CHAPTER 26

BEAM INSTRUMENTATION

26.1 INTRODUCTION

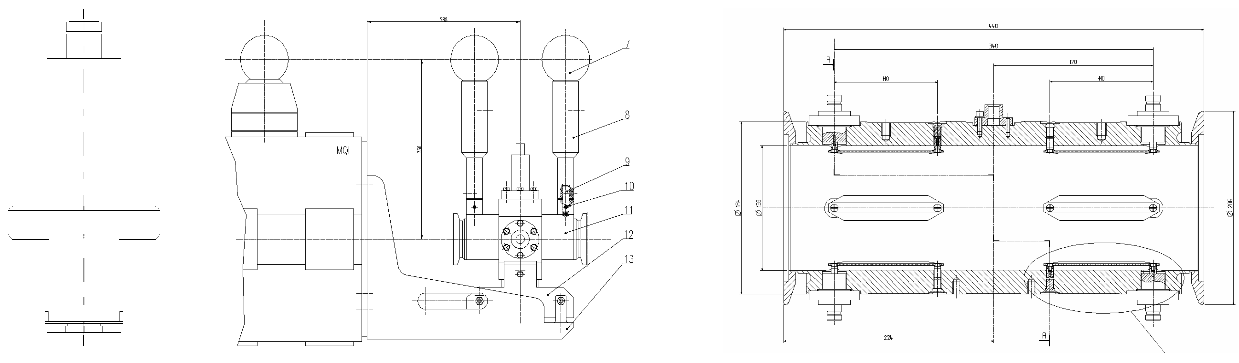
The transfer line beam position monitors (BPMI) allow steering of the beam throughout the length of the line and up to the entrance of the septum magnets. Fast BCT (beam current transformer) coils and acquisition electronics are required to acquire the intensity of individual LHC bunches. Standard SPS type beam-loss monitors (BLMI) will be used to localise the losses linked to the beam transfer. BTVI (beam television) screens using either the standard luminescence screen or optical transition radiation effect (OTR) screens will be provided to allow the transverse beam sizes to be determined and offer complementary position information during the setting up and steering. All of the installed instruments are designed to cope with the full variety of LHC beams planned. All the systems have been developed to fulfil the functional specifications described in [1].

26.2 POSITION MEASUREMENT

The SPS to LHC transfer line trajectory measurement system consists of 53 monitors in TI 2 and 47 monitors in TI 8, connected to acquisition electronics capable of 40 MHz bunch by bunch measurements.

26.2.1 Beam Position Monitors

There are 2 types of beam position monitors (BPMs) in the SPS to LHC transfer lines: 34 mm diameter button electrode monitors (BPMI) and 110 mm strip-line monitors (BPK). The vast majority of the pick-ups are of the button electrode type (48 in TI 2 and 43 in TI 8), for which the buttons have been recuperated from the LEP machine (see Fig. 26.1(a)). Although the majority of the pick-ups will be used to measure a single plane, four buttons have been mounted on each BPM body to allow for a future upgrade of the system to dual plane measurements. The pick-up body has a diameter of 60 mm and is located on the downstream side of the quadrupole (see Fig. 26.1(b)). The mounting and alignment of the body and support will be performed before magnet installation in the tunnel.



(a) (b) (c)

Figure 26.1: (a) LEP button electrode; (b) BPMI body and support mounted on the downstream side of the quadrupole; (c) BPK strip-line monitor

The BPK strip-line monitors are dual purpose monitors developed for the first 4 pick-ups in TI 8 (TT40), which are capable of measuring both the LHC and CNGS beams. For reasons of aperture, the first five pick-ups in TI 2 (TT60) will also be of this type. Since the LHC acquisition electronics cannot measure beams with a 200 MHz structure, a double pick-up is required to avoid having to split the signal at the source. The BPK is therefore a dual strip-line monitor (see Fig. 21.1(c)), each strip-line having a length of 110 mm and short circuited at the downstream end for the LHC electronic output and the upstream end for the CNGS electronic output. The diameter of the body is 133 mm, while the inter-electrode diameter is 116.7 mm.

26.2.2 BPMI Acquisition System

The trajectory acquisition system is identical to that of the LHC orbit and trajectory acquisition system which is fully described in Vol. I, Sect. 13.12 of the design report. In most cases the front-end chassis will be located near the quadrupoles containing the pick-up. The exceptions are the pick-ups near the injection and extraction points, where concerns over the radiation level in these areas has led to a regrouping of the front-end electronics about 150m away from the extraction or injection point. For TI 2 (including TT60) the VME acquisition electronics will be located in BA70, while for TI 8 (including TT40) the VME acquisition electronics will be located in HCA442. As for the LHC system, connection between the front-end and the VME electronics is via a fibre-optic link, while the control of the front-end crate (sensitivity setting, calibration, power supply status etc) is via a 31 kbit/s WorldFIP link. The system is expected to function within specifications between 2×10^9 and 2×10^{11} charges per bunch. A detailed breakdown of the expected performance is given in Vol. I, Sect. 13.13. Three pick-ups in each transfer line will be equipped with acquisition in both planes in order to allow an additional intensity measurement to be performed at these locations (with a precision of around 5-10%). The front-end intensity card will be installed in the same front-end chassis as the position electronics and has been constructed to use the same fibre-optic link and digital acquisition electronics.

26.3 INTENSITY MEASUREMENT

Both TI 2 (TT60) and TI 8 (TT40) will be equipped with two beam current monitors, one located at the start and one at the end of each line. The acquisition crates will be located in BA60 (TT60), UA23 (TI 2), HCA442 (TT40) and UA87 (TI 8). Both the beam current transformers and the acquisition electronics used are identical to those installed in the PS to SPS transfer lines and the fast transformer in the SPS ring.

26.3.1 Beam Current Transformers

The fast beam current transformers (FBCTs) will integrate the charge of each LHC bunch spaced by a multiple of 25nsec. Because of the single-pass nature of the beam in the transfer line, good performance is obtained without applying the DC restoration technique necessary for circulating beams.

26.3.1 BCT Acquisition Electronics

Two multiplexed 20MHz integrators are used and the result of integration is digitised and stored in the memory of the DAB acquisition card. SPS extraction pre-pulses and the 40 MHz bunch clock transmitted via the SPS Beam Synchronous Timing (BST) system are used to trigger the acquisition systems.

The measurement precision for the pilot beam of 5×10^9 protons in a single bunch is expected to be around 5 %. In the worst case a 10 % error should be envisaged, whilst for the nominal LHC beam the error will be below 1 %. The transformer cores will use low droop, radiation hard materials. The specified droop for the cores is below 2 %/µs and the sensitivity should be approximately 1.25 V/A.

26.4 BEAM-LOSS MEASUREMENT

Beam-loss monitors are placed at strategic locations in the SPS to LHC transfer lines, notably where the risk of having losses are the highest.

26.4.1 BLMI monitors

The SPS type beam-loss monitors (BLMI) are used to identify the location of beam losses during the extraction process. About 60 ionisation chambers will be installed in the SPS to LHC transfer lines. The ionisation chambers are parallel plate type monitors and are filled with nitrogen at atmospheric pressure. Each monitor has a volume of one litre. The electrical drift field strength is set to 1600 V/cm.

26.4.2 BLMI Acquisition System

The currents generated by the chambers are treated by the BLMI acquisition system. This consists of a total of 4 VME chassis in for TI 2 and TI 8, which are installed in surface and underground areas. An integrator integrates the ionisation chamber current during the extraction process. The integrator output is then sampled by a 12-bit ADC and the digital output value stored in memory. The whole read-out chain is implemented in a dedicated VME module. The acquisitions are triggered by SPS timing events pre-programmed in the corresponding LHC or CNGS cycle. The beam-loss server can return the data either in raw ADC units, or calibrated in units of mGy. If the losses scale linearly with the total intensity, then dynamic range in losses stemming from the LHC beams reaches a factor of 10^4 between a single pilot bunch and four batches of ultimate intensity. To cover this large dynamic range with the 12 bit ADC, several gain stages are used on the acquisition card. Each VME crate is capable of treating up to 40 beam-loss monitors and is placed such as to minimise the cable lengths.

26.4.3 Beam-loss Interlocks

The beam loss monitors in the transfer lines and in the injection region form part of the SPS extraction interlock system [3]. Whenever the measured rates exceed a given preset threshold, the extraction from the SPS is inhibited for the following cycles. A machine operator has the possibility to reset this interlock in order to perform tests and, if required, improve the steering of the line or of the extraction channel. An automatic reset mechanism may be applied to prevent unnecessary machine downtime in case of a spurious problem, as is already done in the SPS ring.

26.5 BEAM-PROFILE MEASUREMENT

The SPS to LHC transfer line profile measurement system consists of a total of 16 BTV tanks in each of the two transfer lines. The CCD cameras, each connected to acquisition electronics are capable of doing a single 3-D measurement per injection into the LHC. As the passage of the beam through the screens will create a certain amount of emittance blow-up, they will not be left in the beam path, but rather be inserted on demand during studies on the transfer line optics.

26.5.1 BTVI Mechanism

The BTV monitors will be distributed along each of the transfer lines, including the injection point into the LHC. The latter monitors are described in more detail in Vol. I, Sect. 16.5 of the LHC design report. Each monitor will be equipped with a phosphorescent alumina screen which is designed for use mainly with the low intensity pilot beam and with a 12 µm thick titanium foil providing optical transition radiation at nominal currents. The first three monitors, located before the beam dump in TT40 and TT60 are of standard mechanical type as used in all other SPS lines [4]. For the others, new designs have been developed or are under development. The following nine monitors, named BTVI, will be installed on the 60 mm vacuum chamber of the transfer line. As for the SPS standard screens, their mechanism is based on a rotating displacement to set the screens IN and OUT of the aperture, actuated by a DC motor. However their design is more compact in order to fit their environment and to get the necessary precision [4]. In Fig. 26.2(a) 3-D drawing of a BTVI assembly is shown. By a 90° rotation, either of the screens can be set IN or OUT of the vacuum chamber aperture. The BTVI monitors, produced at JINR (Dubna) in Russia, will also be used to equip the TT41 CNGS line.

For completion, the last four TV monitors in the lines, called BTVSI, will be installed at each injection insertion, downstream of each septa and at each end of the injection kickers and upstream the TDI absorber. These last monitors will therefore be installed on the circulating beam vacuum chamber. Because of the proximity of the adjacent ring, space constraints are more severe in this case. Moreover, it is required to ensure the vacuum chamber smoothness to reduce the machine impedance when the screens are removed and the beam circulates. Therefore a completely different mechanical design is under study for these monitors, based on a linear displacement, however, they will still be activated using the same DC control as the BTVI.

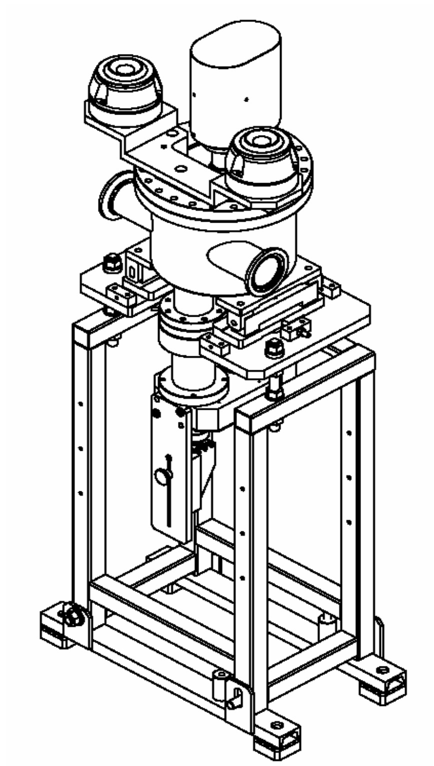


Figure 26.2: Mechanical design of a complete BTVI assembly installed in TI 2 and TI 8

26.5.1 BTVI Acquisition system

The acquisition of the beam profile data is based on high-resolution CCD cameras. These are linked to a newly developed BTV acquisition card that allows the acquisition of a two-dimensional image with a digitisation resolution of 300x400 pixels. The screen position, as well as filters and an external lamp, can be controlled from the same VME module. All monitors will provide two-dimensional information as well as the projections into horizontal and vertical profiles.

26.5.2 Reproducibility on Position and Size Measurements

Measurements on a BTVI tank [5] have shown that the reproducibility on the measurement of the beam size and the centre-of-mass for a spot size equivalent to that of the LHC beam is very good. The beam position (centre-of-mass) acquired over 10 consecutive screen movements changes by around 100 µm peak-to-peak and the beam size is determined to within 1 %. These figures are well within the specifications. Even better results are expected with the newly designed BTVI tank, notably if special care is taken during the alignment of the BTVI screens.

26.5.3 BTI Acceptance

The BTV screens with a 65 mm diameter will entirely cover the vacuum chamber aperture. The profile monitor optics and readout will allow either large area coverage, at the expense of a loss in accuracy or small area coverage optimised for optics and emittance measurements. During the first commissioning of the lines, the profile monitors will be tuned to cover the largest possible fraction of the aperture.

26.5.4 BTVI Interlocks

The position of the intercepting transverse profile monitors will be surveyed by the SPS software interlock system. Depending on the operation mode of the LHC, the software interlock system should prevent beam extraction when the profile monitors would intercept the beam. This is to avoid undesired emittance blow-up of the beam. This interlock can, however, be bypassed for machine experiments and during verifications of the transfer line optics. There are also ideas to incorporate a low-level software interlock on the movements of the BTV mechanisms in case the circulating intensity transmitted by the SPS BST system is above a certain threshold. This is because the alumina screens will be damaged by passage of the very dense high intensity LHC beam.

REFERENCES

[1] *J.Wenninger et al,* "*Instrumentation for the TI 2 and TI 8 Transfer Lines*"*,* EDMS Document LHC-B-ES-0004.

[2] G.Ferioli et al., "*Protection and Diagnostic Systems for High Intensity Beams*", CERN-SL-2000-032-BI.

[3] R. Giachino et. al., "Architecture of the SPS Beam and Extraction Interlock Systems", CERN-AB-2003-010-OP.

[4] R. Jung et al., "*Single Pass Optical Profile Monitoring*" DIPAC 2003

[5] Minutes of the 25th BI LHC/CNGS Technical Board.