

APERTURE MEASUREMENTS OF THE LHC INJECTION REGIONS AND BEAM DUMP SYSTEMS

B. Goddard, W. Bartmann, C. Bracco, V. Kain, M. Meddahi, V. Mertens, J. Uythoven,
CERN, Geneva, Switzerland

Abstract

The commissioning of the beam transfer systems for LHC included detailed aperture measurements in the injection regions and for the beam dump systems. The measurements, mainly single pass, were made using systematic scans of different oscillation phases and amplitudes, and the results compared with the expectations from the physical aperture model of the LHC. In this paper the measurements and results are presented and compared with the specified apertures in these critical areas.

INTRODUCTION

The injection and extraction (beam dump) systems of the LHC have elements with restricted aperture, including the kickers, septum elements, associated protection devices and beamline vacuum chambers. Extensive measurements have been made to validate the design apertures, measurements which in the injection septa and extraction lines were by necessity single pass.

In the P8 injection region for Beam 2 the results with different betatron phases showed a repeat of the several mm mechanical misalignment found in 2008 in P2 for Beam 1, which again necessitated a realignment of the affected elements. The aperture for the circulating beam was measured at all key elements using closed bumps and found to agree with expectations.

For the beam dump lines, the measurements at different betatron phases showed that the aperture in the septum and dump line is at least as large as expected. For the circulating beam measurements with closed bumps, the available aperture in both planes was checked in detail, as P6 has the largest β functions in the LHC; the results agreed well with the expectations.

DESIGN APERTURES

Different assumptions were used in the design of the apertures for the LHC ring, the transfer lines and injection systems and the beam dump systems and dump lines. In the following sections the design assumptions and assumed tolerances are described.

LHC Ring

The LHC ring aperture was designed with the nI convention [1], which assumes a typical XY distribution of the secondary halo and defines the scale factor which can be applied for this halo to still fit inside the physical aperture, taking into account the tolerances on orbit, alignment, mechanical precision etc. To achieve the

required nI of ≥ 7.0 (or ≥ 6.5 at some special warm elements) the orbit, beta-beat, alignment and mechanical tolerances must all be within tolerance.

For the injection septa the design nI were above 8.3 for B2 and above 7.3 for B1 [3].

For the extraction septa the design nI is above 7.0 for both beams, while at the protection device TCDS the design nI is 6.5 [4].

Injection Elements and Transfer Lines

The transfer lines from the SPS to the LHC were designed to have a minimum aperture of $N=6\sigma$ [2], according to the specific definition used.

For the LHC injection elements the same definition was used; however, here the design apertures were smaller, in particular at the MSI septum and upstream TCDIM mask, which have internal apertures of only 20 mm, and which give an aperture using the above equation of 3σ . At these elements the trajectory is assumed to be controlled to better than ± 2 mm, to give an aperture of at least 6σ .

Beam Dump System Elements and Transfer Line

The aperture of the LHC beam dump elements is limited at the protection device TCDS and the extraction septum MSD [4]. The available aperture has been calculated assuming a total beta-beat of 42%, to allow for some tuning of the optics of the LHC using P6. In addition a 10% overshoot of the MKD waveform is assumed. For a normal beam dump, with an orbit tolerance of ± 4 mm, the aperture available is then 4σ at 450 GeV, for the bunches at the extreme part of the MKD waveform. For the case where only 14 of the 15 MKD kickers fire, the aperture at the TCDS is reduced to 3σ , for an orbit of ± 2 mm. In the dump line the apertures are larger, with a design clearance of at least 8σ at all elements at 450 GeV [5].

MEASUREMENT RESULTS

During the beam commissioning of the LHC and its transfer lines, measurements of injected, circulating and extracted beam aperture have been made. The latest results are given, from 2009 and 2010.

SPS-to-LHC Transfer Lines

Detailed measurement campaigns have been made since 2004 to measure the transfer line apertures, see e.g. [6]; the last measurements were made in 2009 after the realignment of the lines and correction of the transfer line optics. Figures 1 and 2 summarise the 2009 results.

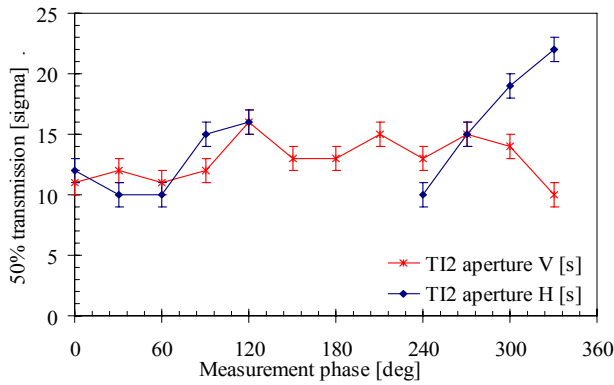


Figure 1: Measured aperture in TI 2 in 2009 (plotted for estimated 50% transmission). The minimum aperture is 9-10 σ . Three phases remain to be measured.

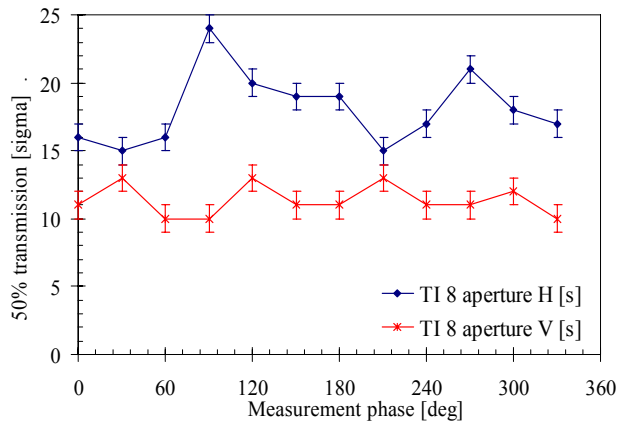


Figure 2: Measured aperture in TI 8 in 2009 (50% transmission). The minimum aperture is 9-10 σ .

LHC Injection Regions

The aperture of the injection regions of the LHC was measured with single-pass in 2008 as part of the sector test [7], when a problem with the vertical misalignment by 10 mm of a vacuum chamber in P2 was discovered and subsequently corrected.

In 2009 after the long shutdown, the apertures were re-measured, Figs. 3 and 4, and a similar problem was discovered in P8, on the corresponding chamber which links the injection septum to the downstream superconducting quadrupole Q5 via a pumping port. The geometry here is complicated by the off-centred chambers and septum magnets, and asymmetric chambers in a BTV device. After realignment the available aperture in the vertical plane was as expected, Fig. 5, and all losses for the different phases were at the elements expected from modelling the trajectories in the aperture model.

Since these problems the documentation, installation and alignment procedures have been improved – however, it appears wise to recheck these specific regions after each shutdown.

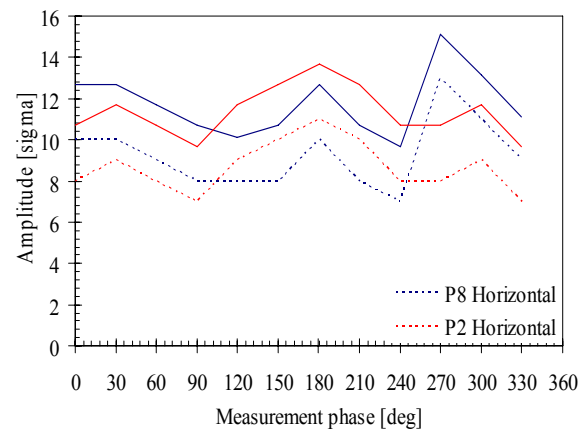


Figure 3: Measured horizontal aperture in the P2 and P8 injection regions. The solid line represents the estimated physical aperture.

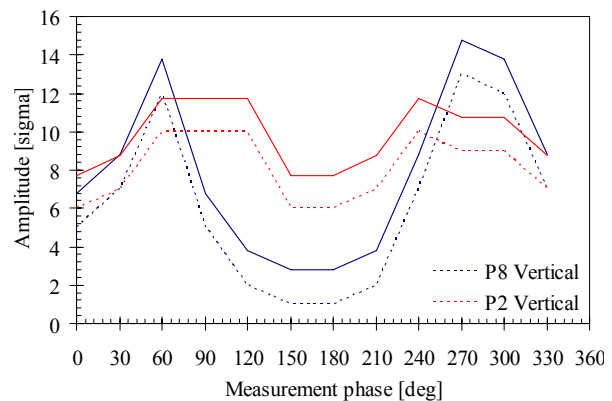


Figure 4: Measured vertical aperture in the P2 and P8 injection regions. The restriction in P8 is clearly visible.

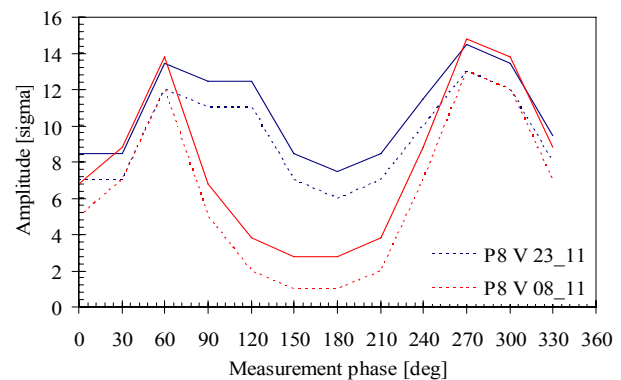


Figure 5: Measured vertical aperture in P8 before (red) and after (blue) correction of the alignment of the suspect chamber.

LHC Extracted Beam

The aperture of the dump channel was measured with single pass in the sector tests in 2008 and again in 2010, Figs. 6-7, as part of the system tests to allow higher intensity. Orbit correctors were used to steer the beam, with the beam extracted before completing one turn. The apertures in the horizontal plane look almost identical for

B1 and B2, while in the vertical plane there are some small differences which might arise from orbits between the two beams. Importantly, the obtained trajectories were examined in the extraction and dump aperture model, and all losses occurred on the expected elements.

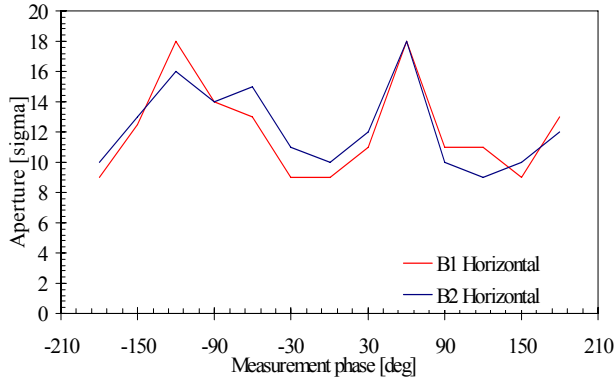


Figure 6: Measured horizontal aperture of the beam dump extraction channel for B1 and B2 at 450 GeV.

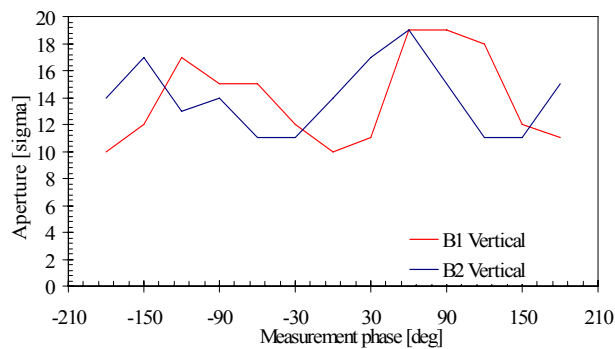


Figure 7: Measured vertical aperture of the beam dump extraction channel for B1 and B2 at 450 GeV.

Circulating Beam Aperture at Injection and Extraction Elements

Full generic aperture measurements have been made over the whole LHC to verify the global design aperture, see e.g. [8]. In addition, specific checks were made at the injection and extraction septa, and also at other injection and dump elements such as the vacuum chamber carrying the non-kicked beam past the extraction kickers, which has a horizontal offset for integration reasons. These checks were made using closed orbit bumps, increasing the amplitude until beam losses were seen. The beam emittance was recorded, and the primary collimator settings used to estimate the extent of the beam envelope. All physical apertures in these regions were found to be as expected – the correct positioning of the dump protection device TCDS which is 16.3 mm horizontally from the beam axis upstream of the extraction septum was also verified, Fig. 8. Since orbit and beta-beating are within tolerance, the *nI* specifications are confirmed.

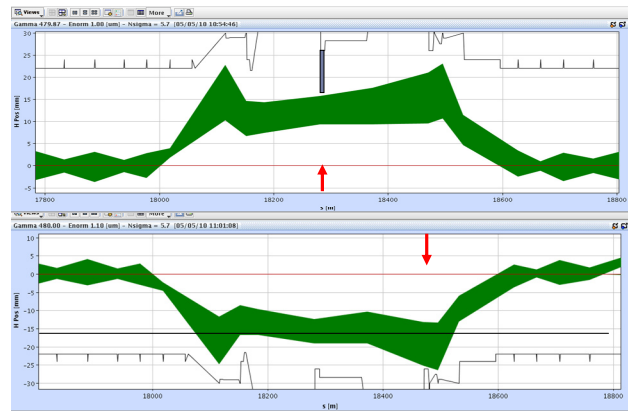


Figure 8: Measured closed orbit bump and beam envelope for check of horizontal aperture in the B1 extraction septum in P6, for +ve and -ve polarity. The physical aperture model is shown, and the TCDS indicated in dark grey on the upper plot. The red arrows show where beam loss occurred.

CONCLUSION

Physical apertures in the transfer lines, injection regions and dump system have been extensively measured during the LHC commissioning. Problems with respect to the design aperture were found only in the injection regions, for one specific vacuum chamber location, for reasons which are understood and corrected. The apertures in the SPS-to-LHC transfer lines, in the injection regions, in the dump regions and in the beam dump lines meet or exceed the design values in all cases.

ACKNOWLEDGEMENT

The excellent results are a testament to the accuracy and diligence of the Survey team at CERN, as well as to the skill of the designers and builders of the magnets and the vacuum systems, some of which posed interesting engineering challenges. In addition, those responsible for the superb applications, controls and beam instrumentation are warmly thanked for their contributions.

REFERENCES

- [1] J.B.Jeanneret and R.Ostojic, CERN LHC Project Note 111, 1997.
- [2] A.Hilaire, V.Mertens, E.Weisse, CERN LHC Project report 122, 1997.
- [3] B.Goddard et al., CERN LHC Project report 753, 2004.
- [4] B.Goddard, M.Gyr, CERN LHC Project Note 320, 2003.
- [5] T.Kramer et al., CERN LHC Project Report 1161, 2008.
- [6] B.Goddard et al., CERN LHC Project report 1119, 2008.
- [7] M.Lamont et al., CERN LHC performance note 001, 2008.
- [8] S.Redaeli et al., proceedings IPAC 2010.