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BPM SIGNAL CHANNEL CHARACTERIZATION TEST BASED ON TDR FOR HLS II STORAGE RING*

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Abstract

A new BPM system on the upgraded Hefei light source (HLS II) storage ring is installed. Before the machine commissioning, the BPM system should be carefully tested, such as the conductivity and integrity of BPM signal channels from button electrodes to digital beam position processors (pickups, cables and connectors). This paper presents an experience of signal channel test based on time domain reflection (TDR) for HLS II storage ring BPM system. Basing on the wave propagation method, an analytic expression for the signal from TDR on BPM signal channel is briefly introduced. The conductivity and integrity of the BPM signal channels can be verified by comparing the TDR waveform with theory signal. All the BPM signal channels are tested by the TDR in order to verify electronic characteristic and the usability. And some breakdowns are analysed and handled.

INTRODUCTION

An upgrade is employed on Hefei Light Source. The energy of injector changed from 200MeV to 800MeV, and the electron storage ring was reconstructed and most of beam diagnosis system were redeveloped include BPM system, as is shown in Fig. 1.

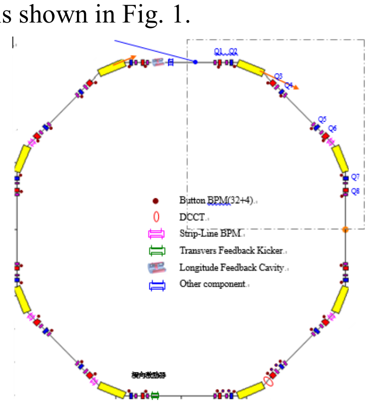

Figure 1: Beam diagnosis component of HLSII storage ring.

Much of the beam diagnosis system are working on radio frequency, such as BPM system, FCT&ICT measurement system, Bunch by bunch Feedback system, Tune measurement system. In this systems, detectors and processors were distributed in different place and connected by RF cables called as signal channel. The electronic characteristic and the usability of signal channel will influence the performance of measurement system. BPM signal channels were test and evaluated in this paper.

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The BPM system of HLS II storage ring has 32 units for beam close orbit distortions measurement. Each unit consists of the digital signal processor, signal channels, and pickups. The pick-up is button-type electrode and the beam position signal processor is Libera Brilliance [1].

Since BPM has four button-type electrodes, each unit has four signal channels severally named as channel A, B, C and D. The signal channels between the BPMs and the position signal processors consists of main signal cables, jumper wires, feedthroughs on the button and the connectors between different sections. The schematic of one BPM signal channels is shown in Fig. 2. The type of main signal cables is LMR-400 of the Times Microwave Company and the jumpers are PRC9104. The delay time of the signal are respectively 3.92 ns/m and 5.0 ns/m, and the attenuation factor of the LMR-400 is about 9.2 dB/100m at 500 MHz [2]. The buttons has a female SMA connector [3]. The idea impedances of main cable and the jumpers are 50Ω. The impedance of the feedthrough of the button was also designed to be 50Ω. As a complex system, the damages of the multitudinous devices are probability during the machine installation. So it is necessary to make a dedicated test for the continuity of signal channels before machine commissioning.

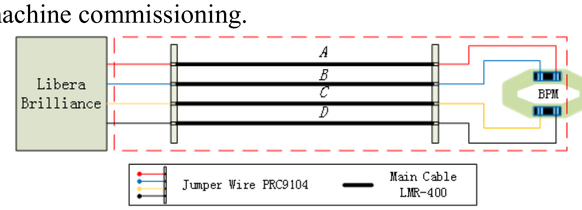

Figure 2: The schematic of the BPM signal channels.

The technique of Time Domain Reflection (TDR) [4] was developed as early as 1960s. A pulse from a signal generator transmit along the transmission line and the reflection of the signal happens when it meet a mismatch of the impedance. The reflecting signal can be received and displayed on the oscilloscope. By observing the wave, the character of the transmission line can be analysed. TDR method can be used to qualitatively test the character of the long-length cables in many engineer fields, as well as in the accelerator beam diagnostics.

SIGNAL CHANNEL EVALUTION BASED ON TDR

Figure 3 illustrates the method for the evaluation of the signal channel. In the BPM system, button, at the end of signal channel, can be seen as a capacitive device. The jumpers and the feedthrough are much shorter than the main cable. The measurement instrument has variable

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current source which is connected to the terminating resistor. A step pulse is generated when the current source is switched on. The pulse propagates out to the external device and the signal at the acquisition point is detected as a function of time. Then the information about the signal channel can be obtained by analysing the waveform in time domain. Since the main cable and the jumper wires have the same idea impedance of 50 Ω, the cables combination can be equivalent to a single cable. The button is equivalent to a transmitting line and a capacitance stemmed from the feedthrough and the gap between the electrode and the feedthrough.

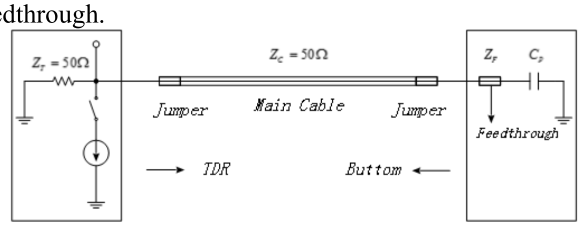

Figure 3: The schematic of the TDR of a signal channel.

The expression of the waveform of the channel on the TDR can be derived from the theory of transmission lines concerning multiple media [5]. The jumpers can be treated as parts of the main cables since generally there is a good impedance match between them. The segmented expression of is

$$V_1(t) = -\frac{I_0 Z_T}{2} \quad (0 \le t \le 2\Delta t_1) \tag{1}$$

$$V_2(t) = \frac{I_0 Z_T}{2}\left[1 + \frac{(Z_C - Z_F)}{(Z_C + Z_F)}\right] \quad (2\Delta t_1 \le t \le 2(\Delta t_2 + \Delta t_1)) \tag{2}$$

$$V_3(t) = V_{a0} + V_{a1}\exp\left[-(1-2r)\alpha(t - 2(\Delta t_1 + \Delta t_2))\right]$$
$$(t \ge 2(\Delta t_2 + \Delta t_1)) \tag{3}$$

$$V_{a0} = -\frac{I_0 Z_T^2 (Z_T - Z_C)}{(Z_T + Z_C)^2} \tag{4}$$

$$V_{a1} = -\frac{4 I_0 Z_T^2 Z_C}{(Z_T + Z_C)^2} \tag{5}$$

where the Δt_1 and Δt_2 are the signal transmitting time respectively in the cables combination and the feedthrough, r is the impedance mismatch ratio and α is the inverse of the product $C_p Z_F$. Figure 4 shows the simulation waveform of the TDR method using expression (1), (2) and (3). The relevant parameters is displayed in Table 1.

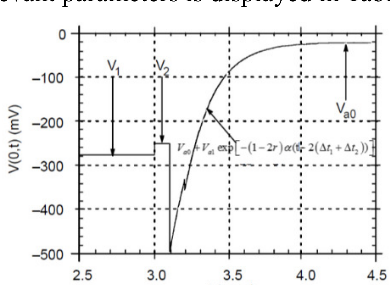

Figure 4: The theoretical waveform of BPM signal channel with button.

Table 1: Main Parameters for Simulation

Parameters	Value
Δt_1	3 ns
Δt_2	100 ps
I_0	10 mA
α	4/nsec
r	-0.1
Z_T	50 Ω

TEST OF BPM SIGNAL CHANNELS

For measuring convenience, a testing cable with a connector was used in the end of processors which only has effect on the reflecting time. The signal delay in the testing cable is about 24 ns. The delay of the pulse step is set 16 ns and the voltage is set 250 mV. After the signal on the scope tends to stabilization, both the full waveforms and the magnifying views at the end are observed for a straightforward estimate. Meanwhile, the curve data are acquired from TDR through GPIB bus and Labview programme running on PC.

With the simple data processing, 128 waveforms in time domain can be obtained. Comparing the curves with the Fig. 4, a judgment about the signal channel can be done straightforward and effectively. The 124 channels tend to be coincident and the only differences are the reflecting time due to the different cable length. So it is reasonable to infer that these signal channels are in a same condition.

As one of the 124 channels, channel D of BPM31 can be representative. In Fig. 5(a), the step pulse is generated at $t \approx 16ns$, transmits along the channel, is reflected firstly at $t \approx 40ns$ and secondly at $t \approx 401ns$. The wave between $t \approx 40ns$ and $t \approx 401ns$ is flat with a relative fluctuation being 4%, which illustrates that the jumper wire and the main cable as well as the connector match well. The obvious shake at $t \approx 40ns$ is caused by the mismatch between the testing cable and the jumpers as well as connector. The amplitude of the signal is slightly larger than the initial one when $t \ge 401ns$, since the instability of waveform caused by the signal reflecting can last for some time.

Figure 5(b) shows a magnifying view of the transition at the reflecting time $t \approx 401ns$ between the cable and the button electrode. The fluctuation stems from the imperfection at the joint. The bump at $t \approx 401.2ns$ is due to the mismatch of the connector on the cable. The exponential decay at $t \approx 401.3ns$ is due to the button capacitance which comes from the gap between the electrode and the feedthrough. From Fig. 5(b) we can see there is no glitch impulse in this area, which implies that the continuity between the jumper and the feedthrough can meet the demand of the signal channel. We can conclude that the cable and the feedthrough of the pick-up have been well connected.

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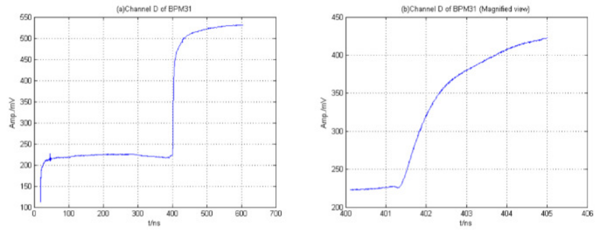

Figure 5: (a) is the full waveform of TDR for channel D of BPM31 and (b) is the magnifying view.

Otherwise there are four waveforms which are largely different from the one of channel D of BPM31 on the TDR. These signal channels are respectively A and B of BPM 02 and A and D of BPM 16. As is shown in the Fig. 6(a), (b) and (c), the full waveforms of the B channel of BPM 02, A and D channels of BPM 16 are completely unsystematic relative to the theoretical waveform. So a careful check need be done for the three channels to make them conductive. Generally, since the LMR-400 cables cross the shielding wall under the ground, the breakdowns can rarely occur for the middle parts of the main cables. Because of the complexity of the accelerator, the crash may happen between the different subsystems in the gallery of the HLS II especially at the cable joints. As an example, Fig. 7 shows the connector of the jumper wire in the B channel of the BPM02. We can see an apparent twisting at the cables joint. After replacement of the twisted jumpers, the waveforms become well, as is shown in Fig. 8(a), (b), (c).

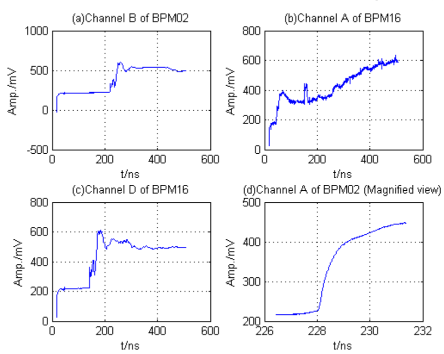

Figure 6: The TDR waveforms of the four distinctive signal channels. (a), (b) and (c) is the full waveforms of the corresponding channels while (d) is the magnifying view of the corresponding channel.

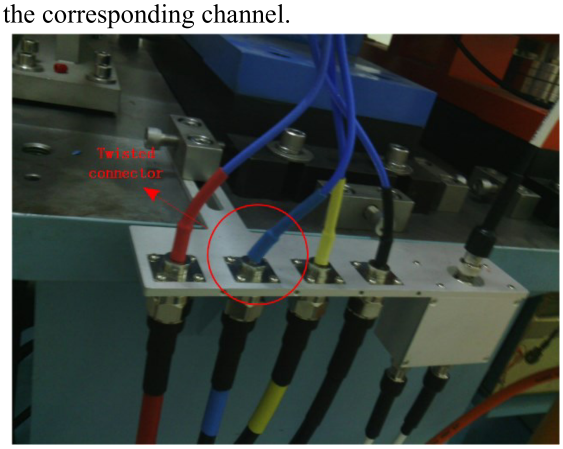

Figure 7: The connector of the twisted jumper for the B channel (blue) of BPM02.

The full waveform of the channel A of BPM02 is almost same as the others. But the magnifying view in the Fig. 6(d) shows no exponential decay caused by the capacitance of the button. This fact illustrates that the button was not well connected in the end of the signal channel. Soon it turned out to be that the SMA connector of the jumper was not close. After consolidating the joint between the jumper and the button and testing this channel again, the exponential decay in the channel A of BPM02 appeared in Fig. 8(d).

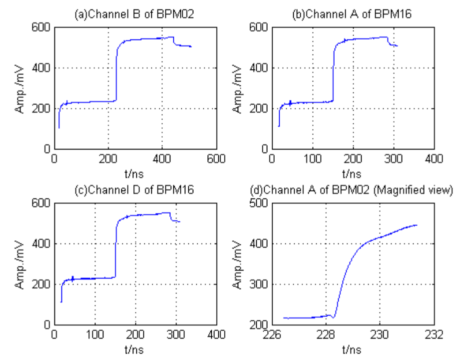

Figure 8: The TDR waveforms of the four distinctive signal channels after handling the problems. (a), (b) and (c) is the full waveforms of the corresponding signal channels while (d) is the magnifying view of the corresponding signal channel.

CONCLUSION

All the signal channels of the 32 BPM (128 signal channels in total) have been tested basing on TDR method after the installation of the BPM system for HLS II storage ring. The 124 of the 128 signal channels are well installed while some breakdowns happened to the rest 4 signal channels during the installation of the new machine. Basing on the results of the TDR-based test, the well-installed signal channels were confirmed and the troubles of the four signal channels were removed. The TDR method provides a selection to efficiently evaluate the connectivity and continuity of the signal channels of the BPM system.

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