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Beam instrumentation for the CNGS facility

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Abstract

An important milestone for the AB/BI group during 2006 is the commissioning with beam of the CNGS facility at CERN. This document describes the AB/BI instruments, their installation and hardware commissioning with some emphasis on the new BPM system developed specifically for the CNGS beam. Some reference to the LTI experience (TI8 test in 2004) will be made as similarities exist.

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1. Background

Work on the CNGS project started for the AB/BI group in 2002 following the first external review of the project [1] and more extensively with the release of the functional specifications for the required beam instrumentation [2]. The official BI representation during coordination meetings chaired by the CNGS project leader started during 2004 when the installation of the CNGS proton line TT41 was being planned. The main objective of the meetings was to provide a platform for discussions between the different departments/groups and to follow-up on technical matters, solve outstanding issues and anticipate upcoming problems. This platform for discussions with written minutes was useful for keeping track of progress and to keep the objectives/deadlines clear to all the involved parties.

2. Instrument specification, design and production

The following instruments were specified, designed and produced [3], [4] for the main proton line TT41 and the secondary beam areas:

- BPMs for measuring the trajectory of the proton beam.
- BTV monitors for measuring the beam size at locations situated from the extraction in LSS4 up to the CNGS target T40.
- Fast BCT transformers in the common TT40 tunnel and in the TT41 line.
- Beam-loss monitors along the proton line to locate losses during the passage of the beam and in TCC4 as secondary monitoring devices
- A TBID monitor with 7 titanium foils for secondary beam monitoring.
- Muon detectors equipped with ionization chambers.

3. Technical services and controls infrastructure

One of the important issues for AB/BI during the CNGS coordination meetings was making sure that the necessary technical services were installed. This concerns racks, cables and 220V sockets in the tunnel areas. The main problem encountered was for the semi-rigid coaxial cables from the TT41 tunnel to the BB4 barracks. Here, several installation and measurement campaigns were needed to get them into a state where they could be used for the BPM system. From the controls infra-structure side, Ethernet plugs, slow and fast timing outlets in HCA442 (SPS BB4) and UA87 (LHC point 8) was installed since 2004, so no special actions were required.

4. Instruments for the CNGS proton-lines TT40 and TT41

4.1. BPM system

In total, 23 beam position monitors are installed:

- 4 BPKs in TT40 [4][8]
- 18 BPGs with recuperated LEP buttons [4]
- 1 BPKG in front of the T40 target [5]

The specifications for the three types of monitor can be found in table 1.

	BPG	BPK	BPKG
Type	34mm diam. button	110mm shorted strip line	120mm strip line
Z_{inf}	1.5 Ω	7Ω	5.3Ω
Aperture at electrodes	60mm	116.74mm	61mm
Aperture of body	60mm	133mm	68.8mm
Remarks	Recuperated LEP buttons (C=8.9pF)	Signal inverted as output is on downstream side	This monitor works in ambient air

Table 1

The CNGS beam position acquisition system is based on logarithmic amplifier technology, first tested at CERN on the TT2 and TT10 PS to SPS transfer lines. To avoid the problems observed here with the timing-in, the CNGS system was designed such that each front-end system is auto-triggering, with the ADC conversion taking place in the tunnel. The digital values (position and intensity) are then encoded and transmitted serially over a coaxial cable to a receiver card, which decodes the information from 6 dual-plane pickups. A DAB64x VME motherboard, originally developed for the LHC orbit system [4], processes the data from two such mezzanines, i.e. regrouping all the data from 12 BPMs. Only two such DAB64x modules are therefore required for the whole CNGS BPM system (23 pickups). New low-level software allows measuring the CNGS beam where the 2 extractions are spaced by just 50 [msec]. Two integration times: 8 [µsec] and 400 [nsec] are foreseen in the front-end electronics. The longer can be used during stable physics runs with 10 [µsec] batches to get the best signal to noise performance. The shorter is foreseen for the initial commissioning of the CNGS facility when a batch length of ~2 [µsec] will be used to limit the total extracted intensity (and therefore the losses). Either of the two integration times can be selected on a cycle to cycle basis and the corresponding calibration parameters are automatically loaded. For the shortest integration time either of two delay settings (1 [µsec] and 2 [µsec]) can be selected to allow a position measurement outside the ripple induced by the non-perfect shape of the extraction kicker pulse. A 16-bit parallel control-bus allows changing the settings common for all the front-end stations situated in HCA442 (SPS BB4), TT41 and TCC4 tunnels. Off-line calibration generators close to the pick-ups are designed to induce signals that simulate the central and an off-centre position to obtain the required calibration factors (offset and scale). This calibration results in a linear performance of the system within a ±4 [mm] position range for the BPG monitors and a slightly extended range for the larger aperture BPK and BPKG monitors. The electronics has been designed to work with beam intensities between 2E11 protons in a 2 [µsec] batch and 4E13 protons in a nominal 10 [µsec] batch with good resolution and no saturation. For the first two BPK pickups situated in TT40, the analogue signals are available in the ECA4 barracks thus allowing parallel observation and database storage through an Oasis (remote oscilloscope) installation provided by AB/CO.

4.2. BTV system

A total of 13 BTV devices to acquire the beam sizes are installed:

- 2 SPS type BTVEs in LSS4 at the entry and exit of the extraction septum
- 3 SPS type BTVs in the common TT40 tunnel (LHC and CNGS)
- 8 in TT41 of the BTVG type

The screens for the installations in LSS4 are controlled by stepping motors due to space limitations in the SPS tunnel whereas all the others are controlled via the standard BTVI control and acquisition module [7]. LSS4 and TT40 BTV installations are equipped with alumina and titanium screens whereas the TT41 are equipped with titanium and carbon screens. The latter is believed to best withstand the nominal CNGS beam intensity. The low-level software developed for the BTVI systems is now CERN standard and it was mainly a question of configuring correctly the software with corresponding MTG timing events to get it to work for the CNGS BTV's. During the beam commissioning at LEIR it was discovered that an integration over 40[msec] (instead of 20[msec]) was needed to cover the entire image. This meant that images for both extractions cannot be provided in the same cycle. It is however possible in the low-level software to select which of the two beforehand. The only way to measure the two extractions in the same cycle would mean using non-standard video-grabbers difficult to integrate for the clients on the SPS control system. The last two BTV devices in front of the T40 target are equipped with radiation-hard CMOS cameras, while all the others (where much lower radiation levels are expected) use standard CCD cameras.

4.3. Fast BCT systems

Two identical Fast BCT installations are used for the CNGS facility:

- In front of the TT40 beam-dump already tested with beam in 2004 [8]
- Towards the end of TT41

To improve the accuracy for the total intensity (transmission) calculation, a separate low bandwidth channel [4] was added for all Fast BCT devices. This means that we expect ~1% accuracy between BCTs. Fast pre-pulse signals derived from the SPS RF are used to trigger the DAB64x acquisition module that acquires the analogue BCT signal at 40 [MHz]. The intensity in number of charges is then calculated as the integral of all calibrated samples above a preset threshold. The calibration procedure described in [8] gives calibration factors for the TT41 BCT of ~5E7 charges/bit (in 25 [nsec]). With the 12 bit ADC, we are therefore able to cover intensities up to ~4E13 charges per 10 [µsec] of beam extracted.

4.4. Beam-loss monitor system

A total of 18 standard SPS type ionization monitors are installed:

- 6 in the common TT40 transfer-line already tested in 2004 [8]
- 12 along the TT41 tunnel

The ionization chambers being outside the vacuum chamber were the last to be installed after all heavy equipment (magnets, vacuum chambers etc) was put in place. The BLM acquisition modules covering 8 beam-loss monitors allow setting a wide range of electronic gains. Off-line calibrations with a radioactive source has established a resolution of around 1E-4 [Gray]/bit for the lowest possible gain. With a 12 bit ADC we are therefore able to cover loss levels up to ~0.2 [Gray].

5. Instrumentation in the CNGS target chamber TCC4

5.1. TBID monitor

The down-stream target monitor is a standard monitoring device used for the slow extracted fixed-target beam where no bunch structure is normally present. For the CNGS requirements [9], it was decided to try a new mechanical design rather than using a spare tank from the West area of the SPS. In the first implementation, the way in which the thin titanium windows at either end were fitted, caused problems as the tank was leaking. A new design in collaboration with vacuum specialists [10] was therefore needed which delayed the installation of the device in TCC4. The tank was finally installed, connected and tested during March 2006. To simplify the multiplicity calculation for the clients, the low-level SEM software will return calibrated values (in charges) for the BSI foils. This requires the use of a calibration factor for each of these titanium foils. Through comparisons with similar BSI's in the SPS North area (with secondary emission coefficients of ~3.5%), we expect a nominal resolution of around 2E11 charges per bit. When a well-steered proton beam hits the carbon target, a multiplicity of around 20 has been estimated. With the 12-bit ADC, the front-end acquisition electronics will therefore saturate around 4E14 charges corresponding to a primary proton intensity of 2E13 per extraction. To allow measuring with higher intensities, a modification will be needed on the SEM acquisition module. The two BSI foils will finally be calibrated with the beam when the target is in its out position. By comparing the signals measured from the two foils with that of the Fast BCT a few metres upstream the calibration factors can be calculated. The nominal resolution (2E11 charges) mentioned above can be improved by a factor 100 during the low-intensity setting-up through the use of remote-controlled gain stages.

5.2. Ionisation chamber monitors

During 2004 the functional specification for additional beam-loss monitors in TCC4 [9] was released. It identified the need for extra ionisation chamber monitors installed in pairs that were to be used as protection and secondary measurement devices. Their locations are:

- Both sides of the T40 target collimator
- Both sides of the TBID downstream of the T40 target.
- Both sides of the cross-hair situated at the very end of TCC4

The target collimator is installed to protect the horn in case the beam is not correctly steered at the end of TT41. Two beam-loss monitors are installed here to measure losses and inhibit further extractions in case the levels observed are above their preset thresholds (see section 8). Only operational experience with high intensity beam will allow setting the thresholds for these monitors and dealing with possibly saturation effects due to back-scattered particles from the collimator and target. The two monitors at the TBID will be used to as a backup solution for the multiplicity calculation in case the TBID breaks down due to the impact of high intensity beams. The two monitors situated at the very end of TCC4 will be used to verify the angular alignment of the low intensity beam when the target is out and with the horn and reflector both off. Again only operational experience with beam will allow verifying that a correct level of sensitivity can be obtained for these last 4 dedicated monitors.

6. Muon detection system

Muon detector assemblies were requested [11], [12] and installed in each of the two muon pits. They will be used to provide an "on-line" display of the distribution of the muon beam on its way to the NGS experiments in Italy. The supports shown here [13] were produced in Italy and installed in their final locations in TNM41 and TNM42. The cables and electronics installed allow acquiring a total of 42 ionisation monitors to be fitted in holes on the supports and connected to the cables leading the signals to the acquisition system in UA87 in point 8 of the LHC. A single mobile (remote-controlled) detector was installed on each of the two monitors allowing the cross-calibration of individual detectors. The first 36 ionisation monitors produced at CERN as part of the LHC pre-series production arrived during February 2006. These monitors were subsequently calibrated with a radio-active source in collaboration with TS/RP. The monitors showed approximately 5% difference in gain which is higher than expected. The ionization chambers are filled with nitrogen gas at 1.1 [bar] pressure. This difference in gain observed can be explained by a higher than expected variation of the gas pressure between monitors. The variation will be taken into account as part of the calibration of the SEM data to obtain an absolute precision of the order of a few percent. The expected resolution of the LHC-type ionization monitors are of the order of 7E9 charges per bit in TNM41 (with a factor 10 less in TNM42) with the lowest possible gain. To allow the observation of the movement of the mobile ionisation monitors, radiation resistant cameras with remote-controlled lamps and real-time video signal transmission system over Ethernet from UA87 to the CCC were installed in both muon pits.

7. Beam Interlocks

The BPM, BLM and BTV systems are part of the LSS4 extraction interlock system as requested in [6]. For the BPM system the requirements are that if a single beam position is correctly measured outside a predefined range (typically 4 [mm]), an interlock will be activated until a user has requested a software reset. A similar interlock has been requested and implemented for the transfer-line beam-loss monitors. For the BTV system, an interlock is created if the screen is moving or if a screen of either Alumina or Titanium type is positioned in the beam. It is also worth mentioned that a simple implementation of the critical-settings management was requested and put in place for the interlock settings for BPM and BLM systems.

8. Hardware commissioning

The general commissioning of the line started during April 2006. For beam instrumentation systems this phase consists of making sure that they are working correctly without actually acquiring the beam induced signals. Special calibration modes are available for the BPM and BCT systems while lamps allow illuminating the screens to verify the correct acquisition of images. For the other systems, the hardware commissioning is done through the acquisition of the raw signals to ensure that noise levels are acceptable. In certain cases, dedicated test equipment is used to verify the integrity of cables and corresponding electronics. Apart from faulty front-end electronics modules for the BPM system that had to be replaced, no major problems were observed during the commissioning phase. The dry-runs organised by the CNGS project leaders allowed in the end, interfacing the different clients developed by members of the AB/CO and AB/OP groups to the AB/BI low-level software systems, and a continued effort by AB/OP allowed verifying that the logic utilized for the beam interlocks is correct.

9. Conclusions and the future

The CNGS facility at CERN will during 2006 become an operational physics installation. Three periods of commissioning with increasing beam intensity have been foreseen during the summer to allow testing all the individual systems. We believe that the instrumentation systems installed will perform well and apart from the possible resolution/saturation problems mentioned in the above text, no problems are foreseen.

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