ESRF Synchrotron Injector Beam Position Monitor System

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Abstract

The complete lay-out of the system which comprises 75 individual stations is presented from electro-static button signals down to the user level of the computer interface. The design of the electrode button and the block geometry is presented.

Highlighted is the concept of time-multiplexing of the 4 button signals through a RF multiplexer for each station individually which greatly facilitates & economises the design and realisation of the signal treatment electronics. The narrowband heterodyne technique is applied here at the RF frequency of 352.2 MHz with a 15 KHz bandwidth.

The timing and the data-acquisition electronics permit precisely timed measurements to be taken simultaneously on all 75 BPM stations at a rate of 1 KHz. The computer interface of this system (circumference 300 meters) is through a Field Bus between four G64 racks (connected to the BPM hardware) and one VME crate (where system control, BPM calculations and user interface are performed).

The results of this BPM system, taken into operation in September "91, are summarised with the performance characteristics of resolution, precision and reproductibility.

1. PERFORMANCE CHARACTERISTICS

For beam with 352.2 MHz structure but independant of bunch configuration :

* beam intensisty range (I) :	0.05 to 10 mA
* absolute precision rms :	<0.5mm+10%
* resolution rms :	<50μm (for I >0.2 mA)
* drift or reproductibility rms :	<100μm
* beam position range :	> ±10 mm

The measurement duration (time window) is programmable in 1ms steps with a minimum of 1ms. A total of 6 individual measurements can be taken during one acceleration cycle (in 50 ms from 200 MeV to 6 Gev) simultaneously at all 75 BPM stations. The exact moment of these measurements can be programmed with 1μs precision with respect to a external trigger signal (fig. 3).
The transport of the acquired data, the operations and calculatations by the control software and the presentation of the results to the user takes less than one second.

2. SENSOR

2.1 *Mechanical Design*

The design of the electrode button is shown in figure 1 together with a cross section of the BPM block in which the four electrodes are symmetrically distributed. The electrode buttons are identical to those used for the ESRF Storage Ring [1] which were designed in collaboration with METACERAM. They are directly welded into the BPM blocks and present a standard male SMA connector to the coaxial cables.

Each BPM block is welded into a so-called diagnostic chamber which has a 60mm inside diameter and is positioned directly adjacent to the quadrapole. The whole diagnostic chamber is supported through an arm from the girder but movable with respect to the quadrapole axis which is defined by means of two survey monuments on top of the quadrapole. By means of a measurement jig and the adjustment screws in the support the position of the BPM block center is aligned on the magnetic axis of the quadrapole with a precision estimated at 200 μm rms (figure 2).

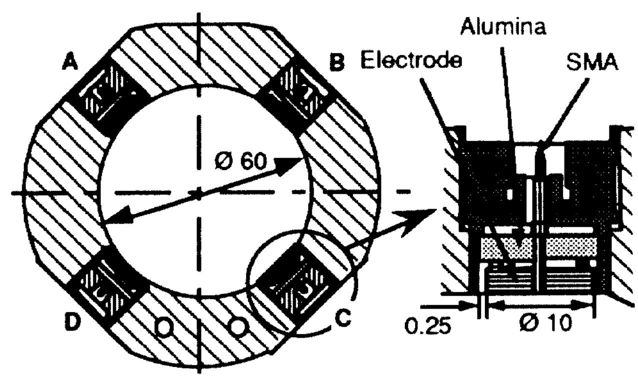

Figure 1. BPM Block with the electrodes

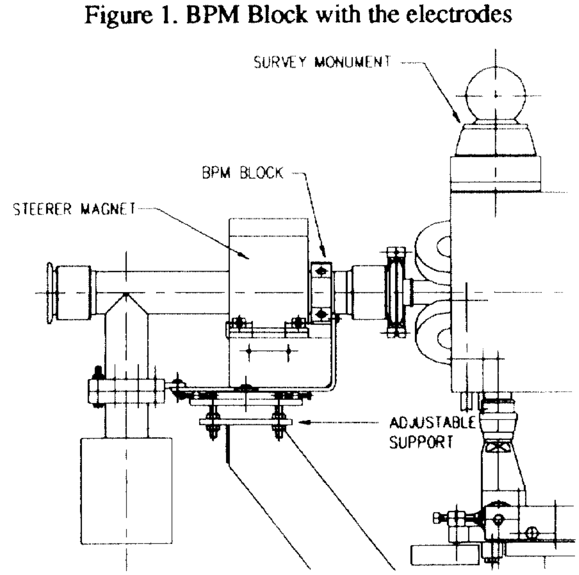

Figure 2. BPM Block position relative to the Qpole.

2.2 BPM Block Offset and mapping

A BPM block can have a center offset if the electrical sensitivities of the four electrodes are not identical. The precision of the block machining and of the electrodes positioning (<50µm rms) as well as the mechanical reproductibility of the electrodes is sufficient enough to limit this position measurement offset to less than 200 µm rms. This was verified by laboratory tests on a few prototype blocks in which a centered antenna simulated the electron beam.

The relation between the beam position and the relative signal strength obtained from the four electrodes (the so-called mapping) has been approximated by simulating the beam and the BPM block geometry on a WINGZ worksheet in the same way as for the the storage ring [1].

The simple formulas (in which A, B, C and D are the respective electrode signals) :

$$X = K_X.P_h \quad \text{with } P_h = \frac{(A+D)-(B+C)}{A+B+C+D} \text{ and } K_x = 21.5\text{mm}$$

and

$$Z = K_Z.P_v \quad \text{with } P_v = \frac{(A+B)-(C+D)}{A+B+C+D} \text{ and } K_z = 21.5\text{mm}$$

are of sufficient precision (error <10%) if the displacement is less than 10 mm from the center

2.3 Electrical characteristics of the button electrodes

The electrodes, having a 3 pF button-ground capacitance value and being charged with a 50Ω load, show a frequency spectrum characteristic with a rising sensitivity up to 1 Ghz and a final cut-off frequency around 10 GHz. This capacitance value has been chosen so as not to determine the electrode sensitivity at 352.2 MHz. This frequency is the acceleration frequency and its component is present in the beam spectrum independant of bunch configurations.

The yielded effective signal strength from the electrode into 50Ω at this frequency component is estimated at 0.3 mV/mA. The peak voltage is around 200 mV with a 10mA multi-bunch beam.

3. ELECTRONICS SIGNAL TREATMENT

3.1 The concept of RF time multiplexing

The four electrode signals of each BPM station are scanned by a RF multiplexer in a programmable time window (Tw) and then treated by the one chain of analog electronics. These analog electronics perform amplifying, filtering and detection operations and yield the time- multiplexed electrode signals at a DC amplitude of a few volts.

The advantage of having one single chain of electronics per BPM station is that any drift of the characteristics of these electronics (like gain, bandwidth or offset) affect the four electrode signals in the same manner. It should be noted here that in order to measure the electrode signals for very low beam currents (0.05mA) the total gain needed is more than 100 dB. If the four signals were to be treated independantly by four different chains of electronics a relative drift of 1 dB in gain between these 4 chains would cause a beam position measurement error of up to 2.8 mm.

The de-multiplexing is done after detection by a clock-circuitry which triggers the ADC card. This means that the control software acquires the four relative electrode signal levels individually. The absolute gain of the treatment electronics is of no importance as the beam position calculation is done on these relative signal levels.

Another advantage of this concept is that the control software can be easily programmed to execute different formulas than those given in 2.2 and can perform various verifications and corrections on the four individual signal levels. Instead of using the formula of 2.2 one can execute four different calculations for each coordinate by using a formula in which only three electrode signals are used. This than yields four results which should be approximatively the same. If these four results show an excessive discrepancy it indicates a mal-functioning of an electrode which can be further analysed and even corrected.

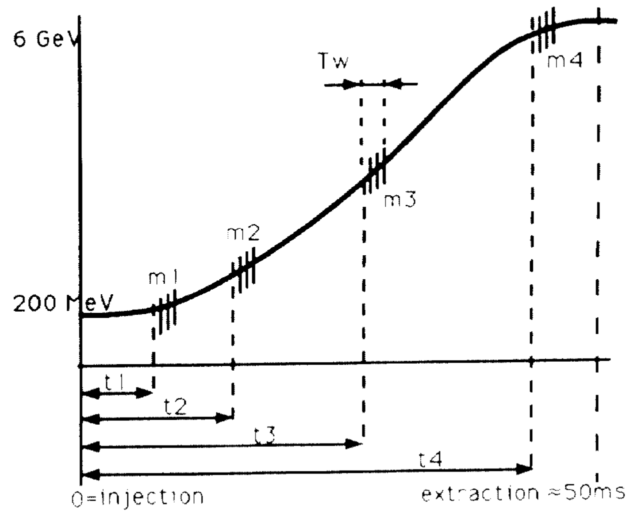

fig.3 : four measurements in one acceleration cycle

3.2 The RF Multiplexer

The RF Multiplexer consists of an array of PIN diodes configured as a SP4T switch (4 inputs, 1 output), a bandpass filter at 350 MHz with 35 MHz bandwidth and an RF amplifier with 26 dB gain. The four inputs are non-reflective i.e. they present under all conditions a 50Ω load to the electrodes.

The difference in insertion loss of the four input channels of the RF Multiplexer causes a offset of the BPM result (if it is not compensated by the control software as it is done for the Storage Ring BPM system). The specifications for the RF Multiplexers had taken this into account and laboratory verifications showed that their offset error contribution to the BPM results is only 50µm rms.

Reproductibility tests showed that the drift of this offset is neglegible.

The Multiplexer is attached to the side of the girder and out of the horizontal plane of the beam so as to obtain a minimum shielding against radiation. Its inputs are connected to the BPM block by RG223 cables of about 1 meter length.

3.3 The signal treatment electronics

The output of the Multiplexer is connected through a long cable (up to 60 meters) to a module which consist of one single card and which performs the amplification (programmable between 50 and 100 dB), filtering (programmable between 300 Hz and 3 KHz) and detection (dislinearity <5% for output signals between 0.5 and 5V) functions.

This module uses the heterodyne narrow band detection technique in which the to be measured frequency component of 352.200 MHz is mixed down to 10.700 MHz after which the Plessey amplifiers, a monolitic crystal filter (15 KHz BW) and a simple diode detector perform the required signal treatment. One of the amplifiers is gain controllable through a DAC circuit and the output of the detector passes by a programmable analog filter.

Both this gain and the final bandwidth are set by the control software as a function of beam intensity and user selected time window (Tw of 1 mS needs 3KHz BW).

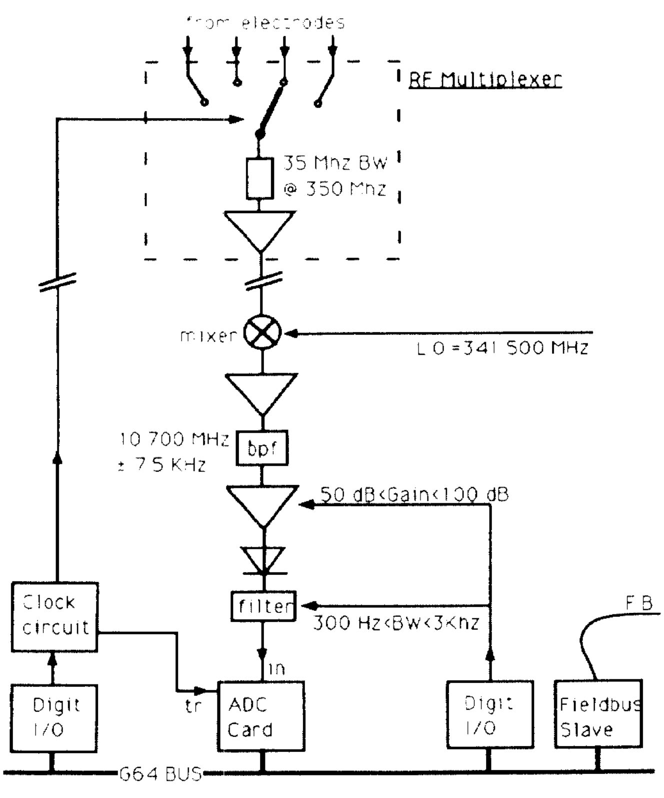

Fig.4 BPM electronics block diagram

3.4 The timing and data-acquisition electronics

The scanning of the electrodes is done simultaneously on all the 75 BPM stations upon the triggering of a clock circuit. This clock circuit takes control of the RF-Multiplexer (electrode selection) and of the ADC card which digitizes the detected output signal. For each triggered BPM measurement the ADC is triggered four times so that the four time-multiplexed electrode signals will be de-multiplexed and stored in the memory of this ADC card.

4. INTERFACE AND CONTROL SOFTWARE

4.1 The G64 - FieldBus - VME interface.

All the analog electronics of this BPM system other than the RF Multiplexers are located in four cabinets situated around the Synchrotron Injector Machine (circumference=300m). Such a cabinet (treating an average of 19 BPM stations) contains 6 Eurocard racks for the analog electronics and one Eurocard rack for the interface to the control system.

The first interface layer is the inexpansive G64 bus with which both the ADC cards and the digital I/O cards (for gain, bandwidth and time window control) are compatible.

The four G64 busses are interfaced to a VME crate by means of a FieldBus which comprises in this case four G64 compatible slave nodes and one VME compatible master. Both this FieldBus and the special ADC card were developped at the ESRF by the Digital Electronics Group.

4.2 The Control software and interface to the users

All the control software runs under OS9 on a single CPU board of one single VME crate. It contains all the intelligence of the BPM system as no computer pre-processing is done on the G64 level. It is interupt driven by a trigger signal (injection from Linac) after which all the necessary operations are executed according to parameters set by the user.

These parameters are essentially the expected beam intensity, the timing of up to six measurement and the time window of these mesurements. The user obtains the complete results generally in less than half a second on all BPM stations. The final interface between the control software running on the VME crate and the user working on the HP work stations is via an ethernet link and according to so-called device server procedures.

5. ACKNOWLEDGEMENT

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