DEVELOPMENT OF THE BEAM CHOPPER TIMING SYSTEM FOR MULTI-TURN INJECTION TO THE J-PARC RCS

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Abstract

Multi-turn injection using charge exchange is employed for the J-PARC Rapid Cycling Synchrotron (RCS). To reduce space charge effects, the bunching factor of the beam in the ring should be increased. Therefore the momentum-offset injection scheme is used. In each turn, the bunch trains from the linac are injected into the RF buckets with a momentum offset. The bunch train is called the "intermediate pulse". The intermediate pulses are generated in the low energy section of the linac by the RF chopper and pre-chopper. Since the pulses must be synchronized to the RF voltage in the ring, the timing signals for the choppers are generated by the low-level RF (LLRF) system of the RCS. The RF chopper and the pre-chopper require different pulse widths. Thanks to the direct digital synthesis (DDS) in the LLRF system, precise zero-cross signals for the reference of the chopper pulses are generated without difficulties. The cable length from the RCS LLRF system to the linac chopper control system is more than one kilometer. Thus, the chopper pulses are sent via optical cables. We developed the chopper timing module. We describe the details of the hardware.

INTRODUCTION

The J-PARC accelerator complex [1, 2] consists of the 181-MeV linac, 3-GeV Rapid cycling synchrotron (RCS), and 50-GeV synchrotron (MR). The accelerating frequencies of the linac, the RCS and MR are 324 MHz, 0.94-1.67 MHz and 1.67-1.72 MHz, respectively. The harmonic number of the RCS is chosen as 2.

To minimize the beam loss in the RCS during the injection period, the multi-turn injection scheme using charge exchange is employed. Combining the injection scheme with the momentum-offset and the second harmonic RF as well, we can increase the bunching factor in the RCS. A typical bunch shape simulated using the schemes is shown in Figure 1. By increasing the bunching factor, we can alleviate the space charge effects.

In the multi-turn injection scheme with the momentum-offset, the bunch trains from the linac are injected into the RF buckets of the RCS with a momentum offset in every turn. The bunch train is called the "intermediate pulse".

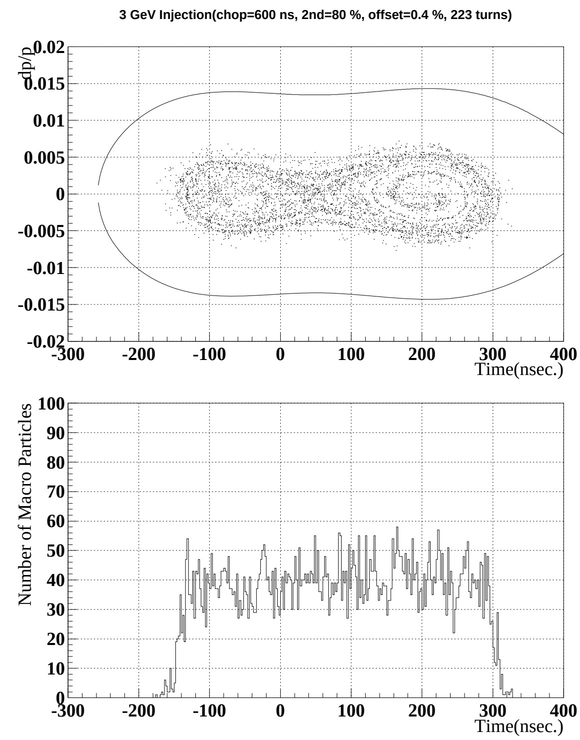

Figure 1: A typical bunch shape after injection using the multi-turn momentum-offset injection scheme. The second harmonic RF is also applied.

The intermediate pulses are generated in the low energy section of the linac. The beam is chopped by the RF chopper and pre-chopper controlled by the external gate signals. These choppers are operated by the gates with different widths. At the beginning of the RCS beam commissioning, only the RF chopper is to be used. Beam signals of the current transformers before and after chopper are shown in Figure 2. In the figure, the beam is chopped by the RF chopper, which is controlled by the gate signals from the local function generator[3].

Because the intermediate pulse must be synchronized to the RCS RF voltages, the timing signals for the choppers are generated in and sent from the RCS LLRF (Low-Level RF) system. The signal path is more than one kilometer.

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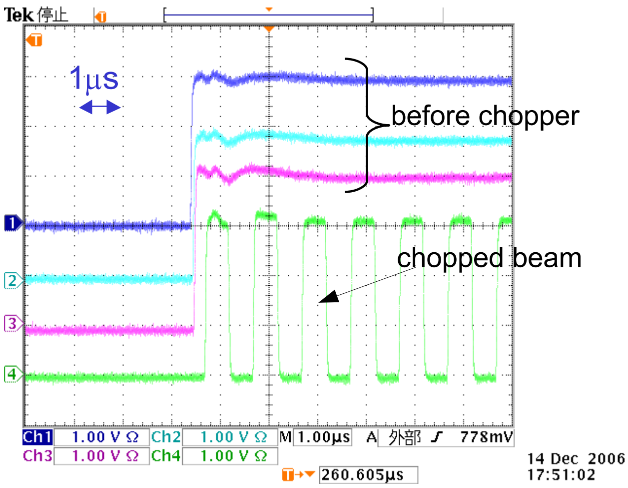

Figure 2: Chopped beam signals measured by current transformers.

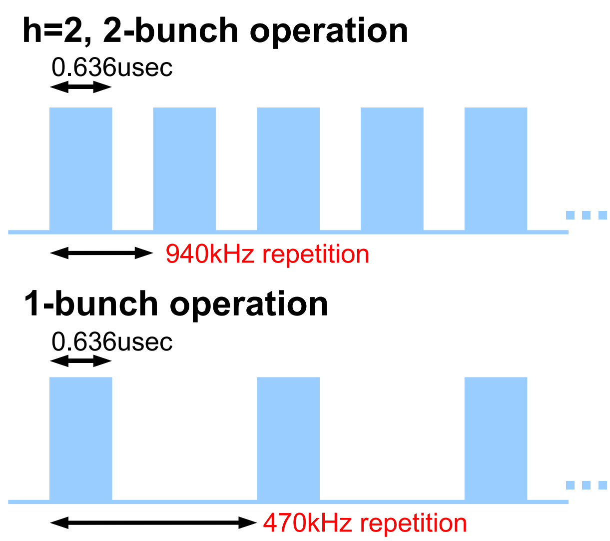

Figure 3: Intermediate pulses for 2-bunch and 1-bunch operation.

Since the intermediate pulse width is one of the knobs for beam commissioning, the width is remotely controlled.

We describe the configuration of the chopper timing system and its hardware in the following sections.

2-BUNCH AND 1-BUNCH OPERATION

In the designed operation of the RCS for the maximum beam power, both of the two RF buckets are filled (it is called "2-bunch operation"). However, "1-bunch operation", in which one of the buckets is filled and the other is empty, is a useful operation especially for beam commissioning.

For example, at the beginning of the beam commissioning, we extract the injected beam at the energy of 181-MeV without acceleration (we call the operation "DC-mode"). The flat-top width of the extraction kickers is optimized for 3-GeV extraction. It is not long enough to extract two bunches at 181-MeV energy, because the bunch length and spacing are much longer than that at the extraction. In the case of the 1-bunch operation, the flat-top width is long enough for the extraction of a bunch. Also, for the timing-scan of the extraction kicker at the 3-GeV, the 1-bunch operation is more effective.

Thus, the chopper timing system must have operation modes for both the 2-bunch and 1-bunch operation.

Intermediate pulses for the 1-bunch and 2-bunch operation are illustrated in Figure 3. In both cases, the widths of the intermediate pulses are same, while the repetition frequency for the 1-bunch operation is the half of that for the 2-bunch operation.

CHOPPER TIMING SYSTEM

Generation of the chopper timing signal

The chopper gate signals are generated by the "CMT (Chopper and Monitor Timing)" module in the LLRF system. A block diagram of the CMT module is shown in Figure 4. The CMT module consists of two functions, the zero-cross generation block and the gate signal generation block.

As described in the previous section, the module can generate the gate pulse for both of the 2-bunch and 1-bunch operation. For the 2-bunch operation, the $(h = 2)$ phase reference signal is used for the generation of the zero-cross pulse. For 1-bunch, the $(h = 1)$ signal is used. We employ the Direct Digital Synthesis (DDS) as the base of the LLRF system. The DDS enables us to generate the multi-harmonic signals precisely without any PLLs[4, 5]. By using the phase reference signals, highly accurate zero-cross pulses are generated.

In the gate signal generation block, the gate signal is defined by the delay from the zero-cross pulse and the width setting. The parameters are individually set for the RF chopper and the pre-chopper. In the figure, "delay A" and "width A" are for the RF chopper and "delay B" and "width B" are for the pre-chopper.

The gate signals are output with TTL level, then converted into optical signals as described in the following subsection.

Transmission of the chopper timing signal

Since the signal path from the RCS LLRF to the chopper control in the upstream of the linac is more than one kilometer, we send the chopper timing signals via single-mode optical fibers.

We consider three options of signal transmission as follows.

- (Option 1) As mentioned in the previous subsection, by using the coding and serializing functions of FPGA on the CMT module, a high-speed serial signal which contains the timing information is generated. The

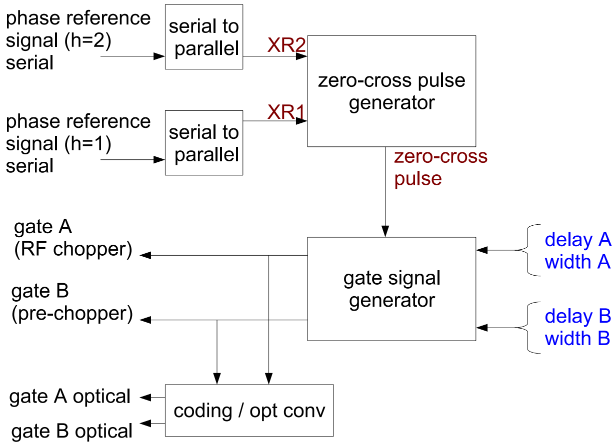

Figure 4: Block diagram of the CMT module, the chopper timing part.

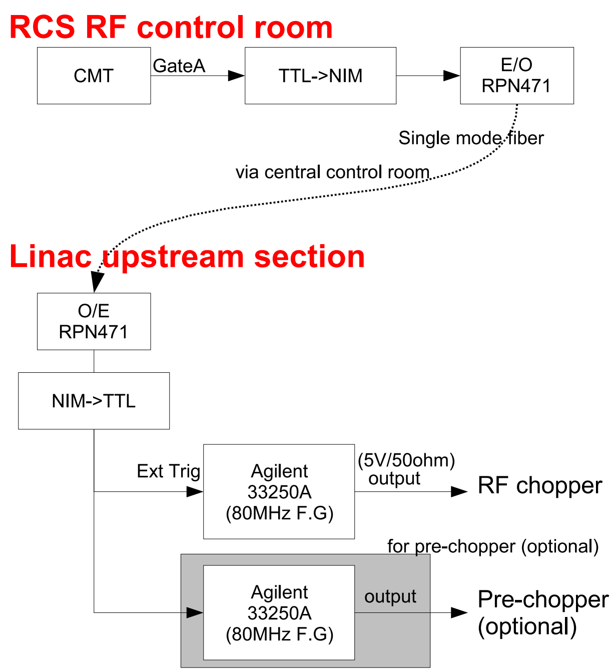

Figure 5: Signal transmission option with a function generator.

high-speed serial signal is suitable for optical transmission. The signal is decoded in the upstream of the linac.

  – This is the original design, but we found a data phase offset between the transmitter and the receiver, which varies at every power-up. By this offset, the total signal delay is not a fixed value. We are trying to solve the issues.

- (Option 2) Using a very wide-band optical link (from 5 kHz to 3 GHz), the gate signal from the CMT module is converted into an optical signal.
  – The signal baseline changes according to the duty factor of the gate signal.
  – AC coupling (5kHz) is not perfectly suitable for burst pulse trains.
- (Option 3) We have an optical module which can send high-repetition (up to 3 MHz) signals without width information. The CMT output as the trigger train for the gate generation is sent by that module to the upstream of the linac. In the upstream, the width is defined by a function generator.

We have decided to employ the option 3.

The configuration of option 3 is illustrated in Figure 5. The module RPN-471 (product of REPIC) is used for pulse transmission. An Agilent 33250A is used for the gate width generation. The optical transmission modules and function generator showed low jitter (less than 1 nsec) when tested.

The CMT module and the 33250A function generator are to be controlled from the central control by EPICS.

SUMMARY

We summarize the presentation as follows.

- The multi-turn injection scheme requires intermediate beam pulses completely synchronized to the RF voltages in the RCS.
- The chopper timing system is ready for both 2-bunch and 1-bunch operations.
- The CMT (Chopper and Monitor Timing) module in the RCS LLRF system generates the chopper timing signals.
- The beam commissioning of the RCS will start with the chopper timing system with trigger transmission modules and a function generator.

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