BUNCH BY BUNCH PRECISION MEASUREMENT OF FAST EXTRACTION EFFICIENCY AT IHEP 70 GeV PROTON SYNCHROTRON

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Abstract

In the course of upgrading the IHEP extraction system, we are developing diagnostic tool aimed at increasing the accuracy of measuring the extraction efficiency on a bunch by bunch basis. The task is solved by using a single Beam Current Transformer (BCT), mounted in front of the exit window of the accelerator beam pipe so that it envelops both the circulating and ejected beams. Readings of the bunch intensities taken sequentially before and during the extraction allow one to calculate efficiencies for each bunch and overall. This paper describes the main components of the diagnostic tool.

1 INTRODUCTION

The U-70 proton synchrotron beam is divided in 30 bunches at interval 166 ns, each one injected from the Booster, so there is the bunch width spread from 30 to 50 ns. Empty RF buckets are used fluently, in fact, a number of the circulating bunches varies from units to 29 and the time interval between them is a multiple of 166 ns. The bunch intensity ranges from about 5×10^{10} to 1.7×10^{12} protons. The Fast Ejection System (FES) extracts a sequential group of 1 up to 29 bunches through the exit window in the straight section SS30 toward the experimental setups. The FES comprises the kicker magnet KM16 and two stationary septum magnets SM24 and SM26. A few bumps are used for local disturbance of the closed orbit necessary to kick successfully the beam into the aperture of the first septum.

A number of factors causes a decrease of the extraction efficiency from 100%: increasing the pulse rise and fall time as well as the instability of the KM flattop, malfunctions of its modules, timing errors, variations of the closed orbit position, the beam momentum spread, etc. Under their influence, the kicked beam can enter the first septum with a range of angular deflections; as a result the beam trajectory is changed thus causing beam losses. Therefore, measuring the efficiency over the extraction and for each bunch separately becomes a very useful tool to minimize losses, define the optimal parameters set, and keep the long-term stability of the extracted beam performance. By our estimates, the necessary accuracy of the measurement is not less than 1%. The system in operation had been built 27 years ago /1/ and is based on the traditional concept of using two BCT's. The first one, placed around the accelerator beam pipe, measures the circulating bunch intensities before the extraction, and the second BCT at the external channel entrance measures the extracted bunches. The precision was about 2% when single-turn injection from Linac was used. After the Booster injection was put in use, an accuracy degraded down to 4%. The main cause is the substantial spectrum difference of BCT's signals. This fact causes frequency-dependency difference of their responses. We have designed the new system for measuring extraction efficiency with an anticipated error of 1%. It uses only single BCT, mounted downstream of the FES around both the circulating and extracted beams /2/. The new fast processing electronics gives turn-by-turn bunch intensities, before and immediately after the kick. Thus, drawbacks above are excluded. Calculated efficiencies are results of reading data delivered in a full-common measurement channel.

The BCT is installed downstream of the SM26 in the SS28, where the separation between deflected and circulating beams is about 80 mm. The whole BCT is mounted for economy inside of the accelerator vacuum chamber in a separate casing, the last one is used as a bypass for the image currents. The BCT toroid core is made of thin tape of cheap high permeability (20,000) alloy with amorphous structure (71KCHR) with high saturation induction and low outgassing. The opening of core including the inner electrostatic screen is 200 mm, the cross-section is 40×40 mm^2 The 12 turns winding is done of thin 75 Om coax cable. The 75 Om low loss cable 300 m of length transmits the signal to the Extracton Control Room for processing. The full rise-time is 7 ns, which ensures a good reproduction of the bunches and a flat base-line between them.

2 ELECTRONICS

The block diagram of Electronics is shown in Fig.1. Its composition and blocking-out are typical for such applications. Some variations are used for high-speed operation, for operator's convenience, e.g. automatic gain selection, etc. The signal after splitting (20% goes to Scope, 80% -for processing) passes through attenuator. Taking into account the high level of the signal (up to 50 V) and nearly 40 dB variation in magnitude, we realized the two-stage attenuator. The first one is based on a coax reed switch, attenuates by 18 dB (one half of full-scale). The second attenuator is of electronical type and has 3 grades: 0-6-12 dB. Thus, the signal range is divided into 7 subrange with 6 dB step. Of course, the first stage is switched infrequently. Auto-ranging is executed some tens of millisecond before the extraction. Three measurements of the circulating bunches are taken sequentially, with gains defined by successive approximation to chose the correct subrange. Then

ranged signal is fed to the Base Line Restorer (BLR) to reset to zero the base-line between bunches. The following Fast Integrator (FI) transforms a pulse square to the proportional voltage with a flattop of order of 30 ns to facilitate timing flash ADC.
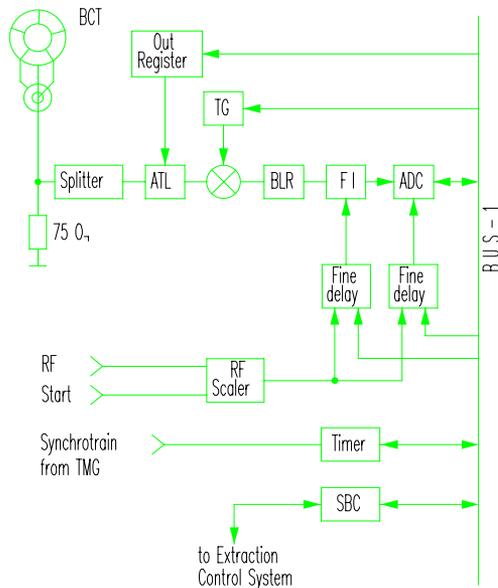
Fig. 1. Block diagram of the processing electronics.

The latter is based on using the 10 Bit 40 MSPS ADC AD9050 and the fast FIFO 9 Bit Memory CY7C441. We realize only 9-bit resolution because of high frequency noises, but after some exercises we hope to get 10 bit one. Using the fast ADC allows to measure both a DC off-set just before a pulse from the FI and pulse 30 ns flattop itself. Thus, an appropriate data processing allows one to calculate intensities and efficiencies of each bunch and overall. The system is synchronized by timing pulses locked to RF. Two channel of Fine Delay with 1 ns resolution are used for fine gating ADC and FI. Rough timing (attenuation setting, data transfer, testing, measuring out extraction time region, etc.) is performed by the IHEP Timing system synchrotrain /3 /. The whole electronics can be tested by the Test Generator (TG) during beam pauses. The attenuator, TG and BLR have been made in non-standard fashion. Remaining electronic modules are packaged into Eurocard style with a Multibus I. Initially, for adjustment of the measurement system we use a Single Bord Computer (SBC) ME186 connected with a PC.

ACCURACY

At present the apparatus is under a bench test. After some operational development caused mainly by decreasing jitter of fine delay we hope to get a precision not worse than 1% over the full intensity range. As for

kicker and RF noises, we have learned that they are successfully suppressed with proper cable grounding and adding a filter formed by winding the coax cable several times around ferrite rings. The last fact helps to reduce the common-mode currents at high frequencies.

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