PRE-COMMISSIONING OF CRITICAL BEAM INSTRUMENTATION SYSTEMS

E.B. Holzer, O.R. Jones, CERN AB/BDI, Geneva, Switzerland

Abstract

This presentation will deal with the main beam instrumentation systems required for the initial commissioning period. The emphasis will be on the set-up and testing of the hardware involved, in particular on the BPM polarity checks, the determination of BLM interlock limits, the tests of the electronics and the calibration procedures. The amount of final testing for which the beam is required and the possible benefits of a sector test will be addressed as well.

BEAM POSITION MONITORS (BPM)

Polarity Errors

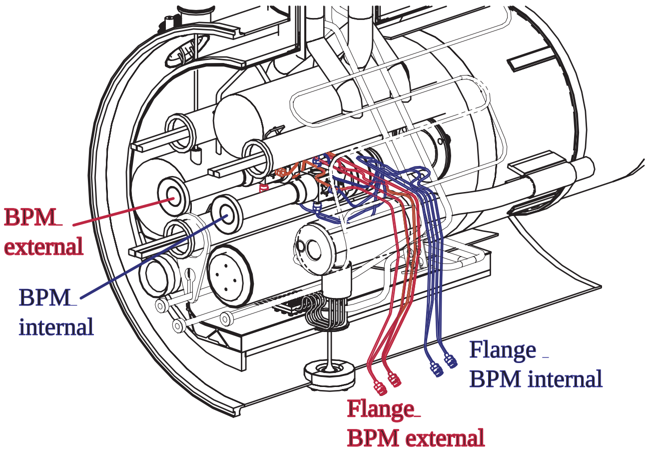

Figure 1: Arc quadrupole cryostat cabling for BPM.

Each arc quadrupole is equipped with two BPMs, one for each beam. Each BPM measures the horizontal and the vertical beam position (see [1] for a general overview of the BPM system). The four pick-up electrodes per BPM are connected with four semi-rigid coaxial cables to an exit flange on the outside of the cryostat (Fig. 1). There are two separate exit flanges for the pick-ups of the two beams to avoid a crossing of the cables from the two beams. Since the cables are preformed, it is not possible to wrongly connect them to the BPM electrodes. The flexibility of the cables does, however, allow for the possibility of cabling errors at the connection to the outer cryostat flanges. In order to minimize this risk the installation of the cables, which is performed in SMI2, follows a predefined sequence and a test procedure is performed after the installation of the cables. A 600 MHz signal generator is connected to one horizontal electrode via the connector on the outside of the cryostat (Fig. 2). The amplitude and phase response of the two neighboring vertical electrodes is verified. An unconnected or broken cable, a broken pick-up button and several kinds of cable mix-ups will lead to an erroneous amplitude response. A phase response which is out of range will indicate a bad cable connection or an incorrectly mounted button. The test is repeated with the signal generator connected to one vertical electrode and on the BPM for the other beam. Most potential installation errors can be detected this way. The cabling errors which will not be detected are: a swap of the two horizontal cables, a swap of the two vertical cables or a rotation of all contacts by any number of positions.

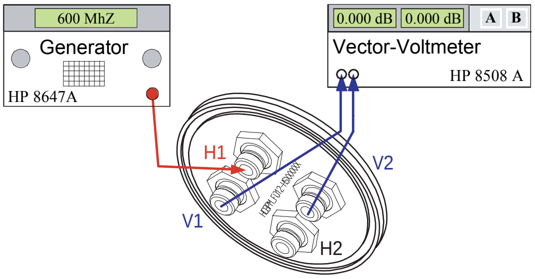

Figure 2: Test set-up for cryostat cable installation of BPM.

A short coaxial cable connects the cryostat socket to the front-end electronics in the arcs. In the long straight sections and the dispersion suppressors an up to 200 m long cable connects to a patch panel and a short coaxial cable from the patch panel to the front-end electronics. Cabling errors in front of the front-end electronics would result in incorrect polarity or in mixing horizontal and vertical electrodes. Such cabling errors cannot be detected remotely after the installation. They can be found by visual inspection and will be seen with the beam.

There are two optical fiber patch links per plane between the front-end electronics and the digital conversion electronics on the surface. A cabling error at this stage would result in a mix-up between BPMs or between planes. These errors should be spotted during hardware commissioning, as each front-end card is turned on individually.

Testing of Electronics

All electronics cards, the front-end cards as well as the digital conversion cards, are adjusted and calibrated individually in the laboratory. The calibration data is stored in a database (MTF). The individual linearization of the front-end cards will reduce the maximum position errors from about 6% to about 1%. All the electronics will be tested after installation by using the calibration mode of the front-end cards. The calibrator sits at the very input of the front-end card (only one resistor is in front of the calibrator) and enables the testing of the complete acquisition chain, including the surface electronics.

The same electronics and the same procedures have already been used in TI8. There, three out of 51 planes (5%) had problems. Two special coupler BPMs, of the type which can measure the LHC or the CNGS beam, were wrongly cabled. This was only detected with the beam. And one electronics card was replaced because of a malfunctioning plane. An error rate of 5% for LHC would imply 50 incorrectly cabled or broken planes per beam.

BPM Database Issues

The database management is important during installation as well as during operation. In the installation phase the beam 1 and beam 2 BPMs have to be correctly assigned to the internal and external beam pipe depending on the sector of the LHC. This task is complicated by rotated cryostats, where the two BPM output ports change place within a sector. Directional coupler BPMs in the long straight sections provide the two beam signals on the upstream and downstream ports of the same BPM respectively.

During operation the complete database of the components of the acquisition chain is required to calculate the beam positions. The linearization depends on the geometry of the BPM (the BPM type). The calibration of the electronics requires the knowledge of the installation position of all cards. Currently, the aim is to implement an automatic identification of all cards.

Timing Issues

Without beam, all testing and calibration is performed in asynchronous mode. The data throughput is driven by the auto-triggered front-end. Hence, no external timing is used or required. In calibration mode, the signals are generated by a 40 MHz crystal oscillator.

For the setting-up with beam three modes of operation will be used depending on the conditions of the beam. During the very initial commissioning with a single pilot bunch and up to a few turns the internal FIFO memory will be used to store all valid auto-triggers. When the number of turns increases the same asynchronous mode as for calibration can be used to process the data. When the RF synchronization becomes available for a beam over many turns, the BST can be used to give the 40 MHz bunch synchronous clock. This requires individual timing adjustments for all BPMs to compensate for the different cable lengths. The phase margin for these adjustments is quite large. The auto-triggered input from the front-end card is stable during 20 ns out of the 25 ns. A method is currently under investigation, to automatically adjust the phase when it is out of range. Operation with the BST will allow bunch tagging, turn counting and provide real time data for orbit feedback.

BEAM LOSS MONITORS (BLM)

Hardware Set-up and Testing

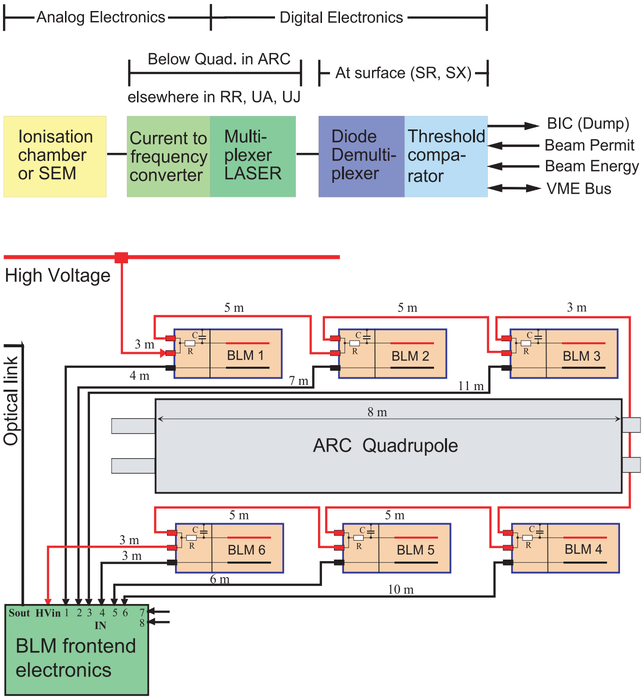

Figure 3: Layout of BLM installation.

Normal beam operation does not give information on the availability of the BLM system ([2]. It does not allow checks for channel mix-up or for location errors. Therefore, possible hardware and installation errors must be sorted out before beam commissioning. The availability of all channels will be monitored during operation by dedicated tests.

All hardware components and all functionalities will be individually tested before installation. The installation itself will be based on a barcode system to avoid channel mix-up and malposition of the chambers. Before installation, barcode labels will be placed on the cryostats at the desired BLM chamber position. The radiation detector, the cables and the connectors at the patch panels as well as the electronics will all be equipped with barcode labels. After the installation campaign the correct cabling and positioning will be verified with a barcode reader.

All electronics channels and chambers will be individually tested after installation. These pre-commissioning tests include a low frequency modulation on the high voltage electrodes of the ionization chambers. This will induce a signal on the signal electrodes of the chambers. In this way all chambers, their high voltage supply and the complete readout chain will be tested. A radioactive source will be placed on each chamber in the LHC tunnel, one after the other, to test the channel matching and the individual chamber and readout channel gains. Gain variations between the chambers are expected to be a few percent only. Bigger variations are a sign of malfunctioning and the chamber or the electronics will be replaced. The test with a source will be repeated yearly during the shutdown. It is the only way to find possible problems with the chamber gas composition. A leak in an ionization chamber will cause a signal amplitude variation of up to 20% and a response time variation. Both effects are negligible for the quench and damage protection.

A constant 10 pA baseline current is applied on each channel of the front-end electronics. It is used to confirm the availability of the electronics during beam operation. The aforementioned high voltage modulation on the ionization chambers will be repeated after each beam dump to test the availability of the whole system, including the chambers.

Threshold Determination

The BLM interlock limits can be set for each of the about 4000 chambers individually. They vary with integration time (10 integration time intervals between 89 μs and 100 s) and the energy of the beam. The determination of the thresholds is based on simulations. Whenever possible, crosschecks of the simulations by measurements are envisaged. Depending on the outcome of these crosschecks, dedicated beam tests might be required to achieve the demanded absolute precision on the number of lost beam particles. A factor of 5 and a factor of 2 are the specified initial and final absolute precisions respectively.

Simulations A number of simulations have to be combined to calculate the BLM signal per lost beam particle. The distribution of the loss locations along the LHC is simulated by particle tracking with a detailed aperture model [3]. The lost beam particles initiate hadronic showers. Proton induced showers through cold magnets in the LHC arc and dispersion suppressor [4] and through the collimators [5] have already been simulated. These simulations give the heat load on the magnets (or the collimators) and the particle fluence at the location of the beam loss monitors. Magnet quench levels as a function of beam energy and loss duration have been calculated [6] and will also be simulated [7]. The signal response of the ionization chamber to the mixed radiation field in the tail of the hadronic shower has been simulated [8]. The corresponding simulations for lead ion beams are being performed as well [9].

Measurements The uncertainties in the threshold level determination are dominated by our knowledge of the longitudinal loss distribution and the magnet quench levels. Hence, the future investigations will concentrate on these points. Quench level measurements on LHC magnets for different time constants (without beam) are planned [7]. A beam loss measurement program at HERA/DESY has started in 2004 [10]. One of its aims is to cross check the simulation of hadronic showers through superconducting magnets. At HERA it is possible to lose up to 100 mA protons at 40 GeV inside one magnet, using a local bump, without causing the magnet to quench. The only possibility to measure the effects of beam loss on the LHC magnets before the LHC start-up is the sector test. A magnet can be equipped with several BLMs. Their response to controlled beam loss can be measured. This would allow to cross check the shower simulations and the quench level calculations for instant losses at 450 GeV. The heat deposition combined with the cable heat capacity can be tested. The sector test will also give information on longitudinal loss patterns.

Beam Tests All beam losses and magnet quenches during the sector test and the LHC start-up can be analyzed offline using the logging and the post mortem database respectively. The tuning of the BLM interlock levels will begin with the first beam data. It will allow to gradually improve the precision of the measurement of the number of lost beam particles and the magnet quench levels.

Whether dedicated beam tests will be required is determined by three points. Firstly, it will depend on the outcome of the measurements described above, which will help to determine the precision of the simulations. Secondly, an adequate safety margin has to be kept between the damage potential of the beam (beam intensity and energy) on the one hand and the magnet damage levels on the other hand. And thirdly, the threshold levels have to be precise enough not to compromise the operation efficiency by false dumps or magnet quenches.

The intensity of the pilot bunch is around the quench level at 450 GeV and around the damage level at 7 TeV, in both cases for instant losses. There is a safety factor of more than 300 between quench and damage levels for fast losses at all energies. For long duration losses the safety factor is much smaller (a factor of 5 at 450 GeV and a factor of 25 at 7 TeV), but at these loss durations there is a redundancy from the quench protection system to catch dangerous losses.

Considering all points, the precision of the threshold levels at the very beginning of commissioning seem rather uncritical. Dedicated tests will be required if the speed of the "parasitic" tuning of the BLM system cannot keep pace with the increasing demand on the precision of the abort thresholds, as the beam intensity and energy increase during LHC commissioning.

EMITTANCE AND CURRENT MEASUREMENT SYSTEMS

This section deals with the wire scanners, the synchrotron light monitors, the ionization profile monitors and the beam current transformers. All systems are tested in the laboratory and calibration is performed where appropriate. The installation and installation tests are generally planned to take place between January and September 2006. This time schedule assumes that the required support from the design office will be available. The installation of the undulators and the final testing of the synchrotron light monitors is planned for November and December 2006. During installation and testing frequent access and vacuum interventions will be required.

Some of the systems have special requirements for the pre-commissioning tests in the tunnel without beam. The beam current transformers require about one week of normal operation conditions, ideally with the magnets cycling, to check for electromagnetic perturbations. They also require about 8 days with the BST timing system working, in order to set up the data acquisition and to calibrate the systems. The ionization profile monitors will need about two days of testing after the bake-out has finished and about one day with power, water cooling and a vacuum of less then 10^{-6} hPa established.

SECTOR TEST

A sector test would allow to find possible problems and still leave time to fix them before the LHC start-up. The BPM and BLM hardware installed in the sector and part of the functionality of the systems could be commissioned. For the BPM system that includes polarity check, database issues and the set-up of the timing. For the BLM system the setting of the threshold values and the beam flags, the generation of the dump signal, database issues, the logging and the post mortem could be tested. The offline analysis and the tuning of the threshold values could be started. All this assumes that the relevant software tools will be available for the sector test.

The sector test will be the only possibility to measure LHC magnet quench behavior with beam and longitudinal proton loss patterns in the LHC, before the start-up of the LHC. Even though these measurements cannot probe the whole range of loss conditions which will be present in the LHC, they are nevertheless important cross checks for the simulations. The design of the BLM system is based on these simulations and any important deviation of the measurements from the simulations would imply adaptations of the BLM system. Considering the complexity of the systems and the time it would take to implement changes or to fix problems, the sector test could prove to be essential for the BLM system.

SUMMARY - CRITICAL ISSUES FOR COMMISSIONING

Possible cabling and database errors of the BPM system have an impact on the LHC commissioning. Dedicated beam tests will be required to locate them. A wrong BPM type in the database will yield a wrong position reading while a mix-up of calibration constants will reduce the position accuracy. Cabling errors (a rate of less than 5% was experienced during TI8 tests in 2004) will in addition require access to the tunnel to fix them.

The two big unknowns for the BLM system are the accuracy of the quench level determination and the prediction of the loss locations. A factor of 10 precision on the abort threshold values should nevertheless be acceptable for the very initial commissioning. Dedicated beam tests might be required to optimize the abort threshold values with respect to the quench levels. An accurate and complete aperture model is essential for the simulation of the beam loss locations and hence the positioning of the beam loss monitors. A sector test would be an important milestone for the BLM and the BPM system. The availability of the complete functionality of the BLM software for the sector test is crucial for the testing and tuning of the system.

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