AN APPLICATION FOR BEAM PROFILE RECONSTRUCTION WITH MULTI-WIRE PROFILE MONITORS AT J-PARC RCS

H. Sako#, S. Hiroki, H. Takahashi, K. Yamamoto, JAEA, Tokai, Ibaraki, Japan
H. Ikeda, Visual Information Center, Inc., Tokai, Ibaraki, Japan.

Abstract

J-PARC RCS (Rapid Cycle Synchrotron) has been commissioned since September 2007. In the early stage of commissioning, Multi-Wire Profile Monitors (MWPM's) are most important beam monitors to measure positions and widths of injection beam from LINAC. The MWPM consists of a horizontal and a vertical wire planes which consist of several wires with a tilt angle. The whole MWPM frame moves horizontally or vertically and scans a beam profile. A software tool is developed to reconstruct a beam profile from a MWPM. Beam profiles have been measured at MWPM's in the injection region and the H0 beam dump line.

INTRODUCTION

In the initial stage of RCS commissioning, it is essential to establish a beam orbit from L3BT (LINAC to 3GeV RCS beam transport line) through RCS ring to the first charge exchange foil, and to the H0 dump line. To measure beam positions from LINAC precisely, MWPM's are installed in those beam lines as shown in Fig. 1 [1]. There are 7 MWPM's. MWPM 2 is installed in L3BT. MWPM 1 will also be installed there in the summer of 2008. MWPM's 3-5 are installed in the RCS. MWPM's 6 and 7 are placed in the H0 dump. MWPM's 1-5 measure H^- whereas MWPM's 6 and 7 measure proton (H^+) beam. The wire of MWPM's 1-5 is a gold plated tungsten wire of 0.1mm diameter which detects dissociation of electrons from H^- beam in the wire. Since the signal level of MWPM's 6 and 7 induced from secondary electron emission of H^+ beam through wire is only about 1% of that of H^- beam, wider Ti plates of ~1mm are used [4]. The MWPM's are designed to have large active areas of 150~250 mm horizontally and vertically, required for various tuning conditions such as tune survey and paint injections, whereas they are designed to have high position resolutions of ~ 0.1 mm to measure small beam profiles of LINAC with 1.5~2.0 mm r.m.s. width [2,4]. To fulfil such requirements, a MWPM has a *u*- and a *v*- planes where wires are arranged in directions 17 degrees tilted with respect to the horizontal and the vertical directions, respectively, as shown in Fig. 2 [1]. The relative positions between *u*- and *v*-planes are fixed, and the combined set of the two planes moves by a stepping motor horizontally or vertically, depending on each MWPM. The combinations of *u/v* wire pitches are chosen so that by moving wire planes by one pitch of wire in one of the *u*- or *v*- planes, the other plane also moves by one pitch. By scanning for one pitch, it can measure the profile in the whole active area in a short time of typically 100 sec. Due to large high-frequency noise from bump magnets, a charge integration type of pre-amplifier is adopted [1,3,5]. The signals of MWPM are integrated for 500 μsec from the start timing of RCS injection to cancel the noise [3]. The integrated signals of all *u*- and *v*- wires are combined into a time series with a multiplexer. The multiplexed signal is sent to a digitizer (Wave Endless Recorder) [1] and then recorded as waveform data. The stepping motor is controlled with PLC (Programmable Logic Controller), which is remotely controlled in EPICS via IOC (Input Output Controller).

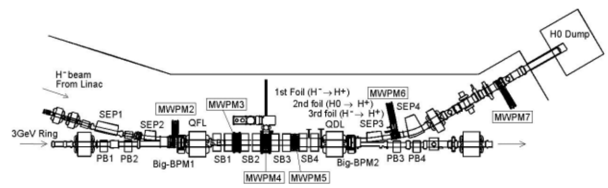

Figure 1: Top view of RCS injection region with MWPM2-7 in L3BT, RCS ring, and H0 dump.

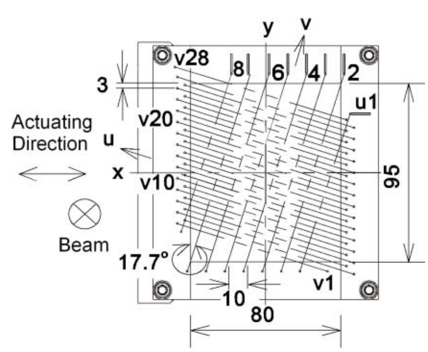

Figure 2: Wire configuration of MWPM7.

Table 1: Geometric Configuration of MWPM

MWPM	#wires		Pitch (mm)		Scan direction
	u	*v*	*u*	*V*	
MWPM1	21	6	2.86	9.53	y+
MWPM2	8	28	9.53	2.86	x-
MWPM3	41	10	2.86	9.53	y-
MWPM4	41	10	2.86	9.53	y-
MWPM5	41	10	2.86	9.53	y-
MWPM6	26	45	9.53	2.86	x-
MWPM7	15	48	19.05	4.10	x+

#hiroyuki.sako@j-parc.jp

MWPM APPLICATION

Analysis of MWPM signals to reconstruct final profiles is quite complicated, since all wire data in each wire plane at different scan positions must be combined, and also wires are tilted while scan direction of the wire frame is either horizontal or vertical directions depending on each MWPM. The data taking and analysis procedure of MWPM is summarized as follows.

- Start scanning procedure for a proper scan range via EPICS records.
- Take digitized data in WER and save it as a binary file. The data at each scan position is obtained as a multiplexed waveform data with combined *u*- and *v*- wire data.
- Import the WER data file into the MWPM application.
- Separate amplitude at each *u*- and *v*- wire at each scan position by averaging a few bins of a waveform for an interval corresponding to one wire data.
- Combine *u*- (*v*-) wire data at different scan positions into a profile with transformation from the wire number and the motor position into *u*- (*v*-) position.
- Fit *u*- and *v*- profiles to a Gaussian+constant function to get center and width.
- Transform (*u, v*) center and width into (*x, y*) coordinates.

The application is implemented in Java language as other control applications in J-PARC RCS.

The application is separated into three parts; Launcher, Control panel and Analysis panel. Control panel or an Analysis panel of a selected MWPM (one of MWPM's 2-7) is launched from Launcher. Control panel and Analysis panel are separated since the analysis function is used not only just after the measurement but also used later offline. From maintenance point of view, a common application code is shared among MWPM's 1-7. The parameters such as wire numbers, wire pitches, scan direction, and wire offset positions as shown in Table 1 are stored in the configuration files and read when the analysis panel has been launched. Exceptionally, only MWPM6 code is slightly different from the others, where two separate waveform data for *u*- wires and *v*- wires are necessary.

In Control panel, one can start or stop scanning MWPM. Setting parameters for stepping motors such as a step interval, number of steps, and motor speed can be set.

Analysis panel consists of the wire view and the profile view. The wire view is shown in Fig. 3. One first should open a data file with "OPEN" button at the up right corner. A plot of waveform is then displayed. In case of MWPM2, the left part with a smaller peak corresponds to *u*- wire data and the right part with a larger peak corresponds to *v*- wires. Red points show data points, and blue lines show averages of each wire. As seen in the figure, because boundary parts have small peaks, these parts are ignored for averaging. To reconstruct *u*- and *v*- profiles, one must specify scan parameters. When measurements have just been done, one can obtain a step interval and a start position from EPICS records by clicking "MONITOR" button in the lower right part, otherwise one must enter parameters into the fields. Finally profiles are reconstructed by clicking "MAKE PROFILES" button. The transformation of *u*, *v* coordinates from the wire number and the motor position is formulated as follows;

$$
\begin{aligned}
u_i(s) &= i\Delta u + s\Delta s\cos\varphi + u_{s_0} \\
v_j(s) &= j\Delta v + s\Delta s\sin\varphi + v_{s_0}
\end{aligned} \qquad (1)
$$

Where i and j represent *u*- and *v*- wire indices, s is step number of the motor, Δs is a step size (mm), i_0 and j_0 show u and v wire indices at the MWPM frame center. ϕ is the angle of u wire with respect to the x- axis. u_{s0} and v_{s0} represent u and v coordinates of the motor zero position in the RCS beam coordinate system (mm).

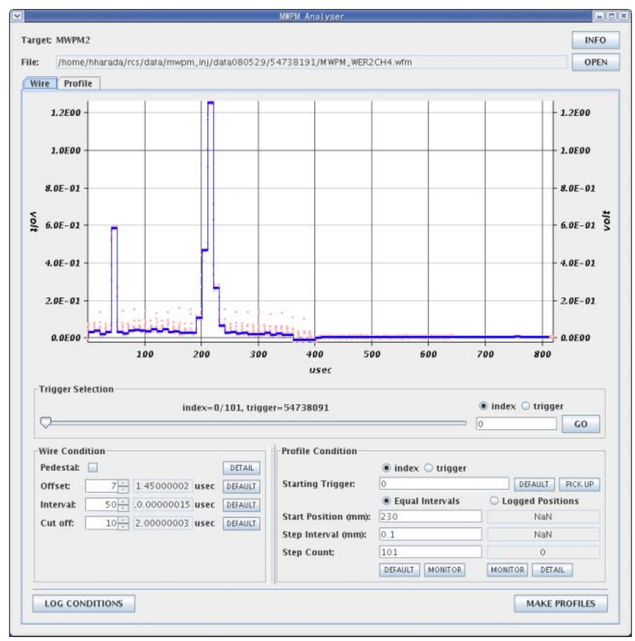

Figure 3: Wire view of the analysis panel for MWPM2.

The profile view is shown in Fig. 4. The plot shows the profile in the *u*-direction. A clean and smooth shape of the profile is seen. In "Statistics" tab in the bottom part, mean *u* or *v* positions and r.m.s. of the profile are calculated. In "Fit Gaussian" tab, the profile is fit with a Gaussian + constant function for a signal and a baseline. A sigma width and center of the Gaussian is calculated. Finally center (*u,v*) coordinates and widths are transferred into (*x,y*) coordinates by a rotation transformation. In the width transformation, independence between *x* and *y* coordinates is supposed. The range of statistics calculation and fit can be specified in the "Range Selection" area. A bad (noisy) data point can be removed by clicking it on the plot. Two kinds of baseline corrections are implemented. Relative baseline differences among wires are corrected by subtracting pedestal data. The pedestal data are taken when there is no beam. The other correction is for variations of baseline during scan time mostly common for wires. The effect of the corrections to the resulting positions and widths are typically 7 µm and 50 µm.

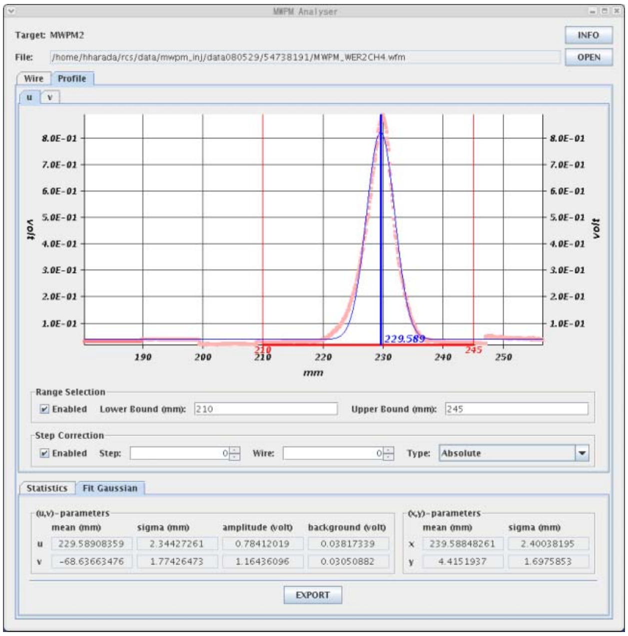

Figure 4: Profile view of the analysis panel for MWPM2.

RESULTS

Fig. 5 shows calculated envelopes (lines) compared to measured beam widths (squares) by wire scanners in L3BT and MWPM2, 3, and 4 (the right most 3 points) in horizontal (magenta) and vertical (cyan). Data between L3BT wire scanners and MWPM's are consistent which commonly agree with the model calculation.

Fig. 6 shows center positions of beam orbits in the RCS injection part from L3BT to H0 dump [6]. Horizontal (above) and vertical (below) positions measured with MWPM's are shown in red points labelled as "MONMWPM2-7". They are compared with calculated beam positions by a beam transport model shown as black points. The agreements are very good, and the measured positions are used to tune injection magnets.

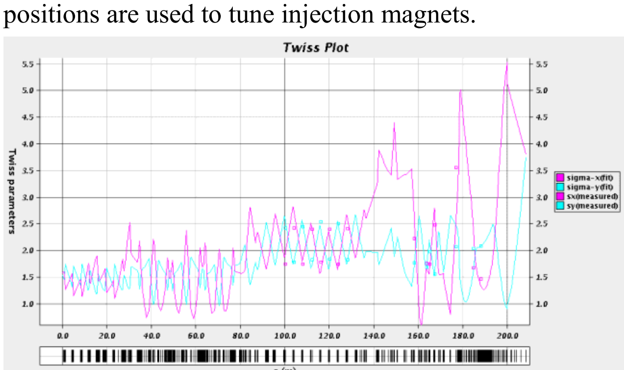

Figure 5: Envelope from L3BT to RCS H0 dump at 30mA.

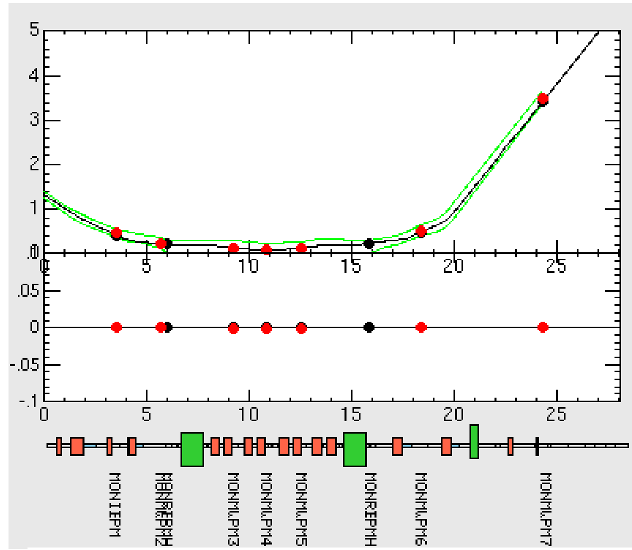

Figure 6: Orbit center positions from L3BT to H0 dump.

SUMMARY

A software tool for beam profile reconstruction with RCS MWPM's has been developed with carefully designed calculation procedure of coordinate transformation, profile analysis and baseline correction methods. Clear profiles in horizontal and vertical are reconstructed. Measured orbit positions are consistent with a model, and used for tuning injection magnets. The beam widths are compared to LINAC wire scanners and consistent results are obtained. Possible improvements for position and width resolutions could be obtained by adjustment of baseline offset for each wire, the first order polynomial fit to the background, and asymmetric Gaussian fit to the peak part.

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