A SYSTEM FOR MONITORING BEAM LOSSES AT THE IHEP U-70 ACCELERATOR

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Abstract

Updated beam monitor system executes continuous monitoring surveillance beam losses around the IHEP U-70 accelerator. The system consists of 120 detectors. One is located upstream of each bending magnet in the median plane outside of the beam-pipe at 60 cm apart. The detectors are cheap ion chambers filled with air under barometric pressure and 1.8 liter volume. Chamber signals processing is based on digital integration and done in the framework of the U-70 Control System. Acquired data are used to facilitate tuning of the accelerator, minimize beam losses at any point of the machine circumference and consequently decrease damage for accelerator equipment. This report gives a brief description of the system and the result of run experience as an example.

INTRODUCTION

During beam circulating at high energy accelerators many possibilities exist for the beam to be lost, partially or even as a whole. Probable beam loss causes are:

- Steering errors at the injection
- Closed orbit distortion
- Erroneous transition crossing
- Improper tuning of the extraction
- Gas scattering because of poor vacuum
- Aperture restrictions
- Equipment malfunctions.

Operational intensities of proton beam at the IHEP U-70 Accelerator are typically around $9*10^{12}$ protons per cycle at the same time full design intensity is $3*10^{13}$ protons. It is then mandatory to operate with the smallest beam losses to minimize damage of accelerator equipment and personnel exposure while maintenance. Time and position distribution of the losses is the very useful diagnostic aid for facilitating tuning the machine. A beam loss monitor (BLM) system for continuous detecting radiation levels around the U-70 accelerator had been developed and put in operation for the first time in 2000 [1,2]. After a seven year experience the main drawbacks have been exposed:

- Used miniature ionization chambers (IC) of 0.16 liter volume produced low level currents in range from tens of pA to hundreds of nA [3]. Their transmission via long (up to 1000 m) coaxial cables to a surface building under high industrial noises caused deficient SNR for many locations. This fact was usually an obstacle for researches at the low intensities.
- The obsolete and very bulky data acquisition means. That cased often errors of data traffic and impeded the maintenance service.

That is why the system was improved by replacing the small IC`s with new chambers and developing a new electronics.

The new BLM system was installed in 2012 and has been operating successfully since the start. It has been included in the U-70 control system [4] and provides the qualitative information about beam losses in each straight section over the accelerator cycle with 100 mc time resolution, or not less than 10 mc for short time intervals at the range of the intensities from $3*10^{10}$ to $3*10^{13}$ protons. The beam loss distribution is given by a histogram. This report presents monitor design, their mounting and the processing electronics.

BEAM LOSS MONITOR

The monitors are home-made IC’s filled with 1800 cm^3 air at local barometric pressure. They are inherently slower devices, but this feature is not a significant drawback in our practice. Figure 1 shows a photograph of the new monitor. It is an electrode assembly, consisting of 31 plane-parallel 0.2 mm thick stainless steel foils, 6 mm apart, alternatively connected to the collector voltage and signal buses. The operating volume is about 1800 cm^3. The assembly is packed into a stainless steel cylinder 100 mm diameter and 43 cm length. Connectors are placed on the end of the cylinder, two ones connected in parallel (for daisy chain connection) are used for applying the bias voltage and third one is the signal output.

The main electrical characteristics of the chamber are next:

• The bias voltage	750 V
• The positive ion transit time	≤ 0.2 mc
• The interelectrode and electrode to ground resistance	≥ 1 TΩ
• The interelectrode capacity	0.65 nF
• Output typical current	200÷6 mkA
• The sensitivity	500 nC/rad

Long-term observations during operation of the U-70 in different modes did not detect a saturation of the monitors. Their gains are all practically identical and do not change with age.

The total charge collected in the monitor is highly depends on its relative position to a loss source. For the sake of homogeneity the IC’s are mounted close to each of 120 bending magnets in the median plane outside of

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-THPSC28

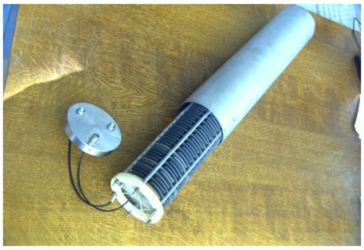

Figure 1: Ion chamber with shifted enclosure.

the beam-pipe at 60 cm apart (Fig. 2). Such a mounting ensures maximum monitor sensitivity to beam losses and uniform geometry with respect to the closed orbit; also, it does not block an access to the magnet and beam-pipe. Magnetic materials are not used in the detector, so the magnetic field force does not act on the detector body. The monitor is attached to the support duralumin tube. The lower part of this tube is clamped in a horizontal steel arm, and the last one is attached to the magnet support by a cramp. For each monitor small box was mounted in the accelerator basement to interconnect the cables. In addition, an RC–filter here is placed in the bias voltage circuit.

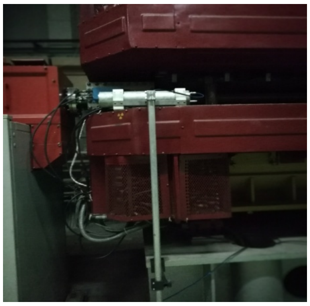

Figure 2: Ion Chamber Mounting.

Figure 3 shows the signals from three IC's spread downstream of the Septum Magnet in SS24 not more 1 m apart. The 1st track is the signal from the former miniature IC, the 2nd one the signal from the new IC and the 3rd presents the response of the argon filled chamber 1100 cm^3 volume. The signals have been fixed under slow extraction (the beam intensity in the ring is presented by the 4th track). Comparison signal level illustrates a big advantage of the new IC over the old monitor.

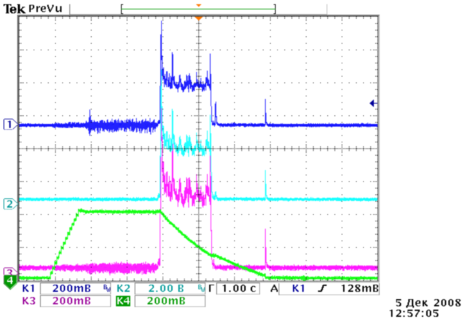

Figure 3: Loss monitors signals during the slow extraction.

PROCESSING ELECTRONICS

The high level of the current signals produced by the new monitors enabled us to refuse using a front-end electronics. The signals directly are fed via long (up to 1 km) coaxial cables to the back end electronics placed in the Accelerator Main Control Room. Since the ion chamber is a current source the high SNR is achieved. These signals typically vary over 90 dB range and have no single correlation with the beam intensity, so their processing is challenging task. We have chosen digital integration to meet these challenges. Such processing is based on using a voltage-to-frequency converter (VFC) followed by a counter. Important advantages are:

- Counter's reading is proportional to the charge collected at the IC;
- Integration time is limited only by the digital memory capacity but not electronic components parameters; thus, integrating over the full cycle is possible.

The monitor signal has current nature, so a current- to - voltage converter is necessary. Its output voltage is converted to frequency. Output pulses are counted by a counter. Fig. 4 makes this processing clear. U1 is the current – to voltage converter, U2 an inverter amplifier and U3 is VFC. The Op Amp's and the AD652 have excellent features and allow us to cope with currents ranging over the 90 dB range without switching.

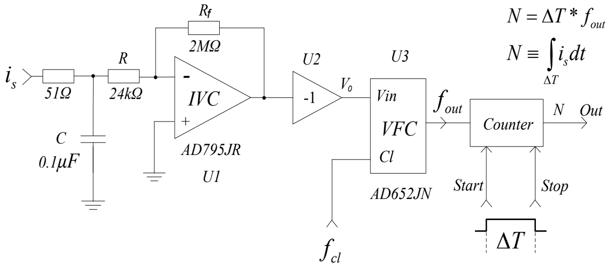

Figure 4: A simplified schematic of the digital integrator.

Output frequency f_{out} can be calculated by:

$$f_{out} = f_{cl} * \frac{i_s * R_f}{R_0 * I_0} = k * i_s ,$$

where i_s - the monitor current, $i_s * R_f = V_o$ output voltage to be converted, f_{cl} the clock frequency, R_o / I_o are inherent parameters of the AD652 and k the proportionality constant. Then reading counter over a time period ΔT is equal to

$$\mathrm{N} = \Delta T * f_{вых} \text{ or } \mathrm{N} \equiv \int_{\Delta T} i_s dt ,$$

i.e. reading is directly proportional to a charge collected over the time ΔT. To avoid overloading or saturating caused by short pulses a passive RC-filter connected to the AD795 input is added. There is the possibility to view the analog signals for study objectives.

The electronic parts U1÷U3 are built-in 15-channel module. Eight such modules are built into a separate Eurocard crate.

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-THPSC28

The clock is provided by a common crystal oscillator. For setting full-scale the frequency can be chosen at will from a range 250-500-1000 kHz.

Gating all 120 counters is done simultaneously. The number of time windows ΔT and their width from 10 ms to 100 ms are chosen at will, but as a rule, the full cycle has to be covered. The time gap between adjacent gates necessary for reading is order of 5 ms and can be neglected.

The counters have been built in the MULTIBUS -1 standard with an onboard memory. Main features:

- 32 Channels per module
- 16 Channel range
- 256 Cells buffer memory per channel.
- It consists of the following functional units (Fig. 5):
- Bus interface drivers (U1÷U5)
- Selector of the address highway MULTIBUS-1, drivers display input and output signals performed on the PLD (U13);
- Bootstrap memory for the PLD (U11);
- Onboard 50 MHz Clock Generator (Y1);
- I/O Signals drivers (U8÷ U10, U14÷ U17).

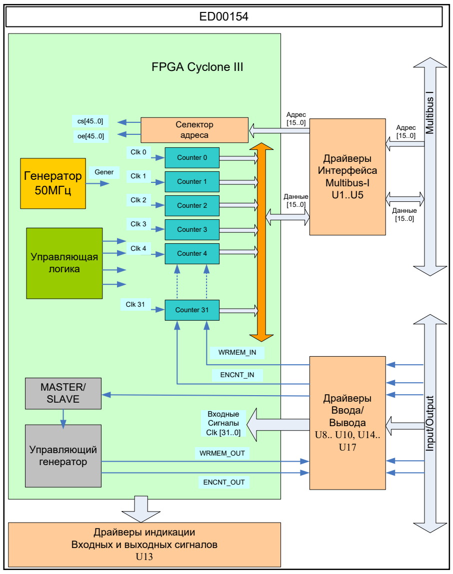

Figure 5: Flowchart of the 32-channel counter.

A simplified block diagram of BLM electronics is shown on Fig. 6.

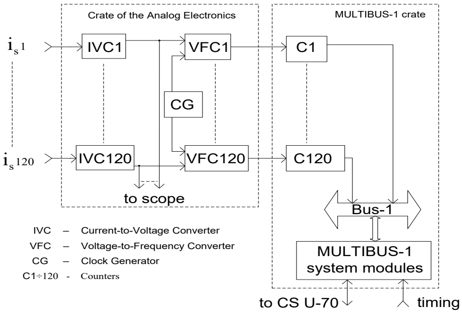

Figure 6: A simplified block diagram of BLM electronics.

Data processing and information display are carried out by the Single Board Computer module and means of the U-70 Control System. Typical the beam loss histogram is shown in Fig. 7.

All electronic modules are packaged into Eurocard style.

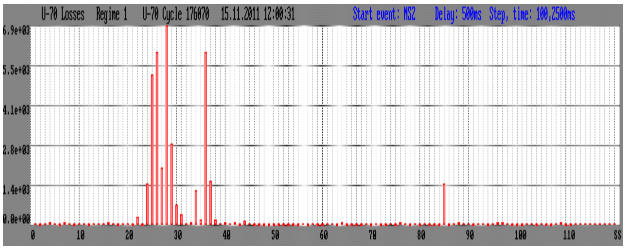

Figure 7: The typical beam loss histogram at slow extraction and internal target operation.

CONCLUSION

The BLM system has been developed for continuous monitoring surveillance beam losses around the U - 70 accelerator. The system consists of 120 detectors. The detectors are the cheap IC's filled with 1800 cm^3 air at the local barometric pressure. The current signals are directly fed to the Accelerator Main Control Room where they are processed simultaneously and continuously over the cycle by digital integrators with the time resolution not less 10 ms. The data acquisition system is integrated in the U-70 Control System. The BLM system was installed in 2012 and has been operating successfully since the start.

ACKNOWLEDGMENT

The authors wish to express their thanks to Dr. O. Lebedev for his encouragement and support during present work.

Also we would like to think O. Vishnyakova for the contribution to the design of the monitors and their mounting accessories.

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