THE ROMAN POT FOR THE LHC

Marco Oriunno, Mario Deile, Karsten Eggert, Jean-Michel Lacroix, Serge Jean Mathot, Elias Philippe Noschis, Roger Perret, Ernst Radermacher, Gennaro Ruggiero
CERN, Geneva, Switzerland

Abstract

The LHC machine will be equipped with Roman Pot stations by the TOTEM [1] experiment. The special optics required by TOTEM, and safety considerations for the machine protection set the limit to 10σ, i.e. 800 μm. Such unprecedented parameters, have requested a new design for the Roman Pot system. To better meet also the challenging requirements of TOTEM, a technology development of a thin window with high planarity has been pursued. Prototypes of the Roman Pot thin window have been manufactured and tested. We describe the main issues of the final design and the results of the preliminary tests.

INTRODUCTION

The Roman Pot is an experimental technique introduced at the ISR [2] for the detection of forward protons from elastic or diffractive scattering. It has been successfully employed in other machines like the SPS, TEVATRON, RHIC and DESY.

Detectors are placed inside a secondary vacuum vessel, called pot, and moved into the primary vacuum of the machine through vacuum bellows. In that way the detectors are physically separated from the primary vacuum which is preserved against an uncontrolled out-gassing of the detector's materials.

The challenging constraints of LHC, such as the narrow high intensity beam with energy of 7 TeV, the Ultra High Vacuum and the high radiation fluxes have required the development of new Roman Pots. The main difference with other Roman Pots designed for other machines lays in the window technology of the pots, which have to be placed very close to the beam and in the driving mechanism requirements, which must have high precision and radiation hardness.

Two stations of Roman Pots will be mounted on each side along the Long Straight Section at IP5 (LSS5), their positions being defined both by the special optics used by TOTEM and by the space available between the LHC components (Fig. 1). The first station is placed between 145 m and 147 m from IP5, before the dipole D2 and the second between 214 m and 220 m behind the quadrupole Q5.

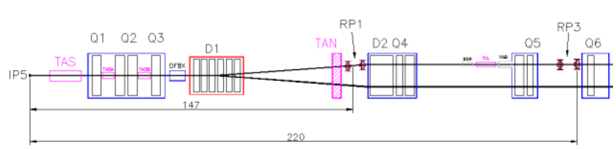

Figure 1: The insertion I5: location of the Roman pots stations RP1, RP3. The layout is symmetric with respect to the interaction point.

Each station is composed of two Roman Pot units separated by a distance depending on the integration constraints with the other beam equipments. For the station at 220 meters a space of 6 meters is available. The space for the station at 145 meters, close to the D2 magnet, is reduced to only ~2 meters to allow the integration of collimators and other vacuum equipments. A total of 8 identical Roman Pot Units have to be installed in the LHC, 4 on each side of the IP5.

The Roman Pot unit is mounted in the LHC ring on the out-coming beam w.r.t IP5 (QRL side). Since the LHC beams are physically separated in two independent vacuum chambers, horizontally spaced by 194 mm, here is only available space one side, the QRL side, for the horizontal pot and the compensation system.

THE MECHANICAL DESIGN

The Roman Pot unit (Fig. 3) for the TOTEM experiment is made of two vacuum chambers, one with two vertical pots and one with an horizontal pot. The vertical pots are needed for the total cross section measurement and the elastics scattering, while the horizontal one is a complement to study the diffractive physics. The detectors in the horizontal pot overlap with the two vertical detectors, helping in the alignment with tracks. The vertical vacuum chamber is also equipped with a beam position monitor (BPM), based on a button feed-through technology. The BPM built-in the chamber improves the precision of relative-to-the-beam position of the pots. For that purpose, a pre-calibration of the BPM relatively to the pots is done in a metrology lab (Fig. 2).

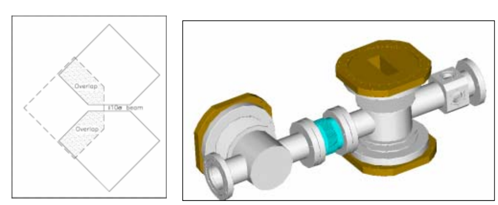

Figure 2: (right) the vertical and the horizontal vacuum chambers and the beam position monitor; (left) the horizontal detector overlaps the verticals.

All the warm vacuum equipment of the LHC must be baked out at ~150°C, the supports of the two Roman pot vacuum chambers have been designed to allow a free dilatation during the bake out. Such a feature relieves the stress on the components and prevents induced permanent deformation. In addition an interconnection bellows between the two vacuum chambers contribute to decouple the thermal deformation.

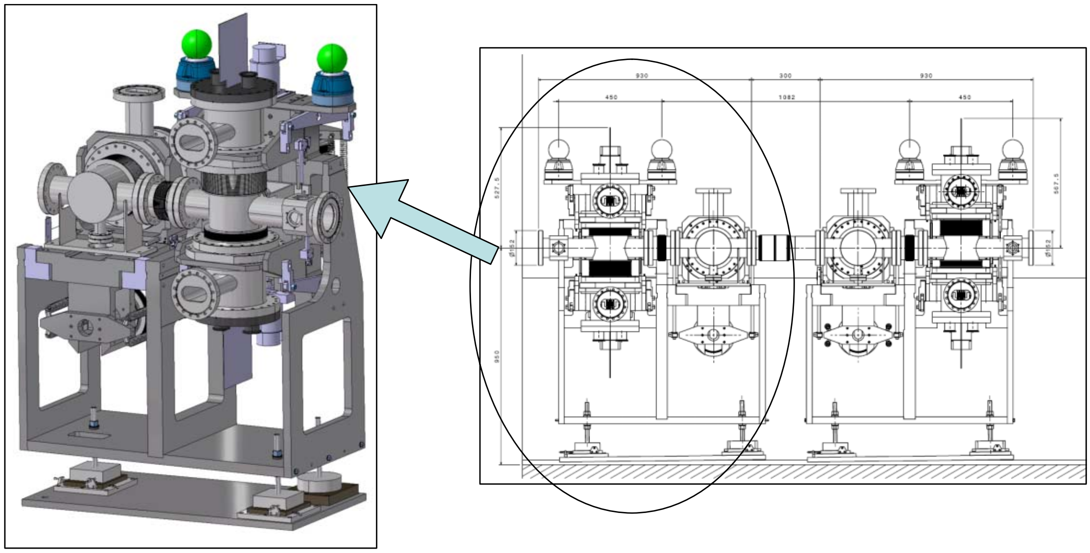

Figure 3: (left) The Roman Pot unit, (right) The Roman Pot station, i.e. an assembly of two Roman pot unit.

The Compensation System

A mechanical compensation system balances the atmospheric pressure loads on the pot (Fig. 4). The system relieves the stress and the deformation on the driving mechanism, improving the movement accuracy and the safety of the operations. It is based on a separate vacuum system connected to the primary vacuum of the machine through a by-pass. The atmospheric pressure load on the pot-bellow system is ~3000 N. With such compensation system the stepper motor works only against the own weight of the pot assembly (~100 N) leaving the possibility to achieve the better accuracy of the motor drive mechanism.

The transformation from the motor rotational movement to the translation movement is done by roller screws which provided elevated precision and zero backlashes. But they are also a reversible mechanism which under high loads may be forced the turn freely.

With bellows on the compensation system larger than the pot bellows a constant pulling load on the pots is guaranteed and the features of the reversible mechanism is exploited to provide auto-retraction of the pots in case of a power cut of the motors.

THE POT

The pot (Fig. 4) provides a volume with secondary vacuum, where the detectors and the services are enclosed. It has a shape of rectangular box 50 mm x 124 mm, with a 2 mm wall thickness, made in 316LN. An UHV flanges is welded to the box by electron beam welding. The bottom side of the flange is connected to the bellows, to tight the machine vacuum. The opposite side is connected to a second flanges equipped with the detectors, which tights the secondary vacuum volume.

The pot plus the bellow create an RF cavity for the beam running in the Roman Pot. Therefore special cares must be adopted to tackle such problem.

Measurements of the RF beam coupling have been done in the lab with a network analyzer and a metallic wire with a pulse shaper to simulate the beam. It can be shown that a thin collar of ferrites of 2 mm on the pot reduces the Z_L/n impedance down to 3.6 mΩ and the power deposition on the pot-bellow system down to ~40 watts. Those are both well bellow the acceptable threshold for the LHC machine impedance budget. The ferrite is fixed on the external wall of the pot after the welding assembly.

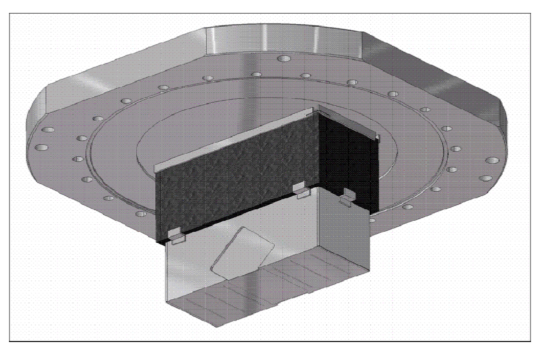

Figure 4: The pot and thin window. A Ferrite collar is needed to reduce the RF beam coupling.

The Thin Window

The details of the machine optics are crucial for this measurement. A TOTEM optics with a β^* of 1540 m has been developed. The minimum distance of a detector from the beam is proportional to the beam size:

$$y_{\min} = K\sigma_{beam}^{y} + d = K\sqrt{\varepsilon\beta_y(s)} + d$$

where ε is the transverse beam emittance, K~10 determines the closest approach to the beam, still enabling safe and stable operation of the Roman Pots in the LHC machine. The inefficiency region between the window and the edge of the detector is *d~0.5 mm*. The inefficiency region depends on the detector technology, the bottom pot flatness and the mechanical mounting, while the minimum safe distance depends on the beam parameters and the collimation system. The TOTEM Roman pot will be equipped with micro strip silicon detectors [3] with a minimized guard ring structure at the edge, which reduces the dead region to less than 50 µm.

For a normalized transverse emittance $\varepsilon_N^* = 1$ µm.rad and the TOTEM optics $\beta^* = 1540$ m, the r.m.s. beam envelope at the Roman pot location is σ_y=80 µm, σ_x =30 µm. Assuming a safety clearance from the beam of 10 σ the pots must be placed ~800 µm above from the beam while the active detector can only start at ~1.3 mm.

The insensitive area at the edge of the silicon strip detectors is ≤ 50 µm. Considering the thickness, the mechanical deformations and the flatness of the thin window, it can be shown that a thickness of 0.15 mm in Stainless Steel represents an optimum.

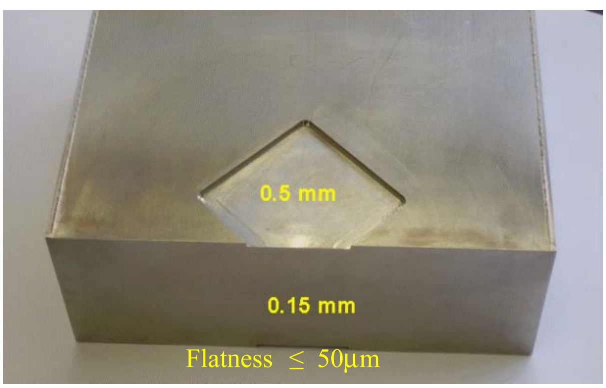

Figure 5: The pot and the thin window prototype. The lateral side are 0.5mm thick, while the bottom is 0.15 mm.

With the requirements of a flatness better than 50 µm, UHV leak tightness, and a capability to stand the limit pressure of 1.5 bars, several assembly procedures, like brazing, TIG and EB welding, have been investigated at the CERN by Assembly Technique group. The most satisfactory results have obtained by brazing (Fig. 5).

The first step consists in brazing a thin window in 316L on the bottom part. Successively the milling of the lateral sides is done, obtaining a 0.5 mm window. An elevated planarity down to 30 micron has been obtained on the prototypes. Cycling pressure tests in the range ± 1bar have been done, followed by vacuum leak tests. The maximum deformation is of 0.4 mm at 1 bar, while no leaks have been detected with a threshold of 2 x 10^{-12} mbar.l/sec.

An ultimate hydraulic pressure test has been done on two prototypes. One has been loaded with a fast pressure rise and it break at 50 bars. The second has been load slower and the test has been stopped at 80 bars without break (Fig. 6). For both case the pressure level are much higher than 1.5 bars which is required for safety.

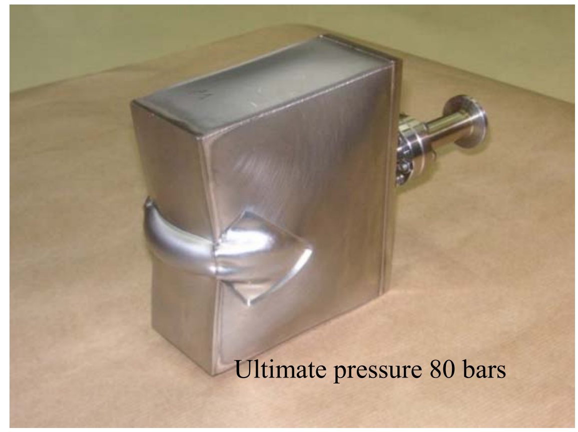

Figure 6: Deformation of the thin window after the ultimate pressure test, stopped at 80 bars.

THE MOVEMENTS

Each Pot is independently controlled by stepper motors, which are operated in micro stepping mode, allowing a resolution of 400 steps per tour, i.e. 1 step = 0.9^o with an expected accuracy of ± 3%. The nominal mechanical resolution of the driving mechanism is 5 µm but final precision depends on the assembly of the motors and the roller screws.

The driver units and the power supplies are placed in a counting room at ~300 m distance, in a radiation protected area, where the access is always possible even with circulating beams.

The stepper motors are equipped with angular resolvers which give the absolute position of each pot w.r.t. the nominal beam axis. Additional displacement inductive sensors (LVDT) provide the absolute position of each pot.

REFERENCES

[1] TOTEM TDR, CERN-LHCC-2004-002, TOTEM-TDR-001, 7 January 2004
[2] U. Amaldi et al., Phys. Lett. 44B (1973), p. 112.
[3] E. Noschis et al.,"Final size detectors for the TOTEM experiment", Nucl. Instr. and Meth. A (2006), Volume 563, Issue 1, 1 July 2006, Pages 41-44