theta - 2x_0 y_0 sin2\theta\} + ... \quad (2)$$

The quadrupole moment can be extracted as follows.

$$Q_{(nomal)} = \int_0^{2\pi} d\theta\hat{\sigma}cos2\theta / \int_0^{2\pi} d\theta\hat{\sigma} = \frac{x_0^2 - y_0^2 + {\sigma_x}^2 - {\sigma_y}^2}{R^2} \quad (3)$$

$$Q_{(skew)} = \int_0^{2\pi} d\theta\hat{\sigma}\sin 2\theta / \int_0^{2\pi} d\theta\hat{\sigma} = \frac{-2x_0 y_0}{R^2} \quad (4)$$

In this paper Q(normal) is called by the quadrupole moment since Q is related to the beam size. Dipole moment can be obtained by Eq. (5).

$$\frac{x_0}{R} = \int_0^{2\pi} d\theta\hat{\sigma}cos\theta / \int_0^{2\pi} d\theta\hat{\sigma}$$
$$\frac{y_0}{R} = \int_0^{2\pi} d\theta\hat{\sigma}sin\theta / \int_0^{2\pi} d\theta\hat{\sigma} \quad (5)$$

Using this, the difference of the square of the beam size is represented by Eq.(6). D_x is dipole moment for x-axis, and D_y is for y-axis.

$$2\frac{{\sigma_x}^2 - {\sigma_y}^2}{R^2} = Q - Dx^2 - Dy^2 \quad (6)$$

Here we make an assumption. The induced charge on electrodes which attached on the pipe is approximately the same as the consideration above. The voltage on the electrode is proportion in the induced charge, so σ can be replaced by the voltage of electrodes. Therefore, these moments can be calculated from signals of electrodes.

The emittance of the beam can be derived by two Q moment measured at two different points under the assumption the emittance conserve during the acceleration.

4-ELECTRODE MONITOR

The 4-electrode monitor has been installed in J-PARC and used to match the beam injection for the dipole moment (see Fig. 2).

The Setup of Data Taking

The 4-electrode monitor has been installed at address #15 in the MR. The shape of electrode of monitor is linear-tapered coupler [4]. The quadrupole magnet, QDC1, is located at the 3-50BT which connects between RCS and MR.

We took data on two conditions, changing the current of the quadrupole magnet, QDC1, to make injection mismatch larger for measuring the oscillation of the quadrupole moment.

At first, we took the data with the normal current. Subsequently, the current was reduced by 10%. (QDC1: 502.71 A -> 452.44 A)

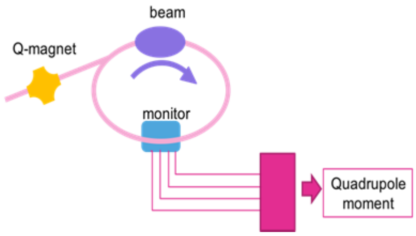

Figure 2: The schematic of the making and measuring injection mismatch.

This test was carried out with single bunch beams with 1.24~1.27e+13 protons. The data taking starts at -0.02ms from injection and continue to take it for 0.20 ms. The horizontal betatron tune is 22.40 and the vertical betatron tune is 20.75 as normal operation.

The Calculation of the Quadrupole Moment

The moments are described by the following formula. V_i represents the voltage from the electrode (i=1, 2, 3, 4: the number of electrodes).

$$Q = \frac{V_1 + V_2 - V_3 - V_4}{\sum_{i=1}^{4} Vi} \tag{7}$$

V_1, V_2, V_3 and V_4 correspond the signals of right, left, up, down. Fig.3 shows the evolution of the quadrupole moment under the two conditions. The figure on the right is after reducing the current, and one on the left is before doing. In the Fig.3, its horizontal axis is the turn of the beam and the vertical is Q calculated by Eq. (7). The first turn is 3905 on this figure.

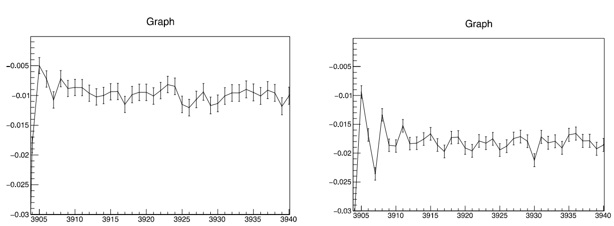

Figure 3: The oscillation of quadrupole moment.

The abscissa is the number of turns and the ordinate is quadrupole moment calculated by Eq. (7). This figure shows that the difference seems clear at the beginning of the circulation of the beam.

The horizontal and vertical beta functions at QDC1 are almost same. On the other hand, those at four-electrode monitor differ almost twice. The quadrupole oscillation will be mix of those two. Detailed behavior will be checked with numerical simulation. Now we can conclude that 4-electrode monitor can catch injection mismatch for the quadrupole moment in the case which the Q-magnet current changes by 10%, but on the normal mode (the left of Fig.3).

MULTI-ELECTRODE MONITOR

In principle, more precise determination of the quadrupole moment can be achieved by putting more observation points inside the beam pipe, i.e. more than four.

The Merit of the Multi-electrode Monitor

To measure the quadrupole moment of the beam oscillation more precisely, we are developing the multi-electrode monitor. Here are the merits of getting the beam profile by using more electrodes:

1) Higher order terms vanish. (show Table.1)
2) The statistical error caused by noise becomes lower.
3) Higher moment can be measured.

Table 1: Higher Order Terms Included the Dipole and Quadrupole Moment ($a_i \propto (x/R)^i$)

	4-electrode	16-electrode
Dipole moment	$D_x = \frac{2a_1 + 2a_3 + 2a_5 + 2a_7 + 2a_9 + 2a_{11} + 2a_{13} + 2a_{15} + ...}{4a_0 + 4a_4 + 4a_8 + 4a_{12} + 4a_{16} + ...}$	$D_x = \frac{8a_1 + 8a_{15} + 8a_{17} + ...}{16a_0 + 16a_{16} + ...}$
Quadrupole moment	$Q = \frac{4a_2 + 4a_6 + 4a_{10} + 4a_{14} + ...}{4a_0 + 4a_4 + 4a_8 + 4a_{12} + 4a_{16} + ...}$	$Q = \frac{8a_2 + 8a_{14} + 8a_{18} + ...}{16a_0 + 16a_{16} + ...}$
Sixtupole moment		$S = \frac{8a_3 + 8a_{13} + 8a_{19} + ...}{16a_0 + 16a_{16} + ...}$

On the contrary, more electrodes are used, more dominant the affect of manufacturing accuracy and the coupling described below is.

The Structure and Characteristic of the Monitor

Figure 4: The picture of 16-electrode monitor.

Figure 4 shows that there are grooves into the pipe. If there is the coupling between electrodes, the waveform will be affected by neighbors. This groove works reducing the coupling between neighbor electrodes. The coupling was compared by changing the position, into the groove or out of the groove. The method of calculating the coupling is the 2-dimentional boundary element method [4][5]. Figure 5 shows the difference of the coupling changing the electrode position. A blue line shows the ratio of impedance on the condition when the electrodes is into the grooves, and a green line shows that when it is out of the groove. The coupling between the

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neighboring electrodes in the grooves is five times smaller than those of outside the grooves (see Fig. 5).

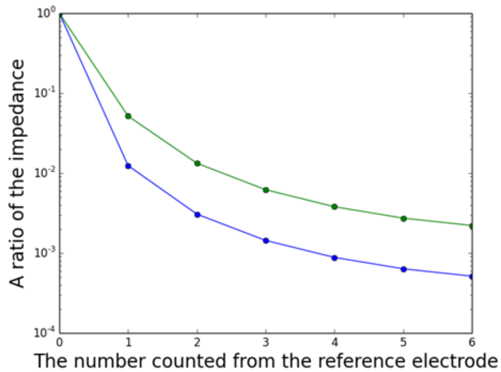

Figure 5: The calculated coupling with near electrodes.

The characteristic impedance of each electrode set 50 Ω. An electrode is fixed by a screw, so the impedance can adjust in the way an electrode moves up or down.

The characteristic of the monitor is as follow.

- Electrode: strip-line
- Characteristic impedance: 50 ohm
- Number of electrode: 16
- Size of electrode: $9.1 \times 5 \times 350$ mm
- Size of groove: 25×8 mm
- Inner radius of the pipe: φ165 mm

The expected height of the beam pulse is 1.18 V. This is the result from the simulation by CST studio. This is under the condition that the passing beam current is 40 A, bunch width is 200 ns. On this condition, the number of protons per bunch is 10^{13}. This is enough high for taking data by ADC and leads S/N smaller than the 4-electrode monitor if the height of noise is the same.

The Result of Test Monitor

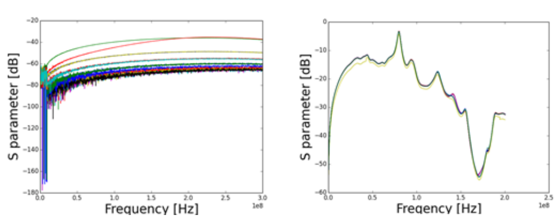

Figure 6: On the left S parameter between #1 and others and on the right S parameter between central wire and electrodes

Comparing with Figure 6 right, the coupling of electrodes is consistent with the predicted one until #4, but isn't with more than #4. This reason is not clear.

Then, we searched the difference of electrodes with wire. The monitor was fixed on the horizontal plane and the wire was put on the center of the pipe. We use the calibration system with the accuracy within ±50 μm [6]. The network analyzer is able to send a current of electricity, connecting the terminal with the end of wire. The warp on Fig. 6 left may be caused by impedance mismatch between electrodes and cables.

Except one electrode, the gain fluctuate within 3%. Only #4 is different from other electrodes. The gain will be used for the normalization of 16 electrodes. We will do calibration with wire changing the position and compare the result with one of 4-monitor. This can reveal the affect of higher order terms in dipole moment.

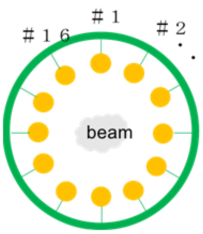

Figure 7: The name of electrodes.

CONCLUSION

We are developing the 16-electrode monitor to measure the quadrupole moment. Prototype of the monitor was fabricated. We achieved to make the gain fluctuation within 3% except #4 electrode, which may be due to impedance mismatch. More precise performance check will be done in the future.

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